BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

ILLINOIS POWER GENERATING COMPANY,	)	
Petitioner,	)	
v.	)	
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,	)	**PCB 2024-056 (Petition for Review – Alternative Source Demonstration)**
Respondent.	)	

NOTICE OF FILING

To: See Attached Service List (Via Electronic Filing)

PLEASE TAKE NOTICE that the undersigned filed today with the Office of the Clerk of the Illinois Pollution Control Board by electronic filing the following NOTICE OF FILING, CERTIFICATE OF SERVICE, CERTIFICATE OF RECORD ON APPEAL, and RECORD ON APPEAL, copies of which are attached hereto and hereby served upon you.

Respectfully submitted,

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

By: /s/Samuel Henderson

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Dated: September 23, 2024

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CERTIFICATE OF SERVICE

The undersigned hereby certifies that on September 23, 2024, before 5:00 PM, he caused to be served by electronic mail, a true and correct copy of the following instruments entitled Notice of Filing, Certificate of Record on Appeal, and Record on Appeal to:

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This email transmission contains 2124 pages.

/s/Samuel Henderson
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Under penalties as provided by law pursuant to Section 1-109 of the Code of Civil Procedure, the undersigned certifies that the statements set forth in this Certificate of Service are true and correct, except as to matters therein stated to be on information and belief and as to such matters the undersigned certifies as aforesaid that he verily believes the same to be true.

/s/Samuel Henderson
Assistant Attorney General
Environmental Bureau

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

ILLINOIS POWER GENERATING COMPANY	)	
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Petitioner,	)	
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v.	)	**PCB 2024-056**
	)	**(Alternative Source Demonstration**
	)	**– Petition for Review)**
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,	)	
	)	
Respondent.	)	

CERTIFICATE OF RECORD ON APPEAL

Respondent, ILLINOIS ENVIRONMENTAL PROTECTION AGENCY ("Illinois EPA"), in accordance with the procedural rules of the Illinois Pollution Control Board ("Illinois PCB") as set forth in 35 Ill. Adm. Code 105.212 and 105.116, files as its Record in this cause the Illinois EPA's record of non-concurrence of the Coffeen Power Plant Ash Pond No. 2 Alternative Source Demonstration ("ASD") which is attached and consists of the following documents:

PAGES	DOCUMENT		DATE
R000002 - R000011	1	Pages from Drever, James 1997 Geochem of Natural Waters Elements and Modeling	12/31/1997
R000013 - R000020	2	Pages from Eby, G 2004 Principles of Enviro Geochem Coal Modeling and Elements	12/31/2004
R000022	3	USEPA SW-846 Disclaimer	7/2014
R000024 - R000048	4	USEPA SW-846 Chapter 1, Project Quality Assurance and Quality Control	7/2014
R000050 - R000139	5	USEPA SW-846 Chapter 2, Choosing the Correct Procedure	7/2014
R000141 - R000177	6	US EPA SW846 Method 1315	7/31/2017

R000179 - R000198	7	US EPA SW846 Method 1316	7/31/2017
R000200 - R000229	8	USEPA GW Guide 2017	9/19/2017
R000231 - R00498	9	Pages from Contaminant Hydrogeology by Fetter et al 2017	12/31/2018
R000500 - R000639	10	TITLE 35: Environmental Protection, SUBTITLE G: Waste Disposal, CHAPTER I: Pollution Control Board, SUBCHAPTER j: Coal Combustion Waste Surface Impoundments, PART 845: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments	4/21/21
R000641 - R001941	11	Coffeen Ash Pond No.2 Part 845 Operations Permit Application	10/25/2021
R001943 - R001945	12	Email from Darin LeCrone to IEPA Staff RE: CCR meeting with NGO *(attachment Enviro initial questions for IEPA for 12.2023 meeting)*	12/11/2023
R001947 - R001949	13	Email from Lynn Dunaway to Gabriel Neibergall RE: CCR meeting with NGO *(attachment Enviro initial questions for IEPA for 12.2023 meeting)*	12/12/2023
R001951 - R001954	14	Email from Lauren Hunt to Justin Bierwagen and Heather Mullenax RE: CCR meeting with NGO (attachment Enviro initial questions for IEPA for 12.2023 meeting)	12/12/2023
R001956 - R001958	15	Email from Lynn Dunaway to IEPA Staff RE: CCR meeting with NGO *(attachment Enviro initial questions for IEPA for 12.2023 meeting)*	12/12/2023
R001960	16	Email from Lynn Dunaway to IEPA Staff RE: Vistra 845 Review Letter Meeting	12/13/2023
R001962	17	Email from Lynn Dunaway to Darin LeCrone and Michael Summers RE: Vistra 845 Review Letter Meeting	12/13/2023
R001964 - R001965	18	Email from Darin LeCrone to Lynn Dunaway and Michael Summers RE: Vistra 845 Review Letter Meeting	12/13/2023
R001967 - R001968	19	Email from Matthew Garee to IEPA Staff RE: Vistra 845 Review Letter Meeting	12/13/2023
R001970 - R001971	20	Email from Lynn Dunaway to Darin LeCrone and Michael Summers RE: Vistra 845 Review Letter Meeting	12/13/2023

R001973	21	Email from Lynn Dunaway to Rhys Fuller RE: Vistra 845 Review Letter Meeting	12/13/2023
R001975 - R001976	22	Email from Rhys Fuller to Lynn Dunaway RE: Vistra 845 Review Letter Meeting	12/13/2023
R001978 - R002020	23	Coffeen Power Plant Ash Pond No. 2 ASD Submittal	12/15/2023
R002022	24	Email from Brian Voelker to EPA.CCR.Part845 and EPA.BOW.GWS.CCR RE: Coffeen Power Plant AP2 Sulfate and TDS ASD Submittal Notice	12/15/2023
R002024	25	Email from EPA.CCR.Part845.Coordinator to EPA.BOW.GWS.CCR RE: Alternative Source Demonstration (ASD) for the sulfate and TDS exceedance observed at well G407, Qtr.2, 2023 from Coffeen Power Plant	12/18/2023
R002026	26	Email from EPA.CCR.Part845.Coordinator to EPA.BOW.GWS.CCR RE: Coffeen Power Plant Ash Pond No. 2 Alternative Source Demonstration	12/18/2023
R002028	27	Email from Lauren Hunt to Michael Brown RE: Statistics Follow up	12/19/2023
R002030 - R002046	28	Email from Jenny Cassel to Justin Bierwagen, EPA.BOW.GWS.CCR, et al. RE: Prairie Rivers Network comments on ASD for Vermilion NEAP *(attachment 12.19.23 PRN comments on ASD for Vermilion)*	12/19/2023
R002048 - R002052	29	Email from Darin LeCrone to Lynn Dunaway RE: Draft Responses *(attachment Responses to NGOs DEL 12.19.23)*	12/19/2023
R002054	30	Email from Lauren Hunt to Michael Summers, Heather Mullenax, et al. RE: Dynegy Statistics Discussion	12/20/2023
R002056	31	Email from Michael Brown to Joey Logan-Pugh RE: Statistics Follow up	12/20/2023
R002058 - R002059	32	Email thread from Lauren Hunt to Michael Summers, Lynn Dunaway, Heather Mullenax, et al. RE: For Statistics meeting later today	12/20/2023
R002061	33	Email thread from Lauren Hunt to Lynn Dunaway, Heather Mullenax et al. RE: Coffeen Statistics letter	12/20/2023
R002063 - R002064	34	Email from Heather Mullenax to Michael Summers, Lynn Dunaway et al. RE: Dynegy Coffeen Statistics Letter Draft *(attachment Dynegy Statistics Letter)*	12/21/2023

R002066 - R002067	35	Email thread from Lynn Dunaway to Lauren Hunt, Heather Mullenax, et al. RE: Dynegy Coffeen Statistics Letter Draft	12/21/2023
R002069 - R002071	36	Email thread from Lauren Hunt to Lynn Dunaway, Heather Mullenax et al. RE: Coffeen Statistics letter	12/21/2023
R002073 - R002074	37	Email thread from Lynn Dunaway to Lauren Hunt, Heather Mullenax et al. RE: Coffeen Statistics letter	12/21/2023
R002076 - R002081	38	Email from Lauren Hunt to Lynn Dunaway, Heather Mullenax, Michael Summers et al. RE: Dynegy Coffeen Statistics Letter Draft *(attachments Coffeen Statistics review Letter; Coffeen Statistics review Letter draft with comments)*	12/21/2023
R002083 - R002084	39	Email thread from Lynn Dunaway to Lauren Hunt, Heather Mullenax, et al. RE: Dynegy Coffeen Statistics Letter Draft	12/21/2023
R002086	40	Email from Lauren Hunt to Michael Brown RE: Meeting Forward Notification: Coffeen ASD Letters (2) signing	12/21/2023
R002088	41	Email from Lauren Hunt to IEPA Staff RE: CANCELED: Meeting request - Coffeen ASD Letters (2) signing	12/29/2023
R002090	42	Email from Lauren Hunt to IEPA Staff RE: Meeting request - Coffeen ASD Letters (2) signing	12/29/2023
R002092	43	Email from Lauren Hunt to IEPA Staff RE: Meeting request - Coffeen ASD Letters (2) signing	12/29/2023
R002094 - R002099	44	Email from Heather Mullenax to Lauren Hunt RE: Coffeen ASD Letters Review *(attachments Draft ASD Coffeen Cobalt letter Dec 2023; Draft ASD Coffeen TDS Sulfate letter Dec 2023; Coffeen ASD Comments*)	1/4/2024
R002101 - R002102	45	Email from Lauren Hunt to Heather Mullenax RE: Coffeen ASD Letters Review	1/4/2024
R002104 - R002108	46	Email from Lauren Hunt to Michael Brown, Darin LeCrone, Heather Mullenax RE: Coffeen ASD Letters for review and approval *(attachments Draft Final ASD Coffeen TDS Sulfate letter Dec 2023; Draft Final ASD Coffeen Cobalt letter Dec 2023)*	1/4/2024
R002110	47	Email from Lauren Hunt to Lynn Dunaway RE: CANCELED: Coffeen ASD Letters (2) signing	1/11/2024
R002112	48	Email from Lauren Hunt to IEPA Staff RE: Coffeen ASD Letters (2) signing	1/11/2024

R002114	49	Email from Lauren Hunt to Michael Brown RE: Coffeen ASD Letters (2) signing	1/11/2024
R002116 - R002117	50	Signed 2023 Coffeen ASD Nonconcurrence Letter TDS and Sulfate	1/11/2024

I, Lauren Hunt, of the Illinois EPA, hereby certify that the documents of the Record on Appeal filed in the above reference matter and summarized in the above Index are complete to the best of my knowledge, information, and belief.

BY: Lauren Hunt
Lauren Hunt
Environmental Protection Geologist III
Illinois Environmental Protection Agency

Respectfully submitted,

KWAME RAOUL,
Attorney General of the
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MATTHEW J. DUNN, Chief
Environmental Enforcement/Asbestos
Litigation Division

By: /s/Mallory Meade
Mallory Meade

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Dated: ___September 19__ , 2024

DOCUMENT 1

R000002

by organisms (nitrogen, phosphorus, sometimes carbon, potassium, and silica), biological processes are often the dominant control in surface waters. For elements utilized in only trace amounts (e.g., Mn, Cu, Ni, Mo, and Se), uptake by organisms in open waters such as lakes probably affects dissolved concentrations significantly only in environments where concentrations are low in general. In environments where concentrations are high as, for example, in polluted waters, the amounts taken up by organisms are likely to be small compared to the amounts in solution or to the amounts removed by adsorption processes.

In terrestrial systems uptake by plants can have a major influence on both heavy metals and organic compounds. One method of water treatment is to route a contaminated water through an artificially constructed wetland—a swamp with abundant plants (e.g., Wieder, 1993). Contaminants are removed by direct plant uptake, by adsorption on solid organic matter, and by precipitation as sulfides where the environment is anaerobic. One problem with artificial wetlands is that their lifetime is generally finite (a decade or so), and then the material that makes up the wetland must be disposed of.

EHAVIOR OF SPECIFIC ELEMENTS

Several specific elements are discussed here to provide an overview of their behavior and to illustrate patterns of behavior that are common to many other elements.

Copper, Zinc, Cadmium, and Lead

These elements have several features in common. The dominant species in solution is a divalent cation (free or complexed). Under oxidizing conditions, they are soluble under acid conditions and their solubilities at higher pH are limited by the solubility of a carbonate or oxide/hydroxide (Figs. 9-12 to 9-16; these and subsequent figures have been simplified by omission of some possible complexes in solution involving sulfate, sulfide species, carbonate species, and OH^-. These omissions do not significantly change the diagrams for the conditions commonly encountered in fresh waters). Under reducing conditions, in the presence of sulfur all form relatively insoluble sulfides. In the absence of sulfur, copper is insoluble as the native metal (Fig. 9-16). The others behave as they do in oxidizing environments: they are relatively soluble at low pH and insoluble as carbonates/oxides/hydroxides at high pH. Copper, zinc, and cadmium form anionic species at high pH. It is rare, however, for pH values in nature to be sufficiently high for such species to be important. The response of these elements to a change in redox conditions is determined less by redox reactions involving the elements themselves than by changes occurring in sulfur species, and in Fe and Mn oxyhydroxides, which are important substrates for adsorption.

All members of the group are complexed by natural organic matter. Some binding constants for complexing of the M^{2+} ion with humic substances are shown in Table 9-2. These constants give a general indication of the strength of interaction between the metal and dissolved organic matter. The constant for calcium is included for comparison. In general, copper is the most strongly complexed member of the group and is very commonly influenced by organic complexation. Lead is next, followed by zinc and cadmium. Complexing of zinc and cadmium by organic solutes is, generally speaking, important only where concentrations of dissolved organic carbon are relatively high.

R000003

All members of the group are potentially affected by adsorption on iron and manganese oxyhydroxides (Fig. 9-17), and Cd is potentially affected by adsorption on calcite. As discussed in Chapter 5, adsorption is pH dependent. Lead adsorbs at the lowest pH, followed by Cu, Zn, and Cd. The curves shown in Fig. 9-17 illustrate the results of experiments conducted under a specific set of conditions and should not be overgeneralized.

The expected behavior of these metals in the environment can be summarized as follows: under oxidizing conditions at low pH, they are all soluble and mobile. As the pH rises, their concentrations tend to decrease, first because of adsorption (particularly for Pb and Cu), and then because of the limited solubility of carbonates and oxides/hydroxides. Under reducing conditions, if sulfur is present, all should be immobilized as sulfides. If sulfur is absent, for Zn, Cd, and Pb the solubility control will be the same as under oxidizing conditions; Cu should be insoluble at all pH values. Adsorption is generally less important under reducing conditions because the most important substrates for adsorption, Fe and Mn oxyhydroxides, tend themselves to dissolve.

Arsenic and Selenium

Arsenic and selenium differ strongly from the previous examples in that both elements undergo important changes in oxidation state themselves, and both occur in solution as anions or as neutral species rather than as cations. *pe*-pH diagrams are shown in Figs. 9-18 and 9-19. Under oxidizing conditions, the dominant form of arsenic is the +V oxidation state, which is present as arsenic acid and its anions (arsenate), corresponding closely to phosphoric acid and phosphate species. For selenium, the dominant form under oxidizing conditions is selenate, which is closely analogous to sulfate. As conditions become reducing, As(V) is reduced to As(III)—arsenious acid and arsenite anions. When sulfate reduction occurs, As precipitates as a sulfide; if sulfur is absent, it remains in solution as arsenious acid or an arsenite. Elemental arsenic should be a stable species under highly reducing conditions, but it does not occur commonly in nature. For selenium, selenite species (analogous to sulfite) occur at intermediate redox levels, followed by elemental selenium and hydrogen selenide (analogous to hydrogen sulfide) species under strongly reducing conditions. Both

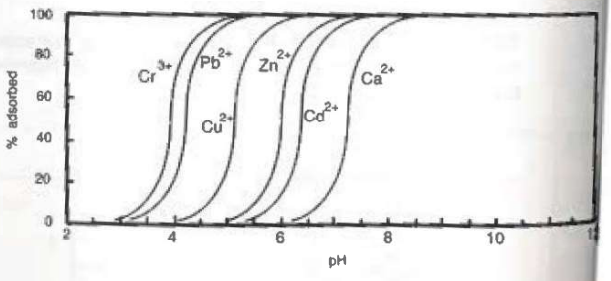

FIGURE 9-17 Adsorption of Cu^{2+}, Cd^{2+}, Zn^{2+}, Pb^{2+}, Cr^{3+}, and Ca^{2+} (for comparison) on hydrous ferric oxide as a function of pH. Each metal shows an adsorption "edge"; at pH values below the edge, the ion is not adsorbed or very weakly adsorbed. At pH values above the edge, the ion is strongly adsorbed. Conditions correspond to a high ratio of hydrous ferric oxide to adsorbing cation and an ionic strength of 0.1 m. The edges move towards higher pH as the ratio adsorbing cation:hydrous ferric oxide increases. From data in Dzombak and Morel (1990).

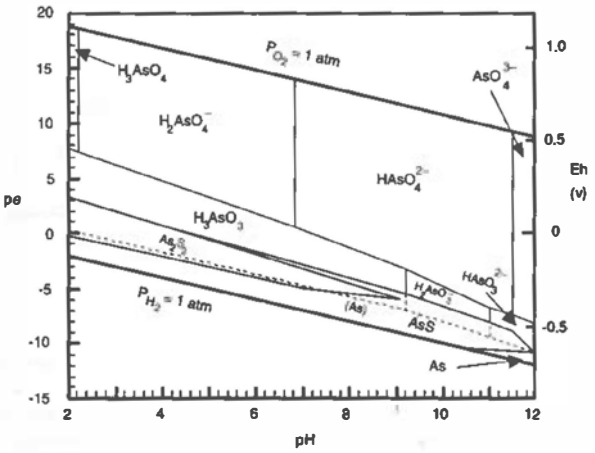

FIGURE 9-18 Simplified pe–pH diagram for the system As–O–H_2O at 25°C and one atm. Total activity of sulfur species = 10^{-2}. Light lines are boundaries involving dissolved species only. Dashed line is field of solid elemental arsenic in the absence of sulfur. Solubility is defined as a dissolved As species activity of 10^{-6}.

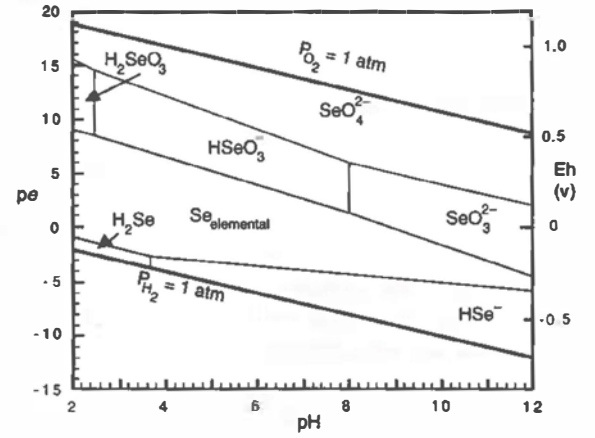

FIGURE 9-19 Simplified pe–pH diagram for the system Se–O–H_2O at 25°C and one atmosphere. Solubility is defined as a dissolved Se activity of 10^{-6}. Data are from Cowan (1988).

arsenic and selenium may be incorporated into iron sulfides under reducing conditions. The kinetics of redox transformations involving arsenic and selenium are slow, so disequilibrium is common (Kent et al., 1994; Runnells and Lindberg, 1990).

Arsenate species form inner-sphere complexes at the iron oxyhydroxide surface and are strongly adsorbed at near-neutral pH (Fig. 9-20). At high pH the strong negative charge on the oxide surface decreases adsorption of anions. As(III) apparently does not form inner-sphere complexes at the oxide surface. It is not strongly adsorbed at any pH value. For selenium, the adsorption picture is reversed. The oxidized form is only weakly adsorbed (similar to sulfate), whereas Se(IV) is strongly adsorbed under near-neutral conditions.

Organoarsenic compounds occur in nature but do not appear to be particularly important in the overall cycle of arsenic. Organic forms of selenium are more important, particularly in plants that accumulate selenium. Certain plants, notably vetches of the genus *Astragalus*, can accumulate high concentrations of selenium and may cause toxicity problems for livestock.

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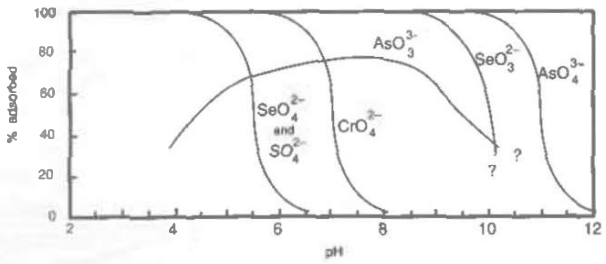
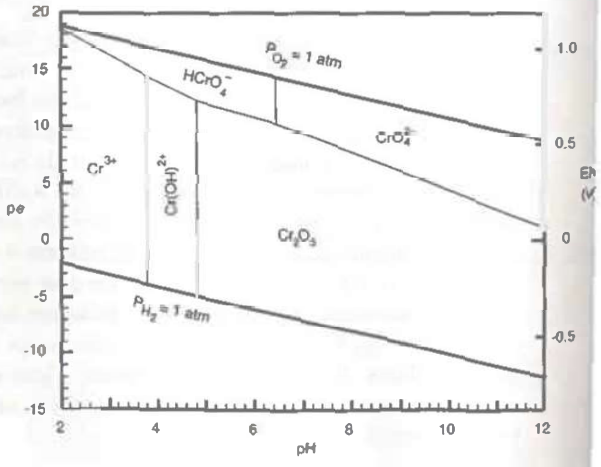


FIGURE 9-20 Adsorption of arsenate, arsenite, selenate, selenite, chromate, and sulfate (for comparison) on hydrous ferric oxide as a function of pH. Most of the anions show an adsorption "edge"; at pH values above the edge (for anions), the ion is not adsorbed or very weakly adsorbed. At pH values below the edge, the ion is strongly adsorbed. The anomalous behavior of arsenite is related to the fact that AsO_3^{3-} is fully protonated to H_3AsO_3 below pH 9 (Fig. 9-18); the symbol AsO_3^{3-} is used for all As in the +III oxidation state. Conditions correspond to a high ratio of hydrous ferric oxide to adsorbing cation and an ionic strength of 0.1 m. The edges move towards lower pH as the ratio adsorbing anion:hydrous ferric oxide increases. From data in Dzombak and Morel (1990).

Chromium

Chromium (Fig. 9-21) shows some similarities to both of the groups of elements discusse above. Under highly oxidizing conditions, the hexavalent form (chromate) is stable as a anion. It is not strongly adsorbed (adsorption edge at about pH 7, Fig. 9-20) and is therefor mobile in the environment. Under intermediate and reducing conditions, Cr(III) is the stabl oxidation state. It is insoluble in the neutral and alkaline pH ranges. It is soluble (largely a $Cr(OH)^{2+}$) under acid conditions. In general, Cr(III) species are strongly adsorbed (Fig. 9-17 Where dissolved chromium pollution occurs, the problem form is generally Cr(VI).

FIGURE 9-21 pe–pH diagram for the system Cr–O–H_2O at 25°C and one atm. Solubility is defined as a dissolved Cr activity of 10^{-6}. Data from Brookins (1988).



R000006



lfate (for comparison)
'edge"; at pH values above
below the edge, the ion
SO_3^{2-} is fully protonated
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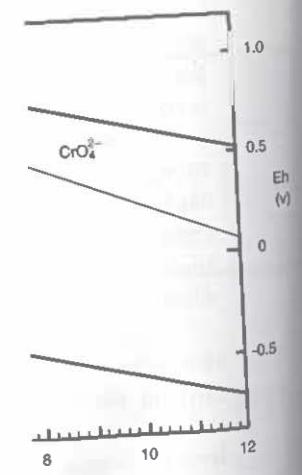

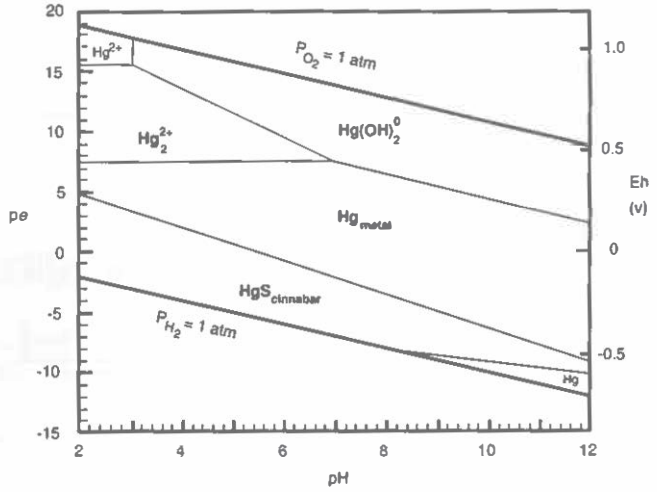

FIGURE 9-22 pe–pH diagram for the system Hg–S–O–H_2O at 25°C and one atm. Solubility is defined as a dissolved Hg activity of 10^{-6}. Total activity of sulfur species = 10^{-2}. The diagram is the same in the absence of S species, with the HgS (cinnabar) field replaced by Hg (metal). In the presence of chloride, the Hg_2^{2+} may be replaced by the insoluble mercurous chloride (calomel). Data are consistent with Allison et al. (1991).

Mercury

The chemistry of mercury in the environment is highly complex. The thermodynamically stable forms are shown in Fig. 9-22. The common soluble form is the oxidized (mercuric) Hg^{2+} ion and its hydrolysis product $Hg(OH)_2^0$, with the reduced (mercurous) Hg_2^{2+} ion being less important. Elemental mercury has a large stability field. The elemental form is volatile and slightly soluble in water. The global cycle of mercury is dominated by vapor-phase transport of Hg^0 through the atmosphere (Mason et al., 1994). Mercury is transformed by microorganisms into organic forms, notably monomethyl mercury (CH_3Hg) and dimethyl mercury [$(CH_3)_2Hg$]. These organic forms, in addition to being highly toxic, are volatile and tend to accumulate in the food chain. High concentrations of Hg in fish, which are common in polluted waters, generally result from accumulation of organomercury species. Pollutant Hg in sediments is partly transformed to organomercury species and partly to the sulfide.

Most of the metals discussed above—Cu, Zn, Cd, Pb, As, Hg, and, to a lesser extent, Se—are transformed to sulfides in anaerobic sediments. So long as conditions remain anaerobic and sulfur is available, they are relatively immobile. However, any disturbance, such as dredging, that brings the sediment into contact with oxygen will cause oxidation of the sulfides and release of the metals into solution. Cleaning up or moving contaminated sediments is a difficult problem because it may lead to oxidation and mobilization of these metals.

SUMMARY

1. To understand the behavior of any trace element in natural waters, it is essential to know the chemical form of the element in the water of interest. Anomalously high concentrations are often related to the presence of stable complexes in solution.

2. The solubility of phases containing the element as a major constituent (commonly an oxide/hydroxide, carbonate, or sulfide) provides a general upper limit to the concentration of a specific element.

R000007

This is exactly the expression we had for a non-adsorbed solute (Eq. 16–9), but with D/R substituted for D (which could be either a dispersion coefficient or a diffusion coefficient). Thus spreading by diffusion or dispersion is retarded in an analogous manner to advection. Provided dispersion is much greater than diffusion, the geometry of movement and spreading of an adsorbed solute as it moves through an aquifer will be exactly the same as that of an unadsorbed solute, but the time taken to reach a particular position and "width" will be a factor of R longer.

Adsorption affects only non-steady-state diffusion. At steady state (e.g., a constant concentration gradient between a constant source and a constant sink), there is no net uptake or release by adsorption, so adsorption has no effect on diffusion. The diffusional flux will be given by Fick's first law with no correction for adsorption.

The above discussion applies only to the limiting case of rapid, reversible, linear adsorption. Because of its mathematical convenience, the retardation equation based on the linear K_d is often used as an approximation even where these conditions do not hold. It should also be remembered that, in general, the numerical value of K_d is specific to the solute, the substrate, and the composition of the groundwater. It is not readily transferred from one experiment or situation to another.

Example 3

Suppose the pollutant in Example 2 above is adsorbed by the sediment, and the adsorption can be described by a constant K_d of 5 *l*/kg. How long will it now take for the pollutant to reach a depth of 50 cm?

If we assume a grain density of 2.6 g/cm^3, the redardation factor, R, is

$$\left(1 + \frac{0.3}{0.7} \times 2.6 \times 5\right) = 6.57$$

The times calculated in Example 2 will be multiplied by this number. The time for 1 percent of the initial concentration to reach 50 cm will thus be 10.97 y rather than 1.67 y. Note that, for a given K_d, the retardation factor increases as the porosity decreases as a result of the factor $(1 - \phi)/\phi$. If, in this example, the porosity had been 10 percent rather than 70 percent, the retardation factor would have been 118 rather than 6.57.

REACTION PATH MODELING

Reaction path calculations, or *mass-transfer* codes, give us the successive compositions of a solution as a mineral (or several minerals) reacts with a solution or as some other process, such as evaporation of the solution, proceeds. The mass of each solid phase or gas produced or consumed is calculated. Such codes do not, in general, contain any kinetic information: They calculate changes as a function of the amount of reaction that has taken place but do not say anything about how long the reaction should take. The most widely available and widely used codes are PHREEQE (Parkhurst et al., 1980), EQ3/6 (Wolery, 1979), SOLMINEQ.88 (Kharaka et al., 1988), and MINTEQA2 (Allison et al., 1991). PHRQPITZ (Plummer et al., 1988) is a version of PHREEQE modified to include Pitzer's equations for calculations at high ionic strength (see Chapter 2); PHREEQC (Parkhurst, 1995) is an updated version of PHREEQE that includes inverse modeling analogous to NETPATH (see Chapter 12 and later in this chapter). Each of these codes was developed for a slightly different purpose, which

gives them advantages and disadvantages for particular applications. PHREEQE is a relatively versatile code that can model many different types of reaction at a fixed temperature. However, the database supplied is fairly limited, particularly for trace elements, so the user may have to enter all the information for particular elements/reactions him/herself. It is not a particularly easy code for a beginner to use. MINTEQA2 is in a sense the reverse: it has an extensive database and is quite "user friendly," but the range of calculations it can perform is more limited. EQ3/6 is a large, complex, and versatile program, currently geared towards simulations associated with radioactive waste disposal. It can simulate reactions with changing temperature as well as reactions at a fixed temperature. SOLMINEQ.88 was designed particularly to simulate processes associated with petroleum basins, which implies moderately elevated temperatures and the presence of several organic species.

As an example of a reaction path calculation, let us consider the case of a mineral reacting with water. The general approach is:

1. A small increment of the mineral is dissolved.
2. A speciation-saturation program (Chapter 2) tests if the solution is supersaturated with respect to any solid phase. (The speciation–saturation program is part of the mass-transfer code. Thus each of these codes can be used for speciation–saturation calculations.)
3. If the solution is supersaturated with respect to any phase (or to specific phases specified by the user), an amount of that phase is precipitated sufficient to bring the solution into equilibrium with that phase. If the solution becomes undersaturated with respect to a previously precipitated phase, that phase redissolves to establish equilibrium.
4. An iteration procedure ensures that the solution is in equilibrium with all solid reaction products before another increment of the original mineral is dissolved.

The procedure for simulating evaporation is the same, except that increments of water are removed instead of increments of mineral being added. The calculated composition of a solution reacting with K-feldspar is shown in Figs. 16-10 and 16-11.

Although mass-transfer programs in the strict sense calculate only the path that the solution composition will follow and do not contain any rate expressions to relate reaction progress to time, it is possible to combine a mass-transfer model with a kinetic model to predict solution composition as a function of time. Examples include KINDIS (Madé et al., 1990) and PHREEQM (Appelo and Postma, 1993). There is some question as to whether our understanding of kinetics at low temperatures is sufficient for this approach to be realistic.

Example 4

A mining company proposes to dig a pit, which will be left to form a lake at the end of mining operations. The composition of the groundwater that will flow into the pit is shown in Table 16-2. The bedrock is altered granite containing calcite as the only reactive mineral. Use MINTEQA2 to predict the composition of the final lake.

In order to solve this problem, we need to make some simplifying assumptions. Some of these are:

1. A chemical equilibrium model is a suitable approximation.
2. The final lake will be in equilibrium with atmospheric oxygen and CO_2.

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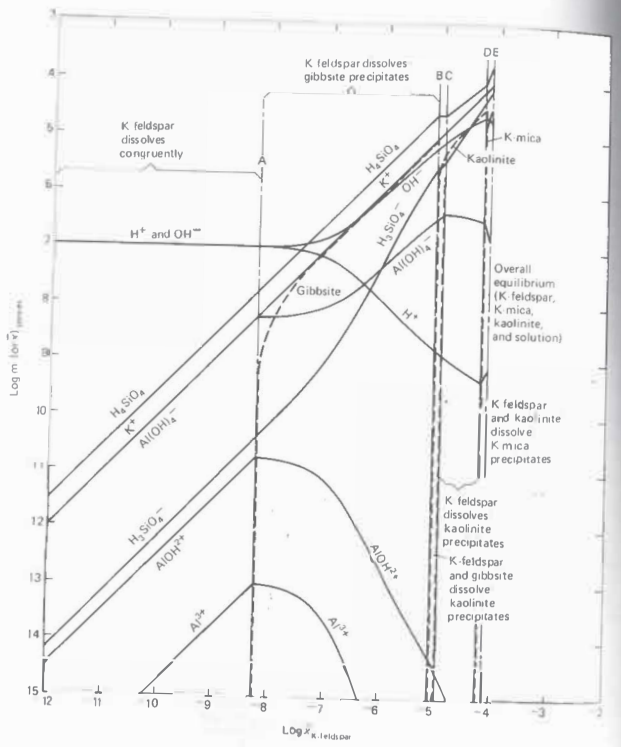
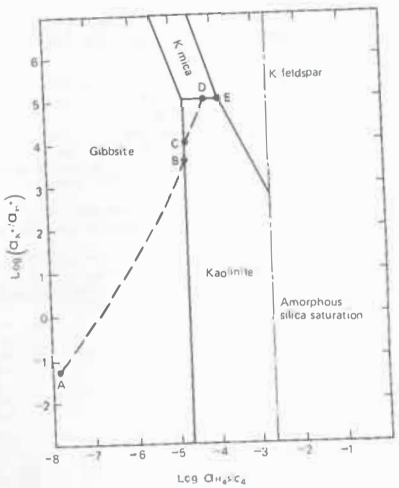


FIGURE 16-10 Concentration (m) of species in the aqueous phase (solid lines) and amounts (mol/kg H_2O) of minerals produced and destroyed (dashed lines) as K-feldspar reacts with water at 25°C and 1 atm pressure. The abscissa represents the number of moles of K-feldspar destroyed per kg H_2O. The letters correspond to the points on the reaction path shown in Fig. 16-11 (Helgeson et al., 1969).

3. Reactions involving silicates can be ignored. The justification for this assumption is that the groundwater has been in contact with the silicate minerals surrounding the pit for a long time and should be close to equilibrium or at least steady state.
4. Our time span and flow rate are such that evaporation and dilution by rainfall can be neglected. In reality these would be incorporated into the model. They are omitted here for the sake of simplicity.

FIGURE 16-11 Path of solution composition (ABCDE) as K-feldspar reacts with water, plotted on a mineral stability diagram (after Helgeson et al., 1969).



The first step is to use MINTEQA2 as a speciation-saturation program only, with the water of Table 16-2 as the input. This has two purposes: (1) To see which phases are supersaturated and hence are likely to precipitate, and (2) To convert the alkalinity input into total concentration of carbonate species and concentration of the component H^+. MINTEQA2 requires the input to be in this form for further calculations. At this stage we also have to decide on an oxidation state for the Fe in the analysis. We can either input it as Fe^{2+} (which is probably the actual form), or we can input it as the oxidized species, Fe^{3+}, with the justification that the final water will be in equilibrium with atmospheric oxygen. If iron is input as Fe^{3+}, MINTEQA2 does not have to perform any redox calculations, as all the inputs are in their oxidized form. There are often advantages to minimizing the number of different reactions that the reaction path code has to consider simultaneously. The concentration of Fe is sufficiently low that the choice of oxidation state does not affect the cation–anion balance significantly. Part of the output from this first run is shown in Table 16-3.

TABLE 16-2 Composition of Inflow Water for Example 4

Na	64.2	ppm	As	0.05	ppm
K	17	ppm	Cu	0.014	ppm
Ca	151.4	ppm	Zn	1.1	ppm
Mg	54.6	ppm			
Cl	23.8	ppm	pH	7.51	
SO_4	104	ppm			
Alkalinity	12.54	meq/ℓ	T	20°C	

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We can see from Table 16-3 that the water is supersaturated with respect to various phases, including calcite, dolomite, magnesite, and a range of compounds containing ferric iron (ferrihydrite, goethite, hematite, jarosite, etc.) the high saturation indices for these phases is a consequence of our decision to specify the total Fe as Fe^{3+}. The next step is to choose which phases will precipitate. We shall choose ferrihydrite as the iron compound, as it is the phase most likely to precipitate. We shall also choose calcite as a phase likely to precipitate in a natural system, but we shall not allow dolomite (or other Mg-carbonate phases) to precipitate because the kinetics of precipitation of these phases are generally slow (Chapter 3). Note that no phases containing the trace elements Cu, Zn, or As are supersaturated.

With these choices, we can now perform a second MINTEQA2 run in which we:

1. Do not specify the input pH, instead allowing MINTEQA2 to calculate the pH.
2. Specify equilibrium with a CO_2 gas phase at a pressure of 3.16×10^{-4} atm (atmospheric CO_2 pressure). We could also list O_2 at a fixed pressure of 0.2 atm, but this is unnecessary if our input does not contain any reduced species.
3. Specify calcite and ferrihydrite as *possible solids*. A possible solid is one that is allowed to precipitate if the solution is supersaturated with respect to it. Phases that are not listed in this way (or in an analogous way) will not be considered in the calculations.

Part of the output from this run is shown in Table 16-4. The solution is in equilibrium with calcite and ferrihydrite, and has a final pH of 8.88. This output would constitute our prediction for the major ions in solution. Note that the solution is still supersaturated with respect to ferric (hydr)oxides more stable than ferrihydrite (Chapter 7), and with respect to Mg-containing carbonates. 99.9 percent of the iron has been precipitated as ferrihydrite, and 98.6 percent of the calcium as calcite. The presence or absence of calcite in the bedrock would make no difference to the calculation, as calcite is precipitating and not dissolving. The main reason why so much calcite precipitated is the drop in P_{CO_2} from a value of $10^{-1.7}$ in the inflow water to $10^{-3.5}$ in the equilibrated pit lake.

So far, the only process we have considered is precipitation of supersaturated phases. Adsorption is also likely to be a significant control on trace element concentrations, particularly As, Cu, and Zn in our example (Table 16-2). As discussed in Chapter 5, adsorption can also be modeled by use of MINTEQA2. This calculation is performed after the major element chemistry has been calculated. It is necessary to specify the amount and properties of the adsorption substrate, which requires further assumptions. The details of these calculations are not presented here. A reasonable set of assumptions would be that ferrihydrite is the adsorbing phase, the amount present is equal to the amount precipitated in the previous modeling step, and its properties are the same as those of ferrihydrite used in laboratory experiments by Dzombak and Morel (1990). The Dzombak and Morel numbers are supplied as a data file with MINTEQA2. Calculations based on these assumptions indicate that adsorption should greatly reduce the concentrations of arsenic, copper, and zinc.

Application to Contaminant Transport in Groundwater

It has become recognized in recent years that human activities are introducing contaminants into groundwater systems on an enormous scale. Examples include leaching from municipal landfills, hazardous waste burial sites, mine tailings, and various spills, both deliberate and accidental. Agriculture itself often causes contamination of groundwater by fertilizers (notably nitrate) and pesticides. A great deal of effort is currently being put into modeling the

TABLE 16-4 Output from the MINTEQA2 Equilibration Calculation for Example 4 (The output file has been greatly condensed.)

```
                    PART 1 of OUTPUT FILE
Example 4: Equilibration with atmosphere and solid phases

Temperature (Celsius):  20.00
Units of concentration: MG/L
Ionic strength to be computed.
If specified, carbonate concentration represents total inorganic carbon.
Do not automatically terminate if charge imbalance exceeds 30%
Precipitation is allowed only for those solids specified as ALLOWED
  in the input file (if any).
The maximum number of iterations is:  40
The method used to compute activity coefficients is: Davies equation
Intermediate output file

INPUT DATA BEFORE TYPE MODIFICATIONS
  ID      NAME      ACTIVITY GUESS    LOG GUESS   ANAL TOTAL
 330   H+1          1.000E-07          -7.000     1.370E+01
  61   H3AsO4       3.548E-07          -6.450     5.000E-02
 150   Ca+2         3.802E-03          -2.420     1.514E+02
 180   Cl-1         6.761E-04          -3.170     2.380E+01
 231   Cu+2         2.188E-07          -6.660     1.400E-02
 281   Fe+3         2.291E-05          -4.640     1.270E+00
 460   Mg+2         2.239E-03          -2.650     5.460E+01
 410   K+1          4.365E-04          -3.360     1.700E+01
 500   Na+1         2.818E-03          -2.550     6.420E+01
 732   SO4-2        1.072E-03          -2.970     1.040E+02
 950   Zn+2         1.698E-05          -4.770     1.100E+00
 140   CO3-2        9.333E-05          -4.030     7.859E+02
   2   H2O          1.000E+00            .000     0.000E-01

  Charge Balance: UNSPECIATED
    Sum of CATIONS=  2.900E-02 Sum of ANIONS =  2.906E-02
    PERCENT DIFFERENCE =  1.065E-01  (ANIONS - CATIONS)/(ANIONS + CATIONS)

Type V - POSSIBLE SOLIDS
  ID      NAME      CALC MOL     LOG MOL   NEW LOGK     DH
5015001  CALCITE    1.937E+02     2.287      8.446     2.585
2028100  FERRIHYDRITE 6.817E+02   2.834     -4.891      .000

                    PART 5 of OUTPUT FILE

                  -EQUILIBRATED MASS DISTRIBUTION-------
                  DISSOLVED                SORBED              PRECIPITATED
IDX   NAME        MOL/KG     PERCENT       MOL/KG    PERCENT   MOL/KG     PER-
CENT
330   H+1         4.365E-03    100.0     0.000E-01      .0    0.000E-01      .0
 61   H3AsO4      3.527E-07    100.0     0.000E-01      .0    0.000E-01      .0
950   Zn+2        1.685E-05    100.0     0.000E-01      .0    0.000E-01      .0
180   Cl-1        6.721E-04    100.0     0.000E-01      .0    0.000E-01      .0
231   Cu+2        2.206E-07    100.0     0.000E-01      .0    0.000E-01      .0
732   SO4-2       1.084E-03    100.0     0.000E-01      .0    0.000E-01      .0
460   Mg+2        2.248E-03    100.0     0.000E-01      .0    0.000E-01      .0
```

(Continued)

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```
410  K+1            4.353E-04   100.0   0.000E-01      .0   0.000E-01      .0
500  Na+1           2.796E-03   100.0   0.000E-01      .0   0.000E-01      .0
281  Fe+3           1.853E-08      .1   0.000E-01      .0   2.275E-05    99.9
150  Ca+2           5.213E-05     1.4   0.000E-01      .0   3.730E-03    98.6
140  CO3-2          4.727E-03    55.9   0.000E-01      .0   3.730E-03    44.1
  2  H2O            9.297E-06   100.0   0.000E-01      .0   0.000E-01      .0

     Charge Balance: SPECIATED
       Sum of CATIONS =  7.178E-03 Sum of ANIONS   7.239E-03
       PERCENT DIFFERENCE =  4.291E-01  (ANIONS - CATIONS)/(ANIONS + CATIONS)
     EQUILIBRIUM IONIC STRENGTH (m) =  1.029E-02
     EQUILIBRIUM pH                =  8.879

                          PART 6 of OUTPUT FILE
Saturation indices and stoichiometry of all minerals
    ID #     NAME      Sat. Index        Stoichiometry in [brackets]
5015000 ARAGONITE        -.154    [  1.000] 150  [  1.000] 140
5015001 CALCITE           .000    [  1.000] 150  [  1.000] 140
5015002 DOLOMITE         1.654    [  1.000] 150  [  1.000] 460  [  2.000] 140
2028100 FERRIHYDRITE     0.000    [ -3.000] 330  [  1.000] 281  [  3.000]   2
2028102 GOETHITE         4.210    [ -3.000] 330  [  1.000] 281  [  2.000]   2
6015001 GYPSUM          -2.897    [  1.000] 150  [  1.000] 732  [  2.000]   2
3028100 HEMATITE        13.405    [ -6.000] 330  [  2.000] 281  [  3.000]   2
5015003 HUNTITE           .812    [  3.000] 460  [  1.000] 150  [  4.000] 140
6041002 JAROSITE K      -7.386    [ -6.000] 330  [  1.000] 410  [  3.000] 281
                                  [  2.000] 732  [  6.000]   2
3028101 MAGHEMITE        3.397    [ -6.000] 330  [  2.000] 281  [  3.000]   2
5046002 MAGNESITE        1.156    [  1.000] 460  [  1.000] 140
2023101 TENORITE         -.815    [ -2.000] 330  [  1.000] 231  [  1.000]   2
5095000 SMITHSONITE      -.861    [  1.000] 950  [  1.000] 140
5095001 ZNCO3, 1H2O      -.546    [  1.000] 950  [  1.000] 140  [  1.000]   2
2095005 ZNO(ACTIVE)      -.449    [ -2.000] 330  [  1.000] 950  [  1.000]   2
2095006 ZINCITE          -.552    [ -2.000] 330  [  1.000] 950  [  1.000]   2
5023101 MALACHITE       -2.691    [  2.000] 231  [  2.000]   2  [  1.000] 140
                                  [ -2.000] 330
3028102 LEPIDOCROCIT     3.520    [ -3.000] 330  [  1.000] 281  [  2.000]   2
```

behavior of contaminants in the subsurface, both for predicting the fate of and designing remediation strategies for existing contaminants and for designing and locating disposal sites for future waste, particularly high-level radioactive waste.

Before any detailed geochemical modeling can be attempted, the hydrology of the area in question, particularly groundwater flow paths and velocities, must be established. This is by no means a trivial requirement; the information required for an adequate hydrologic model may be greater than that required for a chemical model, and the mathematical formulation of the hydrologic model may be extremely complex.

For modeling purposes, it is often convenient to divide the region to be studied into a source, a mixing zone (*near field,* in the terminology of radioactive waste disposal), and a relatively undisturbed aquifer or aquifers (*far field*). This is illustrated conceptually in Fig. 16-12 for a mill tailings pile. A real example of modeling applied to a uranium mill tailings pile is given by White et al. (1984) and Narasimhan et al. (1986). The source is the downward movement of solutions from the tailings pile. These solutions are oxygenated and highly acidic from the processing used in the mill and contain high concentrations of iron and several trace elements such as uranium, molybdenum, and selenium.

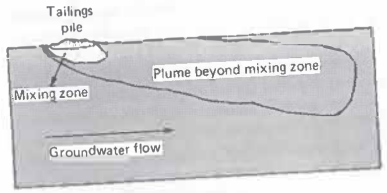

FIGURE 16-12 Schematic illustration of migration of contaminants from a uranium mill tailings pile.

Groundwaters are typically mildly alkaline and may be oxidizing or reducing. When the acid tailings solution enters the aquifer, it reacts chemically with the groundwater and with the minerals of the aquifer. Calcite dissolves, gypsum may precipitate, and iron and aluminum hydroxides precipitate, coprecipitating trace metals with them. Chemical reactions such as these can be modeled successfully by a program such as PHREEQE, MINTEQ, or EQ3/6. The mixing zone, where the major chemical reactions take place, is commonly a relatively small volume, and the hydrology of such a small volume can be modeled in a relatively simple way.

Beyond the mixing zone, the groundwater is more or less in equilibrium with the minerals of the aquifer. Dissolution and precipitation are no longer major processes, and modeling focuses on hydrology/water movement plus hydrodynamic dispersion and on relatively simple chemical processes such as adsorption, radioactive decay, and, for some organic compounds, biodegradation.

An additional problem with modeling of contaminant transport is the question of how to treat uncertainty. One can never know with certainty the porosity, permeability, and dispersivity, for example, at all points in an aquifer. One can make estimates for the regions in which data are missing and, using them, calculate, for example, a travel time for a particular solute between two locations. For problems such as disposal of high-level radioactive waste, it is important to know the uncertainty associated with the travel time as well as the "best estimate." Increasingly, *stochastic modeling* is being used to assess uncertainty. Instead of single values being assigned to the properties of each location in the aquifer, a statistical distribution of properties is assigned, and the model generates a statistical distribution of travel times or whatever other output is required.

CHEMICAL EVOLUTION OF GROUNDWATER

The reaction path modeling discussed above has been "forward" modeling in that we posed the problem in the form: "Suppose we have water A and allow it to react with minerals B and C, what will be the final composition of the water?" For understanding the chemical composition of groundwater, we are generally presented by the "inverse" problem (Plummer, 1992): we know the composition of the final water, the problem is to deduce the reactions that gave rise to it. One approach is simply to solve the forward problem repeatedly, changing the identity and amount of the minerals reacting until a "match" is achieved. Alternatively, one can use the code NETPATH (Plummer et al., 1991) or PHREEQC (Parkhurst, 1995) to solve the inverse problem directly. The use of NETPATH to solve a mass balance problem was discussed in Chapter 12. The input is an initial water composition, a final water composition, and

R000011

a list of phases that may dissolve, precipitate, or both. The output is a list of all the possible reactions involving the listed minerals that satisfy the mass balance constraints. NETPATH also considers isotopic balance for ^{13}C, ^{14}C, ^{34}S, D, T, ^{18}O and ^{87}Sr, and includes WATEQ4F as a subroutine to test whether the reactions deduced from mass balance are chemically reasonable. It would not be reasonable, for example, to postulate that gypsum precipitates from a solution that is undersaturated with respect to gypsum.

An excellent example of this type of modeling is the study by Plummer et al. (1990) of the chemical evolution of groundwater in the Madison aquifer as it moves several hundred km eastward from recharge areas in Montana and Wyoming. The chemical evolution of the water was consistent with dissolution of gypsum and dolomite, precipitation of calcite, and oxidation of organic matter. That set of reactions explained not only the major element chemistry, but also the isotopes of carbon and sulfur.

A major problem with NETPATH-type modeling, particularly of silicate weathering reactions, is that solutions are rarely unique. Several different sets of minerals can usually be found that satisfy the constraints. Also, depending on the number of solid phases chosen, there may be no solution or an indeterminately large number of solutions. The code is thus a tool to be used in conjunction with geologic insight and judgment: it does not provide simple, unique answers. The inclusion of isotopes may greatly constrain the number of possible answers, provided sufficient isotopic data are available.

REVIEW QUESTIONS

1. Suppose you had a 1 mm wide fracture in an igneous rock, and the concentration of a contaminant in the fracture were kept at a constant value (say by rapid flushing). How long would it take for a mass of contaminant equal to the mass present in the fracture at any instant to diffuse into the rock matrix? Assume a porosity for the matrix of 0.01 and an effective diffusion coefficient of $1 \times 10^{-7} cm^2 s^{-1}$.
2. Suppose you assume instead (Problem 1) that the fluid in the fracture were not moving. Estimate how long it would take for half the material in the fracture to diffuse into the rock matrix. How long would it take if the fracture width were 0.1 mm?

   Note: The analytical solution to this problem is by no means simple. You could (a) make an educated guess based on example 1 above; (b) construct a simple numerical model; or (c) (if you have the background) construct a finite difference model.
3. The following analyses (from Plummer et al., 1990) represent two wells from the Madison aquifer in Montana that lie approximately along a flowline. The aquifer contains limestone, dolomite, and occasional evaporites. Use NETPATH to come up with a set (or more than one set) of reactions that could account for the difference. Do you think the reactions are plausible?

	T(°C)	pH	Ca	Mg	Na	K	Cl	SO_4	ΣCO_2
Well 1	11	7.58	1.87	1.15	0.10	0.02	0.05	1.46	3.31
Well 2	32	7.08	6.50	3.96	3.44	0.31	1.89	10.32	3.72

4. In Example 4 above, suppose the pit lake were to stratify, forming an anoxic hypolimnion (Chapter 8). Predict the chemical composition of the anoxic waters. Make your assumptions clear, and discuss how reasonable these assumptions are.

SUGGESTED READING

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DOCUMENT 2

R000013

Coals

Coals are classified as ***humic coals*** if they are *derived from humic substances via a peat stage* and as ***sapropelic coals*** if they are *formed from fairly fine-grained organic muds in quiet, oxygen-deficient shallow waters.* The humic coals are lustrous, dark-brown to black, exhibit stratification, and often contain the remains of woody tissue. The sapropelic coals are dull, unstratified, and contain allochthonous organic and mineral matter. The sapropelic coals are subdivided into cannel and boghead coals. The conversion of organic matter to coal involves two stages: biochemical and geochemical. The biochemical phase involves biological processes; the geochemical stage involves physicochemical processes due to increasing pressure and temperature. These processes lead to a release of volatiles, primarily methane, water, and carbon dioxide; the elimination of oxygen-containing functional groups; and an increase in the percent of aromatic units. These changes are illustrated in Figure 5–27, which shows the relative increase in carbon with increasing degree of coalification.

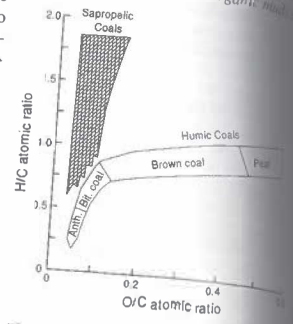

Figure 5–27
van Krevelen (1963) diagram indicating the changes in hydrogen, oxygen, and carbon content during the coalification process. After Killops and Killops (1993).

Of major environmental interest is the metal, sulfur, and fly ash content of coals. Metals that were incorporated in the original organic material tend to remain during the coalification process. Thus, coal is often high in a number of trace elements of environmental concern. Lyons et al. (1989) determined the concentrations of trace elements in a variety of coals, ranging from high-volatile bituminous coals to meta-anthracites. Concentration ranges determined for elements of environmental interest are given in Table 5–6.

Lyons et al. (1989) also investigated the distribution of these trace elements between organic and inorganic (i.e., mineral) components of the coal. For the elements listed in Table 5–6, they concluded that As, Co, Cu, Ni, Sc, and Th generally showed an inorganic association, whereas Cr, Sb, U, V, W, and Zn generally showed an organic association. Se and Pb did not correlate with either association. Metals associated with inorganic components would presumably remain with the fly ash and could be successfully removed from the effluent stream by electrostatic precipitation of the fly ash. Metals associated with organic components would be released to the effluent stream during combustion and dispersed into the atmosphere. These associations would be expected to vary on a coal-by-coal basis, so it is necessary to determine the distribution of elements in a particular coal in order to determine the potential trace metal contribution of this coal to the atmosphere during combustion (see Case Study 5–4).

Table 5–6 Concentration Ranges in Coal for Some Elements of Environmental Interest*

Element	Concentration range (ppm)	Element	Concentration range (ppm)
Sc	0.6–10.3	As	0.7–31
V	6–109	Se	0.4–3.3
Cr	2.6–25.4	Sb	0.1–7.3
Co	1.1–24.1	W	0.2–1.3
Ni	2–50	Pb	3–20
Cu	6–54	Th	0.5–3.7
Zn	3–65	U	0.2–3.8

*From Lyons et al. (1989).

CASE STUDY 5–4
Distribution of Metals and Other Elements in Coals

A number of studies have been carried out on the distribution of metals and other elements in coal. Several of these are cited in this case study to indicate the variability of these elemental associations in coal. Christanis et al. (1998) found that in the Philippi peat of eastern Macedonia, Greece, Ge, Mo, Pb, Se, Ta, Tl, U, and W were correlated with organic content and the other trace elements were correlated with mineral phases. For lignites from central Anatolia, Turkey, Querol et al. (1997) found that Mn, B, Be, Ge, Y, Zr, Nb, Hf, W, and U showed positive correlation with organic matter and Mn, U, Th, Sc, Ge, and HREE showed positive correlation with phosphate, suggesting that apatite or another phosphate mineral is the major host. Co, Mo, Ta, Pb, and IREE showed positive correlation with both Fe and S, indicating that Fe-sulfide minerals are the hosts for these elements. As and V had mixed affinities. For United Kingdom coal fields, Spears and Zheng (1999) found that Rb, Cr, Th, Ce, Zr, Y, Ga, La, Ta, Nb, and V were associated with the clay minerals; As, Mo, Sb, Tl, Se, Bi, and Pb with pyrite; Sr and Ba with phosphate minerals. Germanium was the only element that had a major organic association. For medium- to high-volatile bituminous coals from Nova Scotia, Canada, Mukhopadhyay et al. (1998) found that most lithophile elements, including B, Cr, U, V, and the REE, were associated with the clay minerals; Cu, Pb, and Zn with the sulfide minerals; and Cl, Ca, As, and Mn with organic matter. Of note is the marked variability of the element associations. Major factors affecting trace element concentrations are the abundance and sources of detrital minerals, the presence of volcanic material, and seawater or brine incursions into the basins of deposition.

Sulfur occurs in coal either combined with organic molecules or as physically separate sulfide minerals (of which pyrite is the most common). Sulfur occurs in reduced form (S^-, S^{2-}) because the organic-rich depositional environment is reducing (see Chapter 4). If Fe^{2+} (or other metal ions) is present, it will combine with the reduced sulfur to produce minerals such as marcasite (FeS) and pyrite (FeS_2). If there is a low abundance of metal ions, free hydrogen sulfide (H_2S) and polysulfides (HS_4^-, HS_5^-, S_4^{2-}, S_5^{2-}) are formed. These species can combine with various organic molecules to form a variety of sulfur-containing compounds. In terms of "cleaning up" coal, the way in which sulfur occurs in the coal is of key importance. If the sulfur occurs in separate sulfide minerals, then in principle it can be physically separated by flotation techniques. If the sulfur is bound to organic molecules, there is no effective way to remove the sulfur before burning the coal.

Petroleum

Petroleum is *any hydrocarbon-rich fluid (liquid or gas) derived from kerogen by increases in pressure and temperature.* ***Kerogen*** is *a polymeric organic material that occurs in sedimentary rocks in the form of finely disseminated organic macerals (the preserved remains of plant material).* Four types of kerogen (I, II, III, and IV) have been distinguished on the basis of H/C and O/C atomic ratios, types of organic molecules (aliphatics versus aromatics), functional groups, and other criteria. Type II kerogen is the most common precursor for petroleum. Type I has the highest petroleum-forming potential but is present in low abundance. Type IV kerogen is not a petroleum precursor. Kerogen is converted to petroleum through a series of reactions starting in the ***diagenetic environment*** *(the environment in which processes occur at pressures and temperatures greater than those of the weathering environment but below those required to produce metamorphism)* and ending at temperatures of about 225°C. These reactions result in the expulsion of CO_2 and CH_4 and a reduction in the size of the hydrocarbon molecules. The hydrocarbon formation process for a typical source rock is schematically illustrated in Figure 5–28 (p. 148). Note that natural gas is generated throughout the P–T range, but the formation of oil is confined to a narrow P–T range. Thus, the thermal history of a basin is an important factor in terms of its oil-producing capability. Also note the reduction in the size of the mean hydrocarbon molecule with increasing temperature.

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Graphical Representations of Water Chemistry Two types of diagrams are commonly used to portray water chemistry, Stiff and Piper. Stiff diagrams show the concentrations (in milliequivalents) of the major ions (both cations and anions) as a shape that gives both the relative abundance of the various species and the total abundance. Piper diagrams are trilinear representations of cation, anion, and combined cation and anion proportions. Piper diagrams are often used to classify water types. The following two examples illustrate the plotting of Stiff and Piper diagrams.

EXAMPLE 9–1 In this example we will plot the chemical data for the Columbia and Rio Grande rivers and the Pennsylvania groundwater (Table 9–7) on a Stiff diagram. The following table illustrates the calculation for the Columbia River water. We start by determining the concentration of each ion in millimoles per liter and then calculate the concentration of each ion in milliequivalents. The concentrations in milliequivalents are plotted on the Stiff diagram, as shown in Figure 9–5, and the various points are connected by straight lines. Note that the concentrations of the Na^+ and K^+ ions have been combined.

	Columbia River						
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-
mg L^{-1}	19	5.1	6.2	1.6	3.5	17.1	76
mmol L^{-1}	0.47	0.21	0.27	0.04	0.1	0.18	1.25
meq L^{-1}	0.95	0.42	0.27	0.04	0.1	0.36	1.25

The shape of the field is a representation of the relative proportions of the various ions, and the size of the field represents the total ionic concentration. The Rio Grande river and Central Pennsylvania ground waters are also plotted in Figure 9–5. From the shape of the Stiff diagrams we can easily infer that the Rio Grande has a much greater concentration of all ionic species than the Columbia River and that the bicarbonate ion, relative to the sulfate ion, is much less important in the Rio Grande than it is in the Columbia River. Inspection of the Central Pennsylvania groundwater diagram reveals that the dominant cation is Ca^{2+} and the dominant anion is HCO_3^-, so this is a Ca-carbonate water. Stiff diagrams are particularly useful when plotted on a map because they give a graphical representation of regional variations in water chemistry.

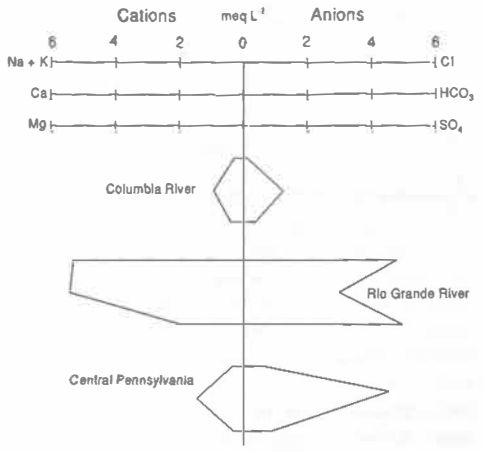

Figure 9–5
Stiff diagram for Columbia and Rio Grande river waters and Central Pennsylvania groundwater. See text for discussion. ■

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EXAMPLE 9–2 In this example we plot the Columbia River data from Example 9–1 on a Piper diagram. As in Example 9–1, we start by calculating the concentration of each ion in milliequivalents. We now normalize the cations and the anions to 100% (as shown in the following table) so that we can plot them on the Piper diagram.

	Cation concentrations			Anion concentrations	
	meq L^{-1}	Normalized		meq L^{-1}	Normalized
Ca^{2+}	0.95	56.5	Cl^-	0.10	5.8
Mg^{2+}	0.42	25.0	SO_4^{2-}	0.36	21.1
$Na^+ + K^+$	0.31	18.5	HCO_3^-	1.25	73.1
Total	1.68	100.0		1.71	100.0

The normalized cation and anion concentrations are plotted in their appropriate triangle (Figure 9–6). The data plotted on each triangle are then projected into the quadrilateral by drawing a line from the point on the cation triangle parallel to the Mg axis into the quadrilateral and by drawing a line from the point in the anion triangle parallel to the SO_4 axis into the quadrilateral. The intersection of these two lines marks the location of the point to be plotted on the quadrilateral (Figure 9–6). Symbols of different size are sometimes used to indicate differences in total dissolved species. This convention is used in the example. The data for the Rio Grande river and the Central Pennsylvania ground waters are also plotted in Figure 9–6. ■

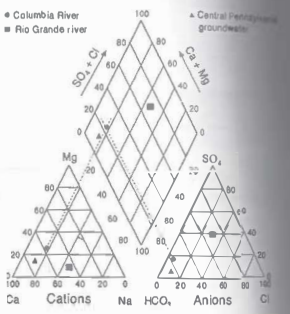

Figure 9–6
Piper diagram for Columbia and Rio Grande river waters and Central Pennsylvania groundwater. See text for discussion.

Piper diagrams have two main uses. The first is the graphical representation of water chemistry for the purpose of water classification (see the next section). The second is to determine if a series of water compositions represent the mixing of two end members. If the samples are the result of two-end-member mixing, they will plot along straight lines in each of the fields of the diagram. If they do not plot along straight lines, then their compositions are not controlled by simple two-end-member mixing (Case Study 9–2).

Hydrofacies Back (1966) divided the ion triangles of the Piper diagram into various fields that correspond to water type or *chemical facies* (Figure 9–7). This is a convenient way to classify water types on the basis of their major ion chemistry. Examples of chemical facies names are calcium bicarbonate and sodium chloride. If the water plots in the center of an ion triangle, it is referred to as *mixed-cation* or *mixed-anion facies*. With reference to the waters plotted in Figure 9–6, the Columbia River water belongs to the calcium-bicarbonate facies, the Rio Grande river water to the mixed-cation–mixed-anion facies, and the Central Pennsylvania groundwater to the calcium-bicarbonate facies. The hydrochemical facies in which the water sample plots potentially reveals information about the factors controlling the water chemistry. For example, the observation that the Columbia River water plots in the calcium-bicarbonate facies suggests that rock weathering is the major factor controlling water chemistry (see next section). The observation that the Central Pennsylvania groundwater plots in the calcium-bicarbonate facies suggests that dissolution of limestone, which would provide the Ca and bicarbonate ions, is important

CASE STUDY 9–2
Mixing of Acid Mine Drainage and Lake Water

In Case Study 2–1, Foos (1997) investigated the mixing of acid mine drainage from an abandoned coal mine with water discharged from a lake. The chemical compositions of the acid mine drainage, lake water, and the stream water downstream from the point of mixing were plotted on a Piper diagram (Figure 9–C2–1). This plot indicated that simple mixing would explain the concentrations of the major ions in the stream (mixed water). Further testing of the mixing model revealed that Ca^{2+}, Mg^{2+}, Na^+, K^+, and Cl^- concentrations could be explained by simple mixing, but not HCO_3^- and SO_4^{2-} concentrations. For HCO_3^- and SO_4^{2-}, the deviation from simple mixing was about 14%, so as a first approximation simple mixing is a reasonable assumption. The deviations from simple mixing for Fe^{2+} (1800%) and Mn^{2+} (39%) were significant. The reasons for the nonconservative behavior of these two species was discussed in Case Study 2–1. In this study, the Piper diagram was used to make an initial evaluation of the conservative versus nonconservative behavior of various species in solution.

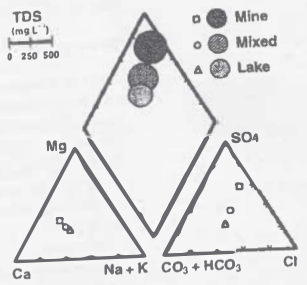

Figure 9–C2–1
Piper diagram showing the compositions of the mine and lake discharges and the mixed stream water. From Foos (1997).

Source: Foos (1997).

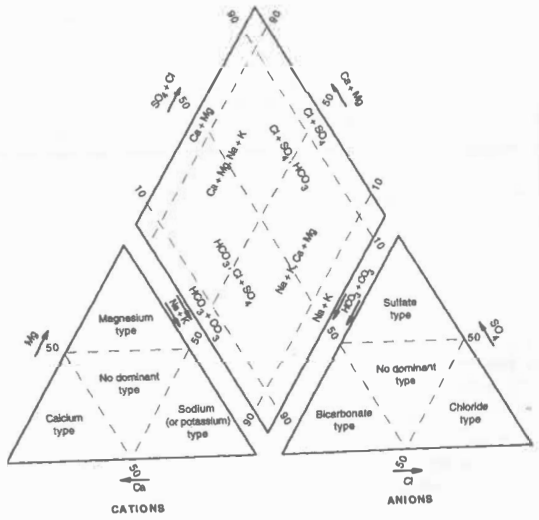

Figure 9–7
Hydrochemical facies. After Back (1966).

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CASE STUDY 9–7
Sulfide Mine Tailings at Two Sites in New Mexico, U.S.A.

Boulet and Larocque (1998) investigated the characteristics of two sulfide mine tailings sites. For both deposits the common ore minerals were chalcopyrite, sphalerite, and galena. At one site (CPA) the tailings were deposited in a polyethylene-lined bermed impoundment. Mining at this site ended in 1995. At the other site (CM) the tailings were deposited in a valley at the headwaters of an ephemeral stream. Mining ceased at this site in 1950.

At the CPA site the dominant tailings minerals are calcite, quartz, and pyrite. A lime slurry was added to the tailings before they were discharged to the tailings pond. The tailings pond water is alkaline (pH = 7 to 8.3) and mineralogical investigation showed no evidence of dissolution of the primary calcite, indicating that the added lime slurry is still providing sufficient buffering capacity. Under the present conditions, the metals in the CPA tailings are immobile and acid drainage is not a problem at this site.

At the CMT site significant weathering and oxidation has occurred. Besides the sulfide minerals, the other primary minerals in this tailing pile were quartz, calcite, and several other silicate minerals. Because of weathering and oxidation, the current assemblage of primary minerals are quartz and the sulfide minerals pyrite, sphalerite, and chalcopyrite. Essentially all the primary calcite has been consumed in buffering reactions. Water draining from the site is strongly acidic (pH = 2.3) and has high metal concentrations. There has been a significant redistribution of metals within the tailings pile. Abundant secondary minerals (the result of the weathering of the primary minerals) have formed throughout the tailings pile. These secondary minerals consist of various iron oxides, hydroxides, and sulfates plus gypsum. In places, these secondary minerals have cemented the tailings to form *hardpans*. The hardpan represents a local zone of neutralization and precipitation, and the highest metal concentrations are found in the hardpan. Elements such as Ag, Au, Pb, and Sb were found at highest concentrations in the layer above the hardpan. These elements form highly insoluble complexes with sulfate, and the slight increase in pH as the waters percolated down through the tailings pile was sufficient to lead to the precipitation of the metal sulfates. The trapping of metals (Ag, Au, As, Pb, and Sb) in the hardpan layers was an important process that inhibited movement of these metals into the local environment. Metals (Cd, Cu, Fe, and Zn) not trapped in the hardpan layers were readily transported by the acid waters draining the site.

Source: Boulet and Larocque (1998).

vironments, such as deltas. Subsequent exposure of this material to subaerial weathering leads to acid drainage and the release of metals. This exposure can be due to either uplift or artificial drainage for land recovery (Case Study 9–8).

Heavy Metals

As defined earlier, heavy metals are those metals of atomic number 20 and greater. Of the heavy metals, the transition elements, As and Se (strictly speaking, metalloids), Cd, Hg, and Pb have attracted the greatest environmental interest. Other metals specifically involved in issues of nuclear waste disposal and radioactive fallout will be considered in the next section.

In a strongly reducing environment, and in the presence of sulfur, all these elements form insoluble sulfides. This, of course, is the reason why coals, which form in strongly reducing environments, contain significant amounts of heavy metals. As long as the environment remains reducing, the elements are immobile and are retained in the sediment. Changes in oxidation–reduction conditions can lead to a release of these elements. For less strongly reducing conditions, or environments that lack sulfur, the heavy metals can become variably mobile. The factors that control element mobility are pH, Eh, and the presence of organic compounds. The most important factors differ depending on the element. Thus, it is convenient to form three metal groups: (1) transition metals, Zn, Cd, and Pb; (2) As and Se; and (3) Hg.

Transition Metals, Zn, Cd, and Pb Under most oxidation–reduction conditions, these elements occur in solution as divalent or trivalent cationic species. Brookins (1988), a very useful reference, gives a number of calculated Eh–pH diagrams for virtually all systems of geochemical interest, and the student should consult this source for Eh–pH diagrams for specific metals. At high pH, many of these elements form insoluble oxyhydroxides or, in the presence of carbonate, insoluble carbonates. As we know from

CASE STUDY 9–8
The Effect of Acid Soil Leaching on Metal Concentrations in Streams

Sulfide-bearing marine and lacustrine sediments are common in the coastal regions of Finland. Artificial drainage of these areas during the past few decades has exposed these sediments to atmospheric O_2 and a high oxidation rate. The result has been the development of acid soils (pH = 2.5 to 5.0). Water-chemistry measurements were made for a stream draining this region under various flow conditions (Åström, 2001). The headwaters originate in an unpopulated area underlain by glacial till, peat, and glaciofluvial deposits. Water-chemistry measurements made at this point constitute the metal baseline concentrations. The concentrations of the metals in the outlet waters (after the stream had traversed the sulfide-bearing sediments) were compared to the baseline values. The outlet-to-baseline ratios varied from 0.3 to 55 as a function of the metal, the magnitude of the stream flow, and the season. The metals that showed downstream depletion were As, Pb, Sb, Ti, and V. The limited leaching of these metals from the acid sulfate soils was believed to be due to low absolute abundances, low concentrations in easily weathered minerals, or low mobility in the soils due to complexation with oxyhydroxides and humic substances. For the elements that showed downstream enrichment, the order, from most enriched to least enriched, was Ni > Co ≈ Cd ≈ Zn > U ≈ Al ≈ Cu ≈ Mn. Åström noted that the downstream variations for all the elements were closely similar to that for SO_4^{2-}, suggesting that the metal and sulfate had a similar hydrogeochemical behavior.

Figure 9–C8–1 shows a typical pH–depth profile for acid sulfate soils and the various redox environments. Seasonal changes in this profile can be directly related to variations in metal release to the stream. Åström proposed the following model to explain the seasonal variations in metal and sulfate concentrations in the stream:

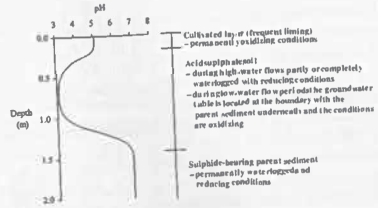

Figure 9-C8–1
pH, redox, and hydrological characteristics of a typical acid sulfate soil. After Åström (2001).

1. During the summer, higher temperatures and a lowered groundwater table favor aerobic bacterial oxidation of sulfide minerals and the release of metals and sulfate to the soils. Substantial alteration of soil minerals also occurs.
2. During periods of heavy rainfall in the autumn, the soluble weathering products are washed from the soils, and sulfate, metal ions, and hydrogen ions are discharged to the stream. As winter approaches, temperatures fall and the water table rises, leading to a cessation in the formation of soluble weathering products.
3. Metal and sulfate inputs to the stream during the early summer are small because most of the soluble weathering products were removed during the fall rains and there has been little formation of new material.
4. Under low flow conditions (summer and early autumn), the contribution from the acid soils is negligible compared to that of the areas covered with the other sediments.

Source: Åström (2001).

earlier discussions, adsorption is an important process. Thus, another important factor is the presence of suitable sorbates, among which are Mn and Fe oxyhydroxides. At low pH, sorbtion is negligible for these metals, but with increasing pH, adsorption becomes an important process (Figure 9–16), effectively removing the metals from solution by adsorption to particles and ultimately to the sediments. These elements also form complexes with dissolved organic matter (humic acids). Tipping and Hurley (1992) determined the following binding order for various metals and humic substances: $Mn^{2+} < Cd^{2+} < Co^{2+} < Ni^{2+} \sim Zn^{2+} < Pb^{2+} < Cu^{2+} < VO^{2+}$.

One notable exception to the behavior just described is vanadium. Under reducing conditions, V occurs as the relatively immobile V^{3+}. In oxic environments, the solubility of V increases dramatically because of conversion to higher oxidation states, V^{4+} and V^{5+}, and the formation of vanadyl cations, $VO_2(OH)_3^{2-}$, H_2VO^{4-}, and HVO_4^{2-}.

Selective Extraction In any given environment, the actual distribution of a metal among various phases may differ substantially from that predicted from first principles. One way to address this question is by a technique known as *selective extraction*, in which various leaching experiments are done to remove the metals from specific phases. The leaching agents are selected so that they remove metals that occur in different ways, i.e., as exchangeable cations, bound to carbonates, bound to amorphous Fe and Mn hydroxides,

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bound to organic matter and sulfides, and as essential components of soil minerals. The experiment is done in a stepwise fashion, starting with a leaching agent that removes only the least tightly held cations. The last step is often a strong acid leach that breaks down the soil minerals. From these types of experiments, estimates can be made of the mobility of various metals in the specific environment. Case Study 9–9 describes a typical selective extraction experiment.

Arsenic and Selenium Arsenic and selenium differ from the transition metals in that they occur in solution as neutral and negatively charged species. Under oxidizing conditions, arsenic is in the +5 state. Given the range of pH values found for the natural environment, As^{5+} exists in solution as $H_2AsO_4^-$ and $HAsO_4^{2-}$. Under reducing conditions, arsenic is in the +3 state and exists in solution as $H_3AsO_{3\,(aq)}$ and $H_2AsO_3^-$. Selenium also shows multiple oxidation states. Under strongly oxidizing conditions, it is in the +6 state (SeO_4^{2-}), under intermediate oxidizing conditions in the +4 state ($HSeO_3^-$ and SeO_3^{2-}), and under reducing conditions, it occurs in its elemental form or in the −2 state (HSe^-). Under reducing conditions, if sulfur is present, both As and Se are incorporated in sulfide minerals. Because As and Se exist in solution as negatively charged species, adsorption increases with declining pH (the surface becomes less negatively charged or positively charged). The arsenate (+5) species form inner-sphere complexes at the iron oxyhydroxide surface and are strongly adsorbed near neutral pH (note from Table 9–11 that for the oxyhydroxides $pH_{pznpc} = 7.8–8.5$), whereas the arsenite (+3) species are only weakly adsorbed at all pH values. For selenium, the situation is reversed and the selenite (+4) species are strongly adsorbed whereas the selenate (+6) species are weakly adsorbed.

The difference in adsorption behavior for the various species of arsenic and selenium is important in terms of their transport in the surface environment. In the case of arsenic, a strongly oxidizing environment that favors the formation of arsenate species will lead to adsorption by oxyhydroxides and removal from the aqueous environment. If conditions become reducing, the bound arsenate will be converted to arsenite and can be liberated from the particles to the solution. The reverse behavior would be noted for the various selenium species; i.e., selenium tends to remain in solution under oxidizing conditions but is removed under reducing conditions. The important point is that changes in the redox conditions of the environment can lead to either removal or liberation of arsenic and selenium. The other important point is that the kinetics of the redox reactions is slow, so

CASE STUDY 9–9
Geochemical Behavior and Mobility of Metals in a Sediment Retention Pond

Lee et al. (1997) studied the mobility of metals in a sediment retention pond located along a motorway in France. The purpose of these retention ponds is to accumulate particulates contaminated by heavy metals, thus preventing their discharge to surrounding streams. Eight sediment cores were driven to depths of 16 to 20 cm. The interstitial fluids were extracted and analyzed for their metal content. The metals associated with the solid phases were then analyzed using sequential chemical extraction. The authors used a five-step process, as follows:

1. Fraction I: *Exchangeable*, 1 M $MgCl_2$ at pH 7
2. Fraction II: *Bound to carbonate*, 1 M sodium acetate adjusted to pH 5.0 with acetic acid for 5 h
3. Fraction III: *Bound to amorphous Fe and Mn hydroxides*, 0.04 M hydroxylamine hydrochloric acid in 25% (v/v) acetic acid at 96°C for 6 h
4. Fraction IV: *Bound to organic matter and sulfides*, 30% H_2O_2 and 0.02 M nitric acid at 85°C for 5 h
5. Fraction V: *Residual*, concentrated HNO_3 and $HClO_4$

For the four metals of interest, Pb was concentrated in Fraction V (35–60%) and Fraction III (20–44%), Zn in Fraction V (30–65%) and Fraction III (13–47%), and Cd in Fraction II (25–68%). Mn showed a more complex behavior, with the bulk of the Mn in the surface layers in the exchangeable fractions (I, II, and III) and a notable increase with depth of Mn in the nonexchangeable Fraction V. The authors ascribed this increase in the nonexchangeable fraction to either the precipitation of Mn^{4+} oxides or the incorporation of Mn in Fe oxyhydroxides. Metals concentrated in Fraction V would be essentially immobile in the surface environment.

Source: Lee et al. (1997).

disequilibrium is common. Thus, predicting the mobility of arsenic and selenium under a particular set of environmental conditions is difficult.

Both elements are of environmental interest. Arsenic in very high concentrations (not those encountered in surface and ground waters, but perhaps due to human intervention) is a poison. Low-level, long-term exposure to arsenic may lead to an increased risk of cancer (National Academy of Sciences, 1999). For this reason, the USEPA (U.S. Environmental Protection Agency) has recommended lowering the allowable amount of arsenic in drinking water. The major anthropogenic source of arsenic is pesticides applied to orchards and other crop lands. Selenium is an essential metal for human health, but at slightly higher levels it becomes a toxic element. Certain plants can accumulate selenium, causing toxicity problems for ruminants that graze on the plants. The major anthropogenic source for selenium is deposition of atmospheric aerosols derived from the burning of coal.

Mercury Under a wide range of Eh–pH conditions mercury exists as mercury metal (remember that at room temperature mercury metal is a liquid). Liquid mercury is essentially insoluble in water, but mercury is transferred to the atmosphere by volatilization. Under strongly oxidizing conditions mercury exists either as the Hg^{2+} ion or its hydrolysis product $Hg(OH)_{2\,(aq)}$. In a reducing environment, if sulfur is present, mercury can form the insoluble sulfide HgS (cinnabar).

The global cycle of mercury is dominated by the vapor phase transport of Hg^0 (Figure 9–21). The residence time of mercury in the atmosphere is 1 year. However, because of the equilibrium between the atmosphere and the surface ocean, the rate constant for mercury removal from the atmosphere is 0.29 y^{-1}. Because of the low removal rate of mercury by the surface ocean, the bulk of the mercury is deposited on land, where it is sequestered in the soils.

In its metallic form mercury is essentially inert. While this means it does not represent an immediate environmental hazard, it also means that mercury can persist for an extended period of time in the natural environment. Certain microorganisms, such as anaerobic bacteria, can mediate the methylation of mercury (Figure 9–21) to monomethyl mercury (CH_3Hg) or dimethyl mercury [$(CH_3)_2Hg$], which are highly soluble species that are readily taken up by aquatic organisms, particularly fish and shellfish. The mercury is concentrated up the food chain and can reach concentrations of several thousand ppm in organisms residing at the highest trophic levels. At these concentration levels, mercury is

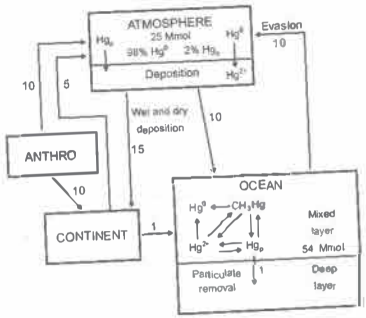

Figure 9–21
Present-day mercury cycle. The fluxes are given in Mmol L^{-1}. Hg_p represents mercury adsorbed to particles. Anthropogenic inputs are approximately 20 Mmol y^{-1}; half is returned to the surface close to the source and the other half is transferred to the atmosphere as volatile mercury. Adapted from Mason et al. (1994).

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hazardous to human health. Because methylation of mercury is mediated by anaerc bacteria, some of the mercury deposited in sediments in a reducing environment, eve sulfur is present, may be converted to soluble methyl species rather than insoluble merc sulfide.

Metal Variations in Space and Time A variety of approaches are used to determ both natural and anthropogenic distributions of metals in the surface environment. (such approach is a regional geochemical survey in which the metal content of s streams, and groundwater is determined (Reimann et al., 2001; Sewell, 1999). The purp of such studies is to gather information on both the background concentrations of the r als and areas of abnormally high metal concentrations. The bulk of these techniques v developed in the 1950s and 1960s, when they were used in geochemical exploration grams for base metal ore deposits. The sampling of different types of material can be u to infer the source of the metals. For example, Reimann et al. (2001) used four diffe sample materials: terrestrial moss, which predominantly reflects the atmospheric inpu metals; the O-soil horizon, which reflects the interplay among atmosphere, biosphere, lithosphere; the B-soil horizon, which reflects weathering processes; and the C-soil h zon, which represents the bedrock geochemistry.

The geochemical patterns can be compared to bedrock geology, surficial geol land use, etc. Such studies have been greatly facilitated by the advent of Geograph Information Systems (GIS), which enables a multidimensional correlation of various rameters. For example, in the case of high levels of arsenic in groundwater, which have both natural (bedrock) and anthropogenic sources (pesticides), a comparison bedrock geology, land use, and arsenic well water concentrations can be used to dis guish between natural and anthropogenic sources of arsenic (Ayotte et al., 1999).

We are also interested in changes in metal concentrations with time. In Chapter 8 discussed how snow, ice, lake sediments, and biological indicators can be used to changes in atmospheric deposition of metals. In the case of the continental environm the most useful information is contained in lake sediments. In general, lake sediment the result of vertical sedimentation. As we have discussed in previous chapters, it is sible to determine the age of lake sediments as a function of depth. Chemical or iso analysis of the various layers can then be used to trace changes in anthropogenic input time.

Metal Contamination of Soils and Sediments A number of processes seq metals in sediments. One way to look at the anthropogenic enrichment of metals in ments is to compare the abundance of the metals to background (or reference) values. of the commonly used references is average shale. The calculation is analogous to tha enrichment factors (discussed in Chapter 8); i.e.,

$$\text{Enrichment factor} = \frac{\text{Concentration in sediment}}{\text{Concentration in reference material}} \quad (9$$

The geoaccumulation index (Müller, 1979) can be used to assess the degree of cont nation. The index is calculated as follows

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (9$$

where I_{geo} is the geoaccumulation index, $\log_2$ is log base 2, C_n is the concentration sediment, and B_n is the background or reference concentration. After the geoaccum tion index has been calculated, it can be used to classify the sediment in terms of qu (Table 9–14).

Radioactive Isotopes and Radioactive Waste Disposal

Radioactive isotopes in the environment come from both natural sources (K, Th, and rocks and minerals) and anthropogenic sources (bomb testing, nuclear medicine, nuc accidents, and the nuclear fuel cycle). Radioactivity and radioactive decay were disco

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health hazard. At these higher concentrations fluoride can cause dental fluorosis (tooth mottling) and skeletal fluorosis (bone deformation and painful brittle joints). Natural sources of fluorine are volcanic emissions and the weathering of fluoride-containing minerals. Anthropogenic sources are mining and industrial emissions.

The concentration of fluoride in natural waters is largely controlled by dissociation reactions involving fluoride containing minerals, of which the most important is fluorite. The dissociation reaction is

$$CaF_{2\ \text{fluorite}} \rightarrow Ca^{2+} + 2F^-$$

From the data in Appendix II, source 3, the equilibrium constant for this reaction at 25°C, is

$$K_{\text{fluorite}} = [Ca^{2+}][F^-]^2 = 10^{-10.51}$$

Writing this equation in logarithmic form gives

$$\log K_{\text{fluorite}} = \log[Ca^{2+}] + 2[\log F^-] = -10.51$$

On a logarithmic plot, the relationship between the concentrations of the two ionic species in solution and fluorite solubility plots as a straight line (Figure 9–24). This is a very useful plot because it allows us to determine if a water is saturated with respect to fluorite, the major mineral controlling F^- concentrations. Consider a water sample of composition A. The water sample is undersaturated with respect to fluorite, and fluoride can be added to the water until it becomes saturated (A → B). At this point the concentration of fluoride will remain constant unless we reduce the Ca^{2+} concentration, in which case the F^- concentration can increase (B → C). If we increase the Ca^{2+} concentration (A → D), the solution will eventually become saturated in fluorite. Continued addition of Ca^{2+} will lead to a decrease in the F^- concentration in solution (D → E). It has been suggested that Ca^{2+} could be added (in the form of gypsum) to high F^- waters, leading to the precipitation of fluorite and a reduction in the F^- concentration. Most natural waters are undersaturated or just saturated with respect to fluorite, suggesting that fluorite solubility controls the F^- concentration of natural waters (Case Study 9–10).

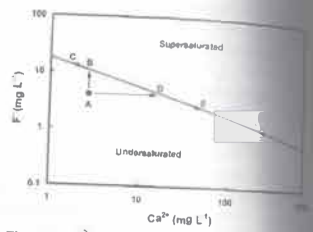

Figure 9–24
Solubility of fluorite at 25°C as a function of F^- and Ca^{2+} concentrations. See text for discussion.

Cl^- and Br^- Chlorine and bromine have both natural and anthropogenic sources. Natural sources include seawater, subsurface brines, and evaporite deposits. Anthropogenic sources for bromine include pesticides, medicines, industrial solvents, gasoline additives, and water purification. For chlorine, the list is even more extensive because it is one of the most widely used elements in modern industrial chemistry. Degradation of these anthropogenic compounds releases Cl^- and Br^- to solution, apparently largely in the form of simple ions. Hydrochemical characteristics of both compounds are (1) low concentration in most rock forming minerals, (2) high solubility of most nonsilicate compounds, (3) virtually no adsorption by particles, (4) lack of volatile compounds, and (5) generally low bioconcentrations in aqueous systems. Because of these characteristics, both elements behave as conservative species and they have been widely used as tracers in hydrological systems. Bromine and chlorine, however, do differ in several important ways: (1) Bromide compounds are even more soluble than chloride compounds. During the formation of evaporite deposits Br is concentrated with respect to Cl in the late-stage brines, leading to a decrease in the Cl/Br ratio. (2) Br does show some adsorption characteristics, particularly at low pH, on kaolinite and iron oxide surfaces.

CASE STUDY 9–10
F^- Concentrations in Streams and Groundwaters from Nalgonda District, India

Ground and surface waters in the Nalgonda District of India contain elevated levels (0.4 to 20 mg L^{-1} for groundwater and 0.4 to 6.6 mg L^{-1} for surface waters) of fluoride, which has led to endemic fluorosis (Ramamohana Rao et al., 1993). There are no fluorine-based industries in the area (nor volcanoes), so the fluorine must originate from the minerals in the rocks and soils. The area is underlain by several varieties of granites that contain the fluorine-bearing minerals fluorite (0 to 3.3%), biotite (0.1 to 1.7%), and hornblende (0.1 to 1.1%). Whole-rock F content ranges from 325 ppm to 3200 ppm, with a mean of 1440 ppm. Acid-soluble fluoride content (fluoride contained in fluorite and fluoroapatite, which can be removed by acid leaching) ranges from 40 to 1150 ppm, with a mean of 410 ppm. The overlying soils are also relatively high in fluoride, have relatively low Ca and Mg concentrations and high Na concentrations. There is an inverse relationship between hardness (Ca + Mg) and fluoride concentration and a direct relationship between alkalinity (due to the presence of Na in the soils) and fluoride concentration. All the soils have basic pH values. In a series of experiments the authors found that the solubility of fluorite was significantly increased in the presence of sodium carbonate and sodium bicarbonate, due to the following reactions:

$$CaF_{2\ \text{fluorite}} + 2Na^+ + CO_3^{2-} \rightarrow CaCO_{3\ \text{calcite}} + 2Na^+ + 2F^-$$

and

$$CaF_{2\ \text{fluorite}} + 2Na^+ + 2HCO_3^- \rightarrow CaCO_{3\ \text{calcite}} + 2Na^+ + 2F^- + H_2O + CO_2$$

The authors concluded that these reactions led to the precipitation of calcite and a reduction in the amount of Ca^{2+} available for fluorite precipitation, thus increasing the amount of F^- in solution.

Source: Ramamohana Rao et al. (1993).

(3) There is some evidence that marine plants and surface plants do concentrate Br (Davis et al., 1998).

Because there are natural processes that will change the Cl/Br ratio, plus anthropogenic inputs that may lead to relative increases in Br or Cl concentrations and changes in the Cl/Br ratio, Davis et al. (1998) suggested that Cl/Br ratios could be used to fingerprint the sources of various waters in an aquifer. Once Cl and Br have entered a groundwater system, they tend to behave conservatively. Thus, variations in the Br/Cl ratio reflect variable degrees of end-member mixing. In Chapter 6 we developed mixing equations for isotopic systems. Analogous mixing equations can be written for conservative species. For a simple binary mixture involving two end members, the mathematics are straightforward if we use the abundances of the conservative species rather than ratios. For a mixture involving one conservative species and two end members, we can write

$$X_M = X_A f_A + X_B(1 - f_A) \tag{9-42}$$

where X_M is the concentration of species X in the mixture, X_A is the concentration of species X in end member A, X_B is the concentration of species X in end member B, and f_A (the mixing parameter) is the fraction of end member A. For a second conservative species in a mixture, we can write

$$Y_M = Y_A f_A + Y_B(1 - f_A) \tag{9-43}$$

where Y is the second conservative species. For a binary mixture involving conservative species, f_A must be the same for all species. We can solve equations 9–42 and 9–43 for f_A and equate the results:

$$f_A = \frac{X_M - X_B}{X_A - X_B} = \frac{Y_M - Y_B}{Y_A - Y_B} \tag{9-44}$$

Cross multiplying equation 9-44 and solving for Y_M gives

$$Y_M = X_M\frac{Y_A - Y_B}{X_A - X_B} + \frac{X_A Y_B - X_B Y_A}{X_A - X_B} \tag{9-45}$$

which is the equation for a straight line (Figure 9–25, p. 368). For any simple binary mixture of two conservative species, the data will fall on a straight line. The purpose of this

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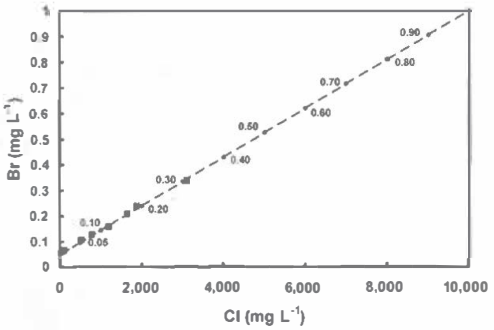

Figure 9–25
Binary mixture of groundwater (0.05 mg L^{-1} Br and 5 mg L^{-1} Cl) and brine (1 mg L^{-1} Br and 10,000 mg L^{-1} Cl). Labeled points are fraction of brine in the mixture. Groundwater samples from an aquifer (filled squares) fall along this line, suggesting they represent mixtures of uncontaminated groundwater and brine. The maximum amount of brine in the groundwater is approximately 31%.

exercise is to determine if a set of data obeys a simple binary mixing model. If the data do obey a simple binary mixing model, and if we know the composition of the end members, either equation 9–42 or 9–43 can be solved for the fraction of each end member in the individual samples. For example, groundwater samples were collected from a number of wells in an aquifer (filled squares in Figure 9–25). It is believed that subsurface brines are mixing with the groundwater. The well data plot on a straight line. The end-member compositions, based on measurements of groundwater entering the aquifer and the brine, are 0.05 mg L^{-1} of Br and 5 mg L^{-1} of Cl for the uncontaminated groundwater and 1 mg L^{-1} of Br and 10,000 mg L^{-1} of Cl for the brine. The labeled points on the diagram represent the fraction of brine. Inspection of Figure 9–25 reveals that the groundwater samples represent mixtures containing from 1% to about 31% brine.

Suppose our water samples consist of a mixture of three end members. As was discussed in Chapter 6, the data will fall within a triangular field. We can determine the fraction of the three end members in any particular sample using a graphical solution (Figure 6–14). If we know the end-member compositions, we can determine the fraction of each end member by solving a set of linear equations. For a three-end-member (A, B, and C) mixture, the concentration of X in the mixture is

$$X_M = X_A f_A + X_B f_B + X_C f_C \tag{9–46}$$

and the concentration of Y in the mixture is

$$Y_M = Y_A f_A + Y_B f_B + Y_C f_C \tag{9–47}$$

The symbols are as defined earlier. For our third equation,

$$f_A + f_B + f_C = 1 \tag{9–48}$$

because the total end-member fractions must add up to 1. Simultaneous solution of these three equations yields the end-member fractions.

Nitrogen

Nitrogen shows a complex and varied behavior in the natural environment (Figure 9–26). In Chapter 4 we constructed the Eh–pH diagram (Figure 4–9) for the various nitrogen species found in water. Depending on redox conditions, nitrogen can occur in natural wa-

DOCUMENT 3

DISCLAIMER

The U.S. Environmental Protection Agency's Office of Solid Waste (EPA or the Agency) has compiled this methods manual in order to provide comprehensive guidance to analysts, data users, and other interested parties regarding test methods that may be employed for the evaluation of solid waste and other testing specified in regulations issued under the Resource Conservation and Recovery Act (RCRA). Except where explicitly specified in a regulation, the use of SW-846 methods is not mandatory in response to Federal testing requirements.

The Agency does not intend to restrict the use of new analytical techniques. Advances in technologies applicable to the sampling and analysis of environmental media and hazardous wastes outpace the ability of the Agency to promulgate revisions to this manual. In addition, given the large number of manufacturers and vendors of scientific equipment, glassware, reagents, and supplies, it is not feasible to cite all possible sources for these materials. Thus, the mention of trade names or commercial products in this manual is for illustrative purposes only, and does not constitute an endorsement or exclusive recommendation for use by EPA. The products and instrument settings cited in SW-846 methods represent those products and settings used during method development or subsequently evaluated by the Agency. Glassware, reagents, supplies, equipment, and settings other than those listed in this manual may be employed provided that method performance appropriate for the intended RCRA application has been documented as described in Chapter Two (see Sec. 2.1).

EPA generally does not intend these methods to be overly prescriptive. The words "shall," "must," or "require" are used to indicate aspects of the method that are considered essential to its performance, based on sound analytical practices (e.g., an instrument must be calibrated before use). In contrast, the words "should," "may," or "recommend" are used to provide guidance on aspects of the method that are useful but not essential. This flexibility does not apply to those method-defined parameters where the analytical result is wholly dependent on the process used to make the measurement.

EPA emphasizes that the ultimate responsibility for producing reliable analytical results lies with the entity subject to the Federal, State, or local regulation. Thus, members of the regulated community are advised to refer to the information in Chapter Two and to consult with knowledgeable laboratory personnel when choosing the most appropriate suite of analytical methods. The regulated community is further advised that the methods here or from other sources need only be used for those specific analytes of concern that are subject to regulation or other monitoring requirements.

Many of the methods include performance data that are intended as guidance on the performance that may be achieved in typical matrices and may be used by the analyst to select the appropriate method for the intended application. These performance data are not intended to be used as absolute QC acceptance criteria. Rather, each laboratory should develop performance criteria as described in Chapter Two and elsewhere in the manual.

In summary, the methods included here provide guidance to the analyst and the regulated community in making judgments necessary to generate data that meet the data quality objectives for the intended use of the results.

DOCUMENT 4

CHAPTER ONE
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CHAPTER ONE

Project Quality Assurance and Quality Control

For a summary of changes in this version from the previously published Chapter One, please see Appendix A at the end of this document.

1.0 INTRODUCTION

The goal of this chapter is to provide an understanding of environmental data and the need for quality. EPA has developed numerous guidance documents on quality assurance. This chapter is not intended to summarize the previously developed EPA guidance. Instead, this chapter will provide familiarity with regulations and guidance relating to QA and where to find them.

Regulations promulgated under the Resource Conservation and Recovery Act (RCRA) of 1976, as amended; require the collection and use of environmental data by regulated entities. In addition, organizations often collect and use environmental data for decision making. Given the significant decisions to be made based on environmental data, it is critical that the data are of sufficient quantity and quality for their intended use and can support decision-making based on sound science.

In response to the need for quality data, it is recommended that all parties follow a structured system of data quality assurance and quality control (QA/QC). In addition, some of the RCRA regulations include specific requirements for ensuring data quality.

This chapter provides general guidance intended to ensure data are of sufficient quality for their intended use. Its intended audience is any entity, government or private party that may be collecting environmental data. It is designed to support the efforts of those responsible for preparing and reviewing project planning documents such as Quality Assurance Project Plans (QAPPs), those involved in implementing and assessing data collection and generation activities in the field or laboratory, and those who use the data for decision-making.

Due to the diversity of data collection efforts, it is not possible to provide all details necessary to meet the needs of all members of the intended audience. However, EPA has developed a variety of detailed QA guidance documents that are incorporated into this Chapter by reference. This series of quality systems documents can be accessed on the EPA's Quality web site at: http://www.epa.gov/quality. These documents describe in detail EPA policies and procedures for planning, implementing and assessing the effectiveness of quality systems.

EPA's quality system comprises three structural levels: policy, organization/program, and project. This document addresses quality at the project level of the system, including technical aspects of analytical method quality assurance (QA) and quality control (QC). Entities which desire guidance on the other two structural levels (policy and organization/program levels) can access such guidance at the aforementioned EPA quality web site.

A project's life cycle under EPA's quality system has three phases: planning, implementation, and assessment. This chapter is organized into these three phases. Additionally, Figure 1 is provided, and illustrates this process.

Additionally, this chapter contains general project QC guidance to be used with the subsequent chapters and methods in this manual. It should be noted that several methods (e.g.,

Method 8000) also contain general QC criteria and guidance that pertain to the individual methods referenced therein (e.g., Methods 8081, 8082, 8260 and 8270). Individual methods may also contain QC criteria specific only to that method. The QC criteria in the general methods take precedence over chapter QC criteria. Method-specific QC criteria take precedence over general method QC criteria.

1.1 PLANNING

Planning, the first phase of a project's life cycle, involves the development of project objectives and acceptance or performance criteria using a systematic process. Data quality objectives (DQOs) and a sampling and analysis design are established to generate data of an appropriate type, quality and quantity to meet project objectives. The final output of this phase is a planning document, such as a QAPP, and/or a sampling and analysis plan (SAP) or a waste analysis plan (WAP).

This section provides guidance on activities and concepts that EPA recommends to be used or considered during the planning phase, when appropriate to a specific project.

1.1.1 Systematic Planning

Systematic planning is a process designed to ensure that the level of detail in planning is commensurate with the importance and intended use of the work and the availability of resources to accomplish it. The ultimate goal of systematic planning is to ensure collection of the appropriate type, quantity, and quality of data to support decisions with acceptable confidence. Following is a summary of EPA's Agency-wide guidance on systematic planning. More detail can be found in the *EPA Quality Manual for Environmental Programs (CIO-2105-P-01-0).*

The systematic planning process generally involves the following elements:

- Identification and involvement of data generators and users.
- Identification of project schedule, milestones, resources (including budget), and any applicable requirements.
- Description of the project goals and objectives (i.e., what is trying to be accomplished by performing this project)
- Identification of the type (e.g., individual data points to be used to estimate risk at a site, multi-point composites to be used to evaluate the average concentration in a decision unit), quantity and quality (e.g., screening for the presence/absence of an analyte, definitive data supported by all method specific QC results) of data needed. Be specific on what kind of analytical result will be needed to make a decision, whether the collected results need to be comprehensive and meet well defined DQOs or are merely for screening purposes to make a presence/absence decision?
- Specification of acceptance or performance criteria for ensuring the data collected meets the needs of the project.
- Description of how, when, and where the data will be obtained, and identification of any constraints on data collection.

- Specification of QA and QC activities needed to assess quality performance criteria (e.g., QC samples for the field and laboratory, audits, technical assessments, performance evaluations, etc.).

- Description of how acquired data will be analyzed (i.e., field and/or laboratory), evaluated, and assessed against performance criteria. If statistical assumptions are made as part of the planning process, the assessment must discuss how the assumptions will be verified as accurate, and what actions will be taken if the statistical assumptions are not supported by the data.

Planners should also recognize that existing data (i.e., secondary data) can be useful in supporting decision making. Secondary data can provide valuable information to help design a plan for collecting new data, while also lowering the cost of future data collection efforts. However, the limitations on using any secondary data must be clearly understood and documented. For example, secondary data must be examined to ensure that their quality is acceptable for a given application. Combining secondary data with current data can be a complex operation and should be undertaken with care. Sometimes, statistical expertise is necessary to evaluate both data sets before they can be combined. If combining data sets, make sure historical data use is appropriate in type and quality to the current project.

1.1.2 DQOs

The DQO process, discussed in detail in the *Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4*, is designed to produce scientific and resource-effective data collection designs that will support decision making with a defined level of confidence.

The DQO process can be applied to any study, regardless of its size. While there is no regulatory obligation to use the DQO process, it is the recommended planning approach for most EPA data collection activities. The depth and detail of DQO development will depend on the study objectives. The DQO process is particularly applicable to a study in which multiple decisions must be reached. By using the DQO process, the planning team can clearly separate and delineate data requirements for each decision to be made or question to be answered. It consists of seven planning steps that are summarized below.

1.1.2.1 Step 1: State the Problem

The purpose of Step 1 is to clearly define the problem that has created the need for the study. In describing the problem, especially for more complex sites, it is often useful to include a conceptual site model (CSM). The CSM is a three-dimensional "picture" of site conditions at a discrete point in time that conveys what is known or suspected about the facility, including releases, release mechanisms, contaminant fate and transport, exposure pathways, potential receptors, and risks.

1.1.2.2 Step 2: Identify the Goals of the Study

The purpose of Step 2 of the DQO process is to identify the key questions that need to be answered in order to resolve the problem(s) identified in Step 1. Step 2 should also identify any actions that may be taken based on study results. The goals of the study and the alternative actions are then combined to form decision statement(s) that will resolve the problem. A decision statement defines which of the identified alternative actions will be pursued depending on the outcomes of the study.

1.1.2.3 Step 3: Identify the Information Inputs

The purpose of Step 3 of the DQO process is to identify the information needed to resolve the decision statement. This may include, but is not limited to:

- Primary data, including sampling and analysis methods
- Secondary data, including the necessary information to ensure the data is of known and documented quality (e.g., sampling and analysis methods used as well as sufficient information to evaluate the quality of the data)
- Action limits to be considered
- Background information about the site or process, including known or anticipated variability of the study parameters that may help the planning team identify critical sampling locations

1.1.2.4 Step 4: Define the Boundaries of the Study

The purpose of Step 4 of the DQO process is to define the spatial and temporal boundaries for the data collection design, including where samples will be collected. Spatial boundaries describe the physical area (i.e., horizontal and vertical boundaries) of the study. They can include geographic area or volume of material. Temporal boundaries include both the period of time the data collection effort will represent and the timeframe to which the decision will apply.

1.1.2.5 Step 5: Develop the Analytic Approach

The purpose of Step 5 of the DQO process is to consider the outputs from Steps 1-4 and develop “If..., then... else” decision rules that unambiguously state which of the alternative actions identified in Step 2 will be pursued. These if/then/else decisions should be formulated to be dependent on how the results of the study compare to an established action level.

1.1.2.6 Step 6: Specify Performance or Acceptance Criteria

The purpose of Step 6 of the DQO process is to set limits on decision errors, and to document those limits. For judgmental and random samples, Step 6 should examine consequences of making incorrect decisions, and place acceptable limits on the likelihood of making decision errors. For random samples, Step 6 should specify any statistical hypothesis to be considered and all applicable statistical tests that will be used to assess the data.

1.1.2.7 Step 7: Develop the Plan for Obtaining Data

The purpose of Step 7 of the DQO process is to develop the data collection plan that will satisfy the objectives presented in Steps 1 through 6. *RCRA Waste Sampling Draft Technical Guidance*, dated August 2002, provides guidance that may be used during sampling design development. EPA also developed a guidance document called *Guidance for Choosing a Sampling Design for Environmental Data Collection (QA/G-5S)*, to specifically provide the information needed to carry out step 7 and develop a sampling design.

The proposed plan should be the most resource-effective data collection design that meets the previously identified performance or acceptance criteria. The plan for obtaining data is documented in detail by developing a project QAPP as per *EPA Requirements for*

Quality Assurance Project Plans (QA/R-5), which presents the requirements for QAPPs, and its companion document, *EPA Guidance for Quality Assurance Project Plans (QA/G-5)*.

1.1.3 Development of QAPPs, Waste Analysis Plans (WAPs) and Sampling and Analysis Plans (SAPs)

Documentation of planning processes and outcomes are critical to the:

- effective communication of planned activities to all participants in the process,
- reconstruction of completed events, and
- reconciliation of the analytical data with the project plans.

Two types of planning documents are discussed in this section. Section 1.1.3.1 discusses QAPPs, which are a key output of the systematic planning process. Section 1.1.3.2 discusses WAPs and SAPs.

1.1.3.1 QAPPs

All environmental data collection efforts performed by or funded by EPA (e.g., through an EPA contractor) must be supported by an approved QAPP. EPA also recommends the use of QAPPs for environmental data collection efforts by other entities (e.g., by other regulated entities in compliance with the RCRA regulations). EPA has issued several documents to aid in preparing QAPPs, including the documents noted in Section 1.1.2.7. These documents provide suggestions for both EPA and non-EPA organizations on preparing, reviewing, and implementing QAPPs.

The primary purpose of the QAPP is to present the data collection activities to be implemented, including all necessary QA and QC, to ensure that all data produced are of known and documented quality, and that the data will satisfy the stated performance criteria.

QAPPs, and any accompanying WAPs or SAPs, should be accessible to all participants throughout the life of the project. They should provide understandable instructions to those who must implement the QAPP, such as the field sampling team, the analytical laboratory, modelers, and the data reviewers.

When preparing a QAPP, a graded approach should be used to determine the level of detail needed. This will ensure that the level of information presented is consistent with the intended use of the results and the degree of confidence needed in the quality of the results. The QAPP should be detailed enough to provide a clear description of every aspect of the project, from site history through assessment of the planned data collection. At a minimum, the QAPP should provide sufficient detail to demonstrate that:

- the project technical and quality objectives are identified and agreed upon;
- the intended measurements and data generation or data acquisition methods are appropriate for achieving project objectives;
- assessment procedures are sufficient for confirming that data of the type and quality needed and expected are obtained; and
- any limitations on the use of the data can be identified and documented.

As described in QA/R-5 and QA/G-5, the QAPP should be composed of standardized, recognizable elements covering the entire project from planning through assessment. These elements may be divided into the following four general groups:

- Project Management - The elements in this group address project organization and management; site background and history; and project objectives. These elements ensure that project goals are clearly defined, that the participants understand the goals and the approach to be used, and that the planning process is documented.

- Data Generation and Acquisition - The elements in this group address all aspects of project design and implementation, including the numbers, types, and locations of all samples to be collected; the rationale for why the proposed data collection effort will be sufficient to address the study objectives; all sampling, subsampling and analytical procedures to be followed (i.e., both sample preparation as well as determinative procedures); QC requirements for all applicable field and laboratory procedures including the data quality indicators (DQIs) discussed below in Section 1.1.4; instrument calibration and maintenance for both field and laboratory equipment; use of secondary data; and data management. Implementation of these elements ensures that appropriate methods for sampling, analysis, data handling, and QC activities are employed and properly documented.

- Assessment and Oversight - The elements in this group address the activities for assessing the effectiveness of project implementation and associated QA and QC activities. The purpose of assessment is to ensure that the QA Project Plan is properly implemented as prescribed.

- Data Validation and Usability - The elements in this group address the QA activities that occur after data collection or generation is completed. These elements address how data will be reviewed, verified and validated as well as how data will be assessed and reconciled with the project objectives.

While most QAPPs will describe project- or task- specific activities, there may be occasions when a *generic* QAPP may be more appropriate. A generic QAPP addresses the general, common activities of a program that are to be conducted at multiple locations or over a long period of time. For example, a generic QAPP may be useful for a large monitoring program that uses the same methodology at different locations. A generic QAPP describes, in a single document, the information that is not site or time-specific but applies throughout the program. Application-specific information is then added to the approved QAPP, either in the form of a site-specific QAPP, QAPP Addendum, or SAP.

1.1.3.2 WAPs and SAPs

In certain cases, WAPs or SAPs are required by a RCRA regulation. For example, WAPs are required as part of a permit application. Where WAPs or SAPs are required by regulation, the applicable regulations should be reviewed to ensure that the content and format requirements for the WAP or SAP are understood. Additionally, it should be noted that EPA has prepared various guidance documents to assist in preparing WAPs and SAPs that meet various regulatory requirements. Examples of these guidance documents include the following:

- EPA guidance on the preparation of WAPs can be found in the document entitled *Waste Analysis at Facilities that Generate, Treat, Store and Dispose of Hazardous Wastes* (ECDIC 2002-011), dated April 1994.
- EPA guidance on SAPs for delisting petitions can be found in the document entitled *EPA RCRA Delisting Program Guidance Manual for the Petitioner*, dated March 2000.
- General SAP guidance can be found in EPA's *RCRA Waste Sampling Draft Technical Guidance*, dated August 2002.
- Chapter 9 of this document (*Test Methods for Evaluating Solid Waste, Physical/Chemical Methods - SW-846*) presents additional discussion on sampling plans.

A QAPP may also be prepared, and required, as a supplement to any WAP or SAP. It should also be noted that if a WAP or SAP is not required by regulation, QAPPs can be prepared such that they present sufficient detail to cover both the QAPP and WAP or SAP in a single document. If a WAP or SAP is prepared along with a QAPP, it is common for these documents to reference one another for necessary information. To enhance the usability of QAPPs and WAPs/SAPs, references between the documents should be specific, providing the full document name, section number, subsection, and page number.

1.1.4 Data Quality Indicators

As part of systematic planning, measurement performance criteria for DQIs must be established and documented for each data collection effort. DQIs apply to both laboratory and field activities. At a minimum, DQIs should include precision, accuracy, representativeness, comparability, and completeness (PARCC). The following presents a discussion of PARCC and other DQIs.

1.1.4.1 Precision

Precision measures the agreement among a set of replicate measurements. Field precision is assessed through the collection and analysis of field duplicates. Analytical precision is estimated by duplicate/replicate analyses, usually on laboratory control samples, spiked samples and/or field samples. The most commonly used estimates of precision are the relative standard deviation (RSD) and, when only two samples are available, the relative percent difference (RPD).

1.1.4.2 Accuracy

Accuracy is the closeness of a measured result to an accepted reference value. Accuracy is usually measured as a percent recovery. QC analyses used to measure accuracy include standard recoveries, laboratory control samples, spiked samples, and surrogates.

1.1.4.3 Representativeness

Sample representativeness expresses the degree to which data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. It is dependent on the proper design of the sampling program and will be satisfied by ensuring the approved plans were followed during sampling and analysis.

1.1.4.4 Comparability

Comparability expresses the degree of confidence with which one data set can be compared to another. It is dependent upon the proper design of the sampling program and will be satisfied by ensuring that the approved plans are followed and that proper sampling and analysis techniques are applied. Further, when assessing comparability, data sets should be of known and documented quality.

1.1.4.5 Completeness

Completeness is a measure of the amount of valid data collected compared to the amount planned. Measurements are considered to be valid if they are unqualified or qualified as estimated data during validation. Field completeness is a measure of the number of samples collected versus the number of samples planned. Laboratory completeness is a measure of the number of valid measurements compared to the total number of measurements planned.

1.1.4.6 Bias

Bias is the systematic or persistent distortion of a measurement process that causes error in one direction (e.g., the sample measurement is consistently lower than the sample's true value). Bias can be introduced during sampling, analysis, and data evaluation. Sampling bias is best addressed through the proper selection and use of sampling tools, uses of correct sampling and subsampling procedures to limit preferential selection or loss of sample media, use of random sampling designs, and use of sample handling procedures that limit the loss or gain of constituents to the sample media. Analytical bias refers to deviation in one direction (i.e., high, low or unknown) of the measured value from a known spiked amount. Analytical bias can be assessed by comparing a measured value in a sample of known concentration to an accepted reference value or by determining the recovery of a known amount of contaminant spiked into a sample (matrix spike). The planning team should specify qualitative criteria for sampling bias and quantitative criteria for analytical bias, typically expressed as "percent recovery."

1.1.4.7 Reproducibility

Analytical reproducibility is a quantitative indicator that is used when referring to the uncertainty associated with the use of multiple laboratories for a specific study. The ability of multiple laboratories to generate the same result for splits of the same sample can be expressed as a measure of interlaboratory precision and bias. Specific indicators of precision and bias (such as range or variance) are generated using data from replicate samples sent to multiple laboratories.

1.1.4.8 Repeatability

Repeatability is a quantitative indicator that in used within a single laboratory (i.e., intralaboratory precision). It is determined when the laboratory, analyst, test method and equipment remain constant and random aliquots of the same sample are analyzed within a short period of time.

1.1.4.9 Sensitivity

Sensitivity is an instrument's or method's minimum concentration that can be reliably measured or reported (i.e., or lower limit of quantitation [LLOQ]).

Please note the glossary section to this chapter includes further discussion of the DQIs.

1.2 IMPLEMENTATION

Implementation is the second phase of the project life cycle. The implementation phase includes the following steps:

1.2.1 Standard Operating Procedures (SOPs)

SOPs are written documents that describe, in detail, the routine procedures to be followed for a specific operation, analysis, or action. Please note, in most cases, referencing a given method or method number is not sufficient, unless the method is performed exactly as written (e.g., a method-defined parameter). Laboratories must have an SOP to demonstrate that their procedure meets the conditions of the referenced method. Information on how to prepare SOPs can be found in EPA's *Guidance for the Preparation of Standard Operating Procedures (QA/G-6)*, dated April 2007.

SOPs enable tasks to be accomplished reproducibly, even if there are changes in the personnel performing them. Consistent use of an approved SOP ensures conformance with organizational practices, reduction in the frequency of errors, and improved data comparability and defensibility. SOPs also serve as resources for training and for ready reference and documentation of proper procedures.

The SOPs, and/or procedures described in the QAPP, must be followed for all project activities from sample collection to validation. If project-specific modifications to SOPs are needed, they must also be presented in the QAPP. Field and laboratory SOPs should be provided for the areas discussed below, as applicable:

- Sample Custody SOPs that describe sample receipt and handling; sample storage; sample security and tracking; and holding times
- Sample collection
- Analytical Method SOPs, including subsampling, sample preparation/clean-up, calibration, QC, and analysis
- Reagent/Standard Preparation and Traceability SOPs
- Equipment Calibration and Maintenance SOPs
- Corrective Action SOPs
- Data Reduction SOPs
- Data Reporting SOPs
- Records Management SOPs
- Waste Disposal SOPs

As indicated above, the QC associated with each method may be provided in appropriate SOPs. The types of QC parameters to include in the SOPs and QAPP are defined in the glossary of this chapter. Since the QC acceptance limits are frequently adjusted more often than SOPs are revised, it may be impractical to update SOPs as these limits change. Therefore, field and laboratory QC limits may need to be presented in QAPP tables rather than SOPs.

1.2.2 Conducting the Study/Experiment

The data collection effort is performed in accordance with approved plans (e.g., QAPP). The QAPP will present all proposed methods (i.e., including sampling, subsampling, preservation, preparation, clean-up and determinative methods), as well as a rationale for why the proposed methods are sufficient to meet the project DQOs.

The QAPP should also indicate whether the proposed analyses include method-defined parameters and/or whether the flexible approach to methods will be utilized. For the flexible approach, the QAPP must also demonstrate that the proposed methods are adequate to reach the study goals outlined in the DQOs.

1.2.2.1 Method-defined parameters

Method-defined parameters (MDP), such as the Toxicity Characteristic Leaching Procedure (TCLP), have been written into regulations, the methods should be followed without deviation, and should not to be modified on a project basis. For a list of method-defined parameters, see Vol 40 CFR 260.11 references or the Methods Innovation Rule (MIR), in Volume 70, Number 113 of the Federal Register (70 FR 34537 Table 3). Some method-defined parameters are discussed in Chapter 8 of this manual.

1.2.2.2 Flexible Approach to Environmental Measurements

The Flexible Approach to Environmental Measurement was finalized in 2008 as EPA's preferred approach for environmental monitoring except in cases where methods are required by regulation.

The goals of the flexible approach are to:

- Provide method users flexibility when choosing sampling and analytical approaches to meet regulatory requirements for measurements
- Develop processes for validation to confirm measurements meeting quality requirements
- Increase collaboration with stakeholders to develop validation processes for new measurement technology
- Ensure timely assessment of new or modified technologies, methods, and procedures.

Chapter Two of this manual entitled, "Choosing the Correct Procedure" provides additional guidance regarding the selection of appropriate methods and method flexibility.

1.2.3 Technical Assessments

Technical Assessments (otherwise known as audits) are systematic and objective examinations of a program or project to determine whether environmental data generation activities and related results comply with planning documents. Technical assessments can be performed to evaluate all phases of a project including field sampling, laboratory analysis, validation and data handling/management.

The QAPP should identify all personnel responsible for performing technical assessments, the authority of the auditor (e.g., do they have the authority to stop work if significant deviations from planning documents are found), and the planned audit frequency. Additionally, if technical assessments are planned or required as part of a project, the QAPP should provide the applicable

technical assessment checklists. These checklists establish and document the scope of all proposed technical assessments. The development of these technical assessment checklists should overseen by an independent party (i.e., someone not involved in the day to day operations of a project), such as the organization's QA personnel. Further, the QAPP should establish a process for correcting technical assessment findings and confirming implementation of any corrective actions taken as a result of the findings.

While most technical assessments will be scheduled in advance with an organization, there may be occasions when unannounced technical assessments are needed. However, an unannounced audit may not reveal a representative picture of project activities if it occurs when the project is not active, or activities that are not within the scope of the technical assessment are occurring.

Technical assessments may be planned as part of the pre-award activities, or throughout the life of a project. For example, pre-award audits, including performance evaluation (PE) samples, are useful tools in determining the ability of a laboratory to perform the proposed analytical work. Additionally, technical assessments may also be used as an investigative tool where problems may be suspected. The EPA document Guidance on Technical Audits and Related Assessments for Environmental Data Operations (QA/G-7), dated January 2000, provides detailed information on various types of technical audits and includes an example checklist for a technical systems audit of a laboratory measurement system.

1.3 ASSESSMENT

Following planning (Sec. 1.1) and implementation (Sec. 1.2), assessment is the third and final phase of the project data generation life cycle. The purpose of this phase is to evaluate whether the data are of the type, quantity and quality needed to meet project DQOs. Assessment can involve many different complex activities, including the use of statistical tools. This section provides an introduction and overview of these data assessment activities.

1.3.1 Data Verification and Validation

Data verification and/or validation is the first step in the assessment process. Validation and verification are defined in the EPA Guidance on Environmental Data Verification and Data Validation (QA/G-8), dated November 2002. According to QA/G-8, verification is the process of evaluating the completeness, correctness, and conformance/compliance of a data set against a specified set of requirements. QA/G-8 defines validation as an analyte and sample specific process that extends the evaluation of data beyond data verification to determine its analytical quality. For the purposes of this chapter, it should be noted that the meaning of verification and validation is often program, organization and/or system specific. Further, these terms are used interchangeably at times, and in other cases have very different meanings. Therefore, it is critical that the procedures for verification and/or validation be clearly documented in the approved QAPP.

In general, data verification/validation involves the examination and review of project data (e.g., field and laboratory data for all applicable QC measurements) to confirm that the sampling and analysis protocols specified in the QAPP (and any other planning or contractual documents) were followed. Data verification/validation also involves examining whether the data met the method performance and acceptance criteria established in the project QAPP. When these criteria are not met, data verification/validation procedures should include qualification of the data (e.g., the *J* qualifier is commonly used to indicate *estimated* data and the *R* qualifier is commonly used to indicate *rejected* data). The reasons for any failure to meet performance criteria also

need to be documented during this phase of assessment (e.g., in a data verification/validation report).

In addition to QA/G-8, EPA has published several references which provide more detailed information on what should be included in data verification and validation procedures. These include EPA regional and programmatic validation guidance documents that may apply to particular projects. It is also common for EPA guidance from one program or region to be modified for use in another area. While this may be acceptable, any modifications or changes to the established validation procedures should be included in the approved QAPP.

Data verification/validation may be performed at various phases throughout a project. As such, the procedures for verifying and/or validating data may need to be described in laboratory SOPs and/or QA Plans, in addition to the project documents like the QAPP. Corrective action based on verification/validation findings may also need to be described in these documents.

Data verification/validation activities may be performed internally (e.g., when the laboratory or data collector review their own data), or externally by an independent entity (i.e., a party that is not associated with the data collection effort). Internal and external data verification/validation procedures should be defined in the QAPP or other project documents.

A data verification/validation report should be generated to document the procedures followed as well as the findings and qualifications applied during data verification/validation. The report should include a list of the samples collected, field information about how the samples were collected, the analyses performed on the samples, the results of the analysis and the quality of the reported data, at a minimum. The usability of this report can be enhanced by listing the samples and analytes affected by each QC criteria exceedance, as well as the extent of the exceedance, and any qualifiers applied. Any other observations noted by the data reviewer that may impact the usability of the data should also be documented.

1.3.2 Data Quality Assessment

Data quality assessment (DQA) is the second step in the assessment process. DQA is often needed because data verification/validation alone is generally not sufficient to determine whether a data set can be used for its intended purpose. Typically, the DQA follows the data verification and/or validation step.

In general, the DQA should include an evaluation of overall trends or biases in the data and associated QC results, as well as how the data may be affected. For random data sets, the DQA should evaluate the validity of any statistical assumptions made during the planning phase. If the statistical assumptions made during the planning phase are not supported by the data, recommendations for corrective action should be presented. All DQA findings should be summarized in a report.

Guidance documents available from EPA that discuss the DQA process include *Data Quality Assessment: A Reviewer's Guide* (QA/G-9R), dated February 2006, and *Data Quality Assessment: Statistical Tools for Practitioners* (QA/G-9S), dated February 2006.

The DQA process described in this guidance is a five-step process.

Step 1: Review the Data Quality Objectives and Sampling Design
Step 2: Conduct a Preliminary Data Review
Step 3: Select the Statistical Method
Step 4: Verify the Assumptions of the Statistical Method

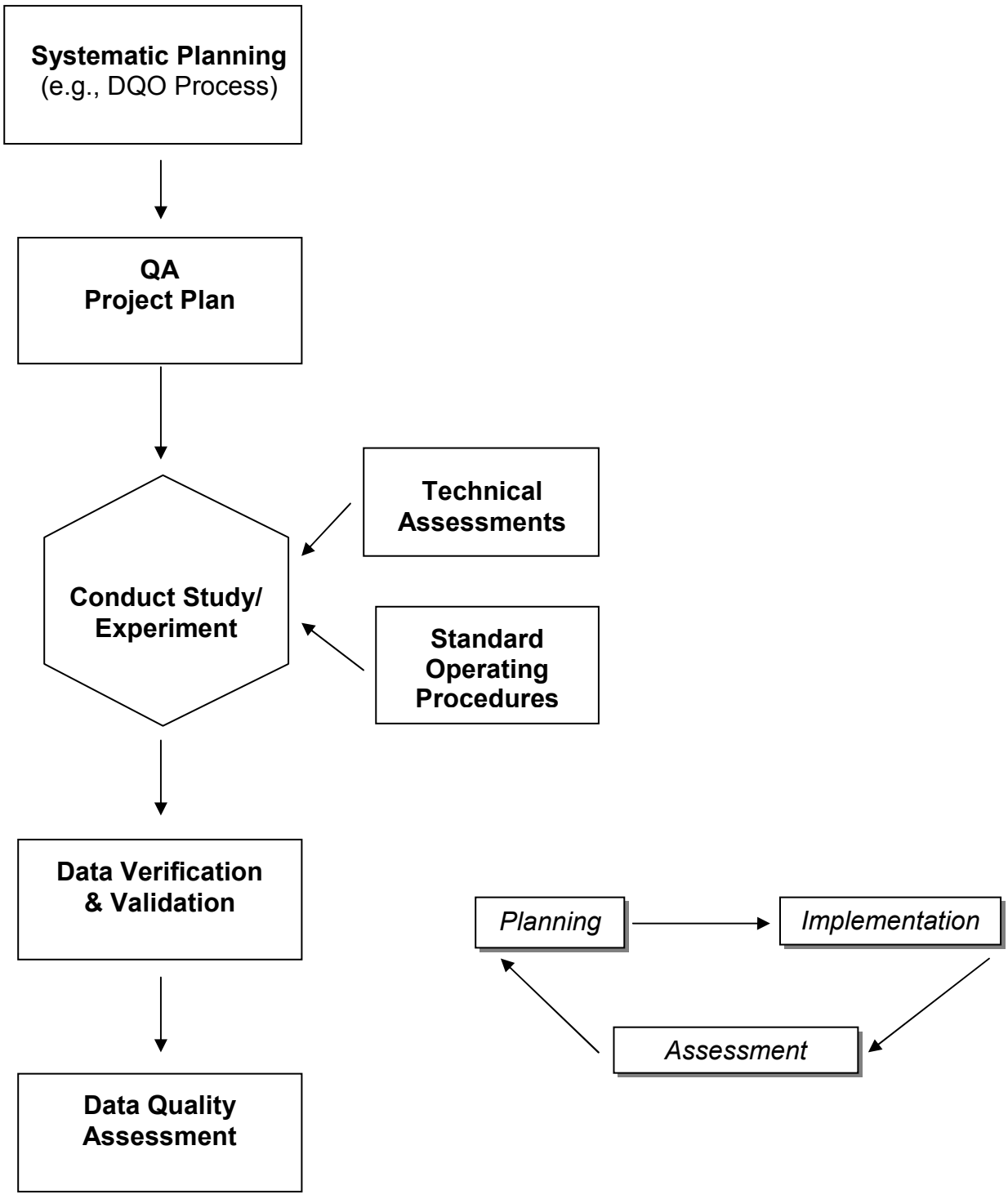
Step 5: Draw Conclusions from the Data

It is recommended that the data user refer to these guidance documents, because they provide extensive information about DQA and the statistical tools that can be employed.

Although the DQA process described in QA/G-9R and QA/G-9S includes a significant amount of statistical procedures, it should be noted that the DQA process is not only applicable to random data sets, where statistics can be used to assess the data. A DQA should also be performed on judgmental, or biased, data sets. The process for how any data set will be assessed should be determined during the planning phase, and documented in the QAPP or other site documents.

FIGURE 1-1

PROJECT LEVEL EPA QA SYSTEM



1.4. REFERENCES AND SOURCES FOR ADDITIONAL QA/QC INFORMATION

1. USEPA. *Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4*. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. February 2006.

2. USEPA. *EPA Quality Manual for Environmental Programs CIO 2105-P-01-0*. Office of Environmental Information Quality Staff, United States Environmental Protection Agency, Washington, D.C. May 5, 2000.

3. USEPA. *Guidance on Choosing a Sampling Design for Environmental Data Collection,* EPA QA/G-5S. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. December 2002.

4. USEPA. *Guidance on Environmental Data Verification and Data Validation*, EPA QA/G-8. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. November 2002.

5. USEPA. *Data Quality Assessment: A Reviewer's Guide*, QA/G-9R. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. February 2006.

6. USEPA. *Data Quality Assessment: Statistical Tools for Practitioners*, QA/G-9S. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. February 2006.

7. USEPA. *Guidance for Preparing Standard Operating Procedures*, EPA QA/G-6. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. April 2007.

8. USEPA. *RCRA Waste Sampling Draft Technical Guidance.* Office of Solid Waste, United States Environmental Protection Agency, Washington, D.C. August 2002.

9. USPEA. *Guidance for Quality Assurance Project Plans*, EPA QA/G-5. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. December 2002.

10. USEPA. *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5. Quality Staff, Office of Environmental Information. United States Environmental Protection Agency, Washington, D.C. March 2001.

11. USEPA. *RCRA Delisting Program Guidance Manual for the Petitioner*. United States Environmental Protection Agency, March 23, 2000.

12. USEPA. *Waste Analysis at Facilities That Generate, Treat, Store and Dispose of Hazardous Wastes*, ECDIC 2002-011. Office of Waste Programs Enforcement, United States Environmental Protection Agency. April 1994.

13. USEPA. *Guidance on Technical Audits and Related Assessments for Environmental Data Operations*, QA/G-7. Quality Staff, Office of Environmental Information, United States Environmental Protection Agency, Washington, D.C. January 2000.

1.5. GLOSSARY

Also see the following for a glossary of quality-related terms developed by EPA:

http://www.epa.gov/fem/pdfs/Env_Measurement_Glossary_Final_Jan_2010.pdf

ACCURACY The degree of agreement between an observed value and an accepted reference value. When applied to a set of observed values, accuracy includes a combination of a random error (precision) and systematic error (bias) components.

ANALYTICAL BATCH A group of samples, including quality control samples, which are processed together using the same method, the same lots of reagents, and at the same time or in continuous, sequential time periods. Samples in each batch should be of similar composition and share common internal quality control standards. For QC purposes, if the number of samples in a batch is limited to 20; laboratory QC samples are not included in the batch count.

Each batch should be uniquely identified within the laboratory for tracking purposes. Samples collected from the same site would normally be grouped together for batching purposes within the constraints imposed by the method holding times and batch size. Samples prepared in the same batch would normally be analyzed together on a single instrument. However, laboratories may find it necessary to group multiple clients' samples into a single batch. Under these circumstances, additional matrix QC samples (*i.e.*, duplicates, matrix spikes) may be needed to evaluate the effect of the matrix from each site on method performance.

BIAS The constant or systematic distortion of a measurement process, different from random error, which manifests itself as a persistent positive or negative deviation from the known or true value. This can result from improper data collection, poorly calibrated analytical or sampling equipment, or limitations or errors in analytical methods and techniques.

Bias can be assessed by comparing a measured value to an accepted reference value in a sample of known concentration or by determining the recovery of a known amount of contaminant spiked into a sample (matrix spike). Thus, the bias (B) due to matrix effects based on a matrix spike is calculated as:

$$B = (x_s - x_u) - K$$

where:

x_s = measured value for spiked sample,
x_u = measured value for unspiked sample, and
K = known value of the spike in the sample.

Using the following equation yields the percent recovery (%R).

$$\%R = 100\ (x_s - x_u)/\ K$$

BLANK	Blanks are generally considered to be acceptable if target analyte concentrations are less than ½ the LLOQ or are less than project-specific requirements. Blanks may contain analyte concentrations greater than acceptance limits if the associated samples in the batch are unaffected (i.e. targets are not present in samples or sample concentrations are ≥10X the blank). Other criteria may be used depending on the needs of the project. For method specific details see methods 6010, 6020 for inorganics and Method 8000 for organics). See also Calibration Blank, Equipment Blank, Method Blank, Reagent Blank and Trip Blank.
CALIBRATION BLANK	A calibration blank is a sample of analyte-free media that can be used along with prepared standards to calibrate the instrument. A calibration blank may also be used to verify absence of instrument contamination (e.g., initial calibration blank and continuing calibration blank).
CALIBRATION CHECKS	Calibration check analyses are used to assess calibration drift and memory effects over time for each analytical system. These analyses may include zero, span (low and high) to cover the full calibration range, and mid-range checks, depending on the method.
CALIBRATION CURVE	A plot of instrument response to an analyte versus known concentrations or amounts of analyte standards. Calibration standards are prepared by successively diluting a standard solution to produce working standards which cover the working range of the instrument. Standards should be prepared at the frequency specified in the appropriate method. The calibration standards should be prepared using the same type of acid or solvent and at the same concentration as the samples following sample preparation. This is applicable to organic and inorganic chemical analyses.
CO-LOCATED SAMPLES	A type of field duplicate where independent samples are collected as close as possible to the same point in space and time. They are two separate samples taken from the same source, stored in separate containers, and analyzed independently by the same method and laboratory. These duplicates are useful in documenting the precision of the sampling process.
COMPARABILITY	The degree to which different methods or data agree or can be represented as similar. Comparability describes the confidence that two data sets can contribute to a common analysis and interpolation.
COMPLETENESS	A measure of the amount of valid data obtained from a measurement system compared with the amount that was expected to be obtained under correct, normal conditions. Percent completeness is calculated as: $$\% \text{ Completeness} = \frac{x}{y} \times 100$$ where:

x = amount of valid data obtained
y = amount of data expected to be obtained

DATA QUALITY INDICATORS (DQIs)	The quantitative statistics and qualitative descriptors that are used to interpret the degree of acceptability or utility of data to the user. The principal indicators of data quality are precision, bias, accuracy, representativeness, comparability, completeness, and sensitivity.
DATA QUALITY OBJECTIVES (DQOs)	Qualitative and quantitative statements derived from the DQO Planning Process that clarify the purpose of the study, define the most appropriate type of information to collect, determine the most appropriate conditions from which to collect that information, and specify tolerable levels of potential decision errors.
DATA VALIDATION	The process of evaluating the available data against the project DQOs to make sure that the objectives are met. Data validation may be very rigorous, or cursory, depending on project DQOs. The available data reviewed will include analytical results, field QC data, laboratory QC data, and may also include field records.
DUPLICATE	See Co-located Samples, Laboratory Duplicate, Field Duplicate, Field Split Samples, and Matrix Spike Duplicate.
EQUIPMENT BLANK	A sample of analyte-free media which has been used to rinse the sampling equipment. It is collected after completion of decontamination and prior to sampling at a location. This blank is useful in documenting adequate decontamination of sampling equipment.
EQUIPMENT RINSATE	See Equipment Blank.
FIELD BLANK	Field blanks include any sample submitted from the field that is identified as a blank. These include trip blanks, rinsates, equipment blanks, etc. Field blanks may also be obtained by the sampling organization to measure ambient contamination in the field. If this type of field blank is requested, a container of reagent water or a solid blank material is opened in the field for a predefined period of time. The sample is then sent to the laboratory for analysis.
FIELD DUPLICATES	Field duplicates are useful in documenting the precision of the sampling process. Field duplicates are used to assess improper homogenization of the samples in the field; reproducibility of sample preparation and analysis; and, heterogeneity of the matrix. See also Co-located Samples and Field Split Samples.
FIELD SPLIT SAMPLES	A type of field duplicate where the sample is homogenized and then divided into two or more aliquots so that variability can be evaluated, (i.e., often between laboratories or methods). Homogenization may have an impact on sample integrity for some sample types (e.g., VOCs

in soil), and in these cases co-located samples may be more appropriate.

INITIAL DEMONSTRATION of PROFICIENCY (IDP)

Prior to the analysis of samples an initial demonstration of method proficiency is accomplished through the successful calibration of method-specific instruments according to project requirements and criteria set forth in the applicable analytical methodology. This initial demonstration should be performed prior to independently running an analytical method, and should be repeated if other changes occur (e.g., instrument repair, significant change in procedure).

Please see individual methods for additional guidance on IDP.

INTERNAL STANDARD

Internal standards may be spiked into prepared field samples and QC samples (or sample extracts). Their recovery is generally used to demonstrate the lack of severe matrix effect in the instrumental analysis by setting criteria for the internal standard response in comparison to a response in a sample with a known lack of matrix effect (*i.e.*, a standard). Internal standards are also used to account for matrix effects and/or variability in instrument response by normalizing the response of the target analytes and surrogates, thereby decreasing measurement bias to the extent that their behavior mimics that of the target analytes.

LABORATORY CONTROL SAMPLE

The Laboratory Control Sample (LCS) is analyzed to assess general method performance based on the ability of the laboratory to successfully recover target analytes from a control matrix. The LCS is similar in composition to the method blank in that it is an aliquot of analyte-free water or analyte-free solid (e.g., Ottawa sand, anhydrous sodium sulfate, or other purified solid) to which known amounts of the method analytes are added. LCS analyses help determine if the system is running properly (i.e., within pre-defined limits). Although the frequency of LCS analysis should be determined by the needs of a project, typically one LCS is prepared and analyzed for every analytical batch. The LCS sample is prepared and analyzed in the same analytical batch and in exactly the same manner as the other routine samples. The recovery of the target analytes in the LCS analysis demonstrates whether the methodology is in control and the laboratory is capable of making unbiased measurements. The results of the LCS are evaluated in conjunction with other QC information to determine the acceptability of the data generated for that batch of samples. Acceptance criteria for LCS recovery are calculated based on statistical treatment of historical LCS recovery data through the use of control charts.

LABORATORY DUPLICATE

The analysis or measurements of the variable of interest performed identically on two sub-samples of the same sample, usually taken from the same container. The results from duplicate analyses are used to evaluate analytical or measurement precision and include variability associated with sub-sampling and the matrix, but not the precision of field sampling, preservation, or storage internal to the laboratory.

Laboratory duplicate analysis entails removing two aliquots from the

same sample and taking them through the same preparative and analytical procedures to evaluate analytical precision. Laboratory duplicates are more commonly used to assess precision for inorganic and radiological constituents, while precision for organic analyses is usually assessed by determining the RPD between matrix spike and matrix spike duplicates. The frequency of laboratory duplicate analysis will depend on project requirements.

LOWER LIMIT OF QUANTITATION (LLOQ)

The lowest point of quantitation which, in most cases, is the lowest concentration in the calibration curve. The LLOQ is initially verified by spiking a clean control material (e.g., reagent water, method blanks, Ottawa sand, diatomaceous earth, etc.) at the LLOQ and processing through all preparation and determinative steps of the method. Laboratory-specific recovery limits should be established when sufficient data points exist. Individual methods may recommend procedures for verifying the LLOQ and acceptance limits for use until the laboratory has sufficient data to determine acceptance limits. LLOQs should be determined at a frequency established by the method, laboratory's quality system, or project.

Please see individual methods for additional guidance on implementing LLOQ (e.g., 8000, 6020).

MATRIX

The material of which the sample is composed or the substrate containing the analyte of interest, such as waste water, storm water and biosolids. Also called medium or media.

MATRIX SPIKE

Matrix spikes are aliquots of environmental samples to which known concentrations of certain target analytes have been added before sample preparation, cleanup, and determinative procedures have been implemented. Matrix spike analysis would normally be included with each preparation batch of samples processed. Under ideal circumstances, the original, unspiked, field sample will be analyzed first, to determine the concentration in the unspiked sample. However, if this approach is not practical, the samples may be spiked at the midpoint of the calibration range or at the same level as the LCS.

The matrix spike analysis is used to assess the performance of the method by measuring the effects of interferences caused by the sample matrix and reflects the bias of the method for the particular matrix in question.

MATRIX SPIKE DUPLICATES

Matrix spike duplicates are additional replicates of matrix spike samples that are subjected to the sample preparation and analytical scheme as the original sample. A matrix spike duplicate sample would normally be included with each preparation batch of samples processed. Analysis of spiked duplicate samples ensures a positive value, allowing for estimation of analytical precision.

Matrix spike duplicates are used to document the precision as well as bias of a method in a given sample matrix. When critical decisions are based on the matrix spike and matrix spike duplicate recoveries, the laboratory should maintain control charts for these samples to monitor

precision and bias for each particular matrix.

METHOD BLANK

Method blanks are analyzed to assess background interference or contamination that exists in the analytical system that might lead to the reporting of elevated concentration levels or false positive data. The method blank is defined as an interference-free blank matrix, similar to the sample matrix, to which all reagents are added in the same volumes or proportions as used in sample preparation and carried through the complete sample preparation, cleanup, and determinative procedures. For aqueous analyses, analyte-free reagent water would typically be used. For soil analyses, a purified solid matrix (e.g., sand) would typically be used, except for metals analyses. Method blank results are evaluated in conjunction with other QC information to determine the acceptability of the data generated for that batch of samples. The method blank results should be below the LLOQ for the target analytes being tested; otherwise, corrective action should be taken. A method blank is included with the analysis of every analytical batch of 20 samples or less or as stated in the QAPP or method, whichever is more frequent.

ORGANIC-FREE REAGENT WATER

All references to water in the methods refer to water in which an interferant is not observed at the LLOQ for the compounds of interest. Preparation of organic-free reagent water may depend on the types of interferants of concern for the analysis and may include boiling, sparging with an inert gas, reverse osmosis purification, distillation, particle filtration, activated carbon filtration, ion exchange filtration, etc.

POST-DIGESTION SPIKES

Post-digestion spike samples are typically prepared for inorganic analyses when pre-digestion/pre-distillation matrix spike recoveries are outside the required control limits. They are prepared by spiking a known amount of standard to the sample digestate. The recovery data from the post digestion spike analyses are used to further assess if matrix effects may be a source of measurement bias in sample quantitation.

PRECISION

The agreement among a set of replicate measurements without assumption of knowledge of the true value. Precision is estimated by means of duplicate/replicate analyses of separate aliquots of the same sample (not multiple runs of a single digestion/extraction). These samples should contain concentrations of analyte at or above the LLOQ, and may involve the use of matrix spikes. The most commonly used estimates of precision are:

Relative standard deviation (RSD), also known as the coefficient of variation (CV):

$$RSD = CV = (100)*(S/\bar{x})$$

where:

$\bar{x}$ = the arithmetic mean of the i measurements, and
S = the square root of the variance of i measurements; and,

Relative percent difference (RPD) when only two results are compared:

$$RPD = \frac{|X_1 - X_2|}{\left(\frac{X_1 + X_2}{2}\right)} * 100$$

where: x_1 and x_2 are measurements of independently prepared aliquots of the same sample or replicate samples.

PROJECT — Single or multiple data collection activities that are related through the same planning sequence.

QUALITY CONTROL SAMPLE — A sample made from standards or matrix and used to verify acceptability of the results from preparation and/or analysis of a batch of samples. Examples of laboratory quality control samples are method blanks, laboratory duplicates, and laboratory control samples; field quality control samples are field blanks, trip blanks, field duplicates, and matrix spikes.

QUALITY ASSURANCE PROJECT PLAN (QAPP) — A formal document describing in comprehensive detail the necessary quality assurance, quality control, and other technical activities that should be implemented to ensure that the results of the work performed will satisfy the stated performance criteria.

REAGENT BLANK — Reagent blanks are analyzed to assess background interference or contamination that exists in the analytical system that might lead to the reporting of elevated concentration levels or false positive data. The reagent blank is defined as an interference-free blank matrix, to which all reagents are added in the same volumes or proportions as used in sample preparation but are NOT carried through the complete sample preparation, cleanup, and determinative procedures. The purpose of a reagent blank is to gauge contamination from chemical inputs and instrumental factors only. A reagent blank is NOT run as part of a digestion or preparation method.

REAGENT GRADE — Analytical reagent (AR) grade, ACS reagent grade, and reagent grade are synonymous terms for reagents which conform to the current specifications of the Committee on Analytical Reagents of the American Chemical Society.

REAGENT WATER — Water that has been generated by any method which would achieve the performance specifications for ASTM Type II water. For organic analyses, see the definition of organic-free reagent water.

REFERENCE MATERIAL — A material containing known quantities of target analytes in solution or in a homogeneous matrix. It is used to document the bias of the analytical process.

REPEATABILITY — The degree of agreement between mutually independent test results produced by the same analyst using the same test method and equipment on random aliquots of the same sample within a short

	period of time.
REPRESENTATIVE-NESS	A measure of the degree to which data accurately represent a characteristic of a population, a parameter variation at a sampling point, a process condition, or an environmental condition.
REPRODUCIBILITY	Reproducibility is defined as the closeness of the agreement between the results of measurements of the same analyte carried out under variable conditions of measurement.
STANDARD ADDITION	The addition of a known amount of analyte to the sample in order to determine the relative response of the detector to an analyte within the sample matrix. The relative response is then used to assess either an operative matrix effect or the sample analyte concentration.
SURROGATE	Surrogates are most commonly used to monitor the performance of organic analyses using methods such as high performance liquid chromatography (HPLC), gas chromatography (GC), and gas chromatography/mass spectrometry (GC/MS). Surrogate spikes are added to field samples and QC samples for organic analyses at known amounts, and their recoveries are used to assess matrix effects and, to some extent, verify proper processing and instrument performance for each sample. The analytes used as surrogates mimic the behavior of the target analyte(s) throughout sample preparation and instrument determination. Surrogates are organic compounds which are similar to the target analytes in chemical composition and behavior in the analytical process, but are not normally found in the environmental samples. Surrogates added to LCS samples and blanks are used to assess recovery in a matrix known to be free from interference. This information can be used to determine the magnitude of matrix interference effects on environmental sample results.
TRIP BLANK	A sample of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened. Trip blanks should be prepared at a frequency of one per day of sampling during which samples are collected for volatile organic constituents (VOCs). Trip blanks are prepared prior to the site visit at the time sample containers are shipped to the site. The trip blank should accompany the sampling kits throughout all the sample collection and transport operations. This blank will not be opened during the sampling activities and will be used to assess sample VOC contamination originating from sample transport, shipping, or site conditions. A trip blank is used to document contamination attributable to shipping and field handling procedures.

APPENDIX A

SUMMARY OF UPDATES/CHANGES IN CHAPTER 1

1. The entire Chapter has been rewritten and reorganized to reflect changes in the EPA data quality system approach.
2. The revision number was changed to two and the date published to July 2014.
3. This appendix was added to document changes made during the editorial process.
4. The document was updated to match the current SW-846 style guidelines.
5. Figure 1 was added based on information in EPA QA/G-8, November 2002, Figure 1.

DOCUMENT 5

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CHAPTER TWO

CHOOSING THE CORRECT PROCEDURE

SW-846 is not intended to be an analytical training manual. Therefore, method procedures are written based on the assumption that they will be performed by analysts who are formally trained in at least the basic principles of chemical analysis and in the use of the subject technology.

In addition, SW-846 methods, with the exception of required method use for the analysis of method-defined parameters, are intended to be guidance methods containing general information on how to perform an analytical procedure or technique which a laboratory can use as a basic starting point for generating its own detailed Standard Operating Procedure (SOP), either for its own general use or for a specific project application. The performance data included in these methods are for guidance purposes only, and are not intended to be and must not be used as absolute quality control (QC) acceptance criteria for the purposes of laboratory accreditation.

2.0 INTRODUCTION

The purpose of this chapter is to aid the analyst in choosing the appropriate methods for sample analyses, based upon the sample matrix and the analytes to be determined. The ultimate responsibility for producing reliable analytical results lies with the entity subject to the regulation. Therefore, members of the regulated community are advised to refer to this chapter and to consult with knowledgeable laboratory personnel when choosing the most appropriate suite of analytical methods. In addition, analysts and data users are advised that, except where explicitly specified in a regulation, the use of SW-846 methods is not mandatory in response to Federal testing requirements.

SW-846 analytical methods are written as quantitative analytical methods, and specific methods may be used to demonstrate that a waste does not contain analytes of concern that cause it to be managed as a hazardous waste. SW-846 methods typically contain relatively stringent recommended QC criteria appropriate to many levels of analyses, including trace. However, if a particular application does not require data of this quality, less stringent QC criteria may and should be used.

The choice of the appropriate sequence of analytical methods depends on the information sought and on the experience of the analyst. Appropriate selection is confirmed by the usability of data (i.e., adequate for its intended use). The use of the recommended procedures, whether they are approved or mandatory, does not release the analyst from demonstrating the correct execution of the method.

Sec. 2.1 provides guidance regarding the analytical flexibility inherent to SW-846 methods and the precedence of various QC criteria. Sec. 2.2 reviews the information required to choose the correct combination of methods for an analytical procedure. Sec. 2.3 provides useful information on implementing the method selection guidance for organic analyses. Sec. 2.4 provides guidance on choosing procedures for characteristic analyses. Sec. 2.5 provides guidance on the determination of analytes in groundwater. Finally, Sec. 2.6 provides

information regarding choosing procedures for inorganic analyte analyses. Tables and figures referenced in this chapter are sequentially located after the last page of chapter text.

2.1 GUIDANCE REGARDING FLEXIBILITY INHERENT TO SW-846 METHODS AND THE PRECEDENCE OF SW-846 QUALITY CONTROL CRITERIA

The specific products and instrument settings cited in SW-846 methods represent those products and settings used during method development or subsequently evaluated by the Agency for use in the method. Glassware, reagents, supplies, equipment and settings other than those listed in this manual may be employed, provided that method performance appropriate for the intended application has been documented. Such performance includes consideration of precision, accuracy (or bias), recovery, representativeness, comparability, and sensitivity (quantitation or reporting limits, now referred to as lower limit of quantitation (LLOQ)) relative to the data quality objectives (DQOs) for the intended use of the analytical results. In response to this inherent flexibility, if an alternative analytical procedure is employed, then EPA expects the laboratory to demonstrate and document that the procedure is capable of providing appropriate performance for its intended application. This demonstration must not be performed after the fact, but as part of the laboratory's initial demonstration of proficiency with the method. The documentation should be in writing, maintained in the laboratory, and available for inspection upon request by authorized representatives of the appropriate regulatory authorities. The documentation should include the performance data as well as a detailed description of the procedural steps as performed (i.e., a written standard operating procedure).

Given this allowance for flexibility, EPA wishes to emphasize that this manual also contains procedures for "method-defined parameters," where the analytical result is wholly dependent on the process used to make the measurement. Examples include: the use of the toxicity characteristic leaching procedure (TCLP) to prepare a leachate, and the flash point, pH, paint filter liquids, and corrosivity tests. In these instances, changes to the specific methods may change the end result and incorrectly identify a waste as nonhazardous. Therefore, when the measurement of such method-defined parameters is required by regulation, those methods are <u>not</u> subject to the flexibility afforded in other methods.

Analysts and data users are advised that even for those analytes that are not method-defined, different procedures may produce some difference in results. Common examples include the differences in recoveries of phenolic compounds extracted from water by separatory funnel (Method 3510) and continuous liquid-liquid (Method 3520) extraction techniques, differences in recoveries of many compounds between Soxhlet (Method 3540) and ultrasonic (Method 3550) extraction techniques, and differences resulting from the choice of acid digestion of metals (Method 3050) or microwave digestion (Method 3051). Where practical, the Agency has included guidance in the individual methods regarding known potential problems, and analysts are advised to review this information carefully in choosing or modifying analytical procedures. Chapter One describes a variety of QC procedures that may be used to evaluate the quality of the analytical results. Additional QC procedures may be described in the individual methods. The results of these QC procedures should be used by the analyst to evaluate if the analytical procedures and/or any modifications are appropriate to generate data of the quality necessary to satisfy the data quality needs of the intended application.

The performance data included in the SW-846 methods are <u>not</u> intended to be used as absolute QC acceptance criteria for method performance. The data are intended to be guidance, by providing typical method performance in typical matrices, to assist the analyst in selection of the appropriate method for the intended application. In addition, it is the

responsibility of the laboratory to establish actual operating parameters and in-house QC acceptance criteria, based on its own laboratory SOPs and in-house QC program, to demonstrate appropriate performance of the methods used in that laboratory for the RCRA analytical applications for which they are intended.

The regulated community is further advised that the methods here or from other sources need only be used for those specific analytes of concern that are subject to regulation or other monitoring requirements. The fact that a method provides a long list of analytes does not mean that each of those analytes is subject to any or all regulations, or that all of those analytes must be analyzed each time the method is employed, or that all of the analytes can be analyzed using a single sample preparation procedure. It is EPA's intention that the target analyte list for any procedure includes those analytes necessary to meet the DQOs of the project (i.e., those analytes subject to monitoring requirements and set out in a RCRA permit or other applicable regulation, plus those analytes used in the methods for QC purposes, such as surrogates, internal standards, system performance check compounds, etc.). Additional analytes, not included on the analyte list of a particular method(s) but needed for a specific project, may be analyzed by that particular method(s), if appropriate performance can be demonstrated for those analytes in the matrices of concern at the levels of concern.

2.1.1 Trace analysis vs. macroanalysis

Through the choice of sample size and concentration procedures, the methods presented in SW-846 were designed to address the problem of "trace" analyses (<1000 ppm), and have been developed for an optimized working range. These methods are also applicable to "minor" (1000 ppm - 10,000 ppm) and "major" (>10,000 ppm) analyses, as well, through use of appropriate sample preparation techniques that result in analyte concentrations within that optimized range. Such sample preparation techniques include:

1. Adjustment of size of sample prepared for analysis (for homogeneous samples)
2. Adjustment of injection volumes
3. Dilution or concentration of sample
4. Eelimination of concentration steps prescribed for "trace" analyses
5. Direct injection (of samples to be analyzed for volatile constituents)

The performance data presented in each of these methods were generated from "trace" analyses, and may not be applicable to "minor" and "major" analyses. Generally, extraction efficiency improves as concentration increases.

CAUTION: Great care should be taken when performing trace analyses after the analysis of concentrated samples, given the possibility of contamination.

2.1.2 Choice of apparatus and preparation of reagents

Since many types and sizes of glassware and supplies are commercially available, and since it is possible to prepare reagents and standards in many different ways, the apparatus, reagents, and volumes included in these methods may be replaced by any similar types as long as this substitution does not affect the overall quality of the analyses.

2.1.3 Quality control criteria precedence

Chapter One contains general QC guidance for analyses using SW-846 methods. QC guidance specific to a given analytical technique (e.g., extraction, cleanup, sample introduction, or analysis) may be found in Methods 3500, 3600, 5000, 7000, and 8000. Method-specific QC criteria may be found in Sec. 8.0 of most older individual methods, in Sec. 9.0 of newer methods, or in Sec. 11.0 of some air sampling methods. When inconsistencies exist between the information in these locations, method-specific QC criteria take precedence over both technique-specific criteria and those criteria given in Chapter One, and technique-specific QC criteria take precedence over the criteria in Chapter One.

2.2 INFORMATION NECESSARY FOR CHOOSING THE CORRECT PROCEDURE

In order to choose the correct combination of methods to comprise the appropriate analytical procedure, some basic information is necessary. This includes information on:

1. The physical state of the sample
2. The analytes of interest
3. The analytical sensitivity needed
4. The analytical objective
5. Whether the purpose is quantitation or monitoring
6. What sample containers and preservation will be used and what holding times may apply

2.2.1 Physical state(s) of sample

The phase characteristics of the sample must be known. There are several general categories of phases into which the sample may be categorized, including:

Aqueous	Oil or other Organic Liquid
Sludge	Multiphase Sample
Solid	Groundwater
Stack Sampling –Volatile Organics Sampling Train (VOST) Condensate	
TCLP or Extraction Procedure (EP) Extract	

There may be a substantial degree of overlap between the phases listed above and it may be useful to further divide these phases in certain instances. A multiphase sample may be a combination of aqueous, organic liquid, sludge, and/or solid phases, and generally must undergo a phase separation as the first step in the analytical procedure.

2.2.2 Analytes of interest

Analytes may be divided into various classes, based on the determinative methods used to identify and quantify them. The most basic differentiation is between organic (e.g., carbon-containing) analytes and inorganic (e.g., metals and anions) analytes.

Table 2-1 is an alphabetical list of analytes cited within the SW-846 organic determinative methods (excludes immunoassay and other screening methods). These analytes have been evaluated by those methods. The methods may also be applicable to other analytes that are similar to those listed. Tables 2-2 through 2-38 list the analytes for each organic determinative method. Table 2-39 indicates which methods are applicable to inorganic analytes.

NOTE: Analysts should review the discussion in Sec. 2.1 of this chapter with regard to the presence of an analyte in a method versus the need for its analysis for a given project.

2.2.3 Sensitivity

Some regulations may require a specific sensitivity or quantitation limit (LLOQ) for an analysis, as in the determination of analytes for the Toxicity Characteristic (TC). Drinking water quantitation limits, for those specific organic and metallic analytes covered by the National Primary Drinking Water Regulations, are desired in the analysis of groundwater.

2.2.4 Analytical objective

Knowledge of the analytical objective is essential in the choice of sample preparation procedures and in the selection of a determinative method. This is especially true when the sample has more than one phase. Knowledge of the analytical objective may not be possible or desirable at all management levels, but that information should be included in the project planning document and transmitted to the analytical laboratory management to ensure that the correct techniques are used during the analytical effort. Screening methods or composite sampling may be highly beneficial for some applications in order to generate a broader view of contaminant distribution than may be possible with a more precise and more costly method. Table 2-46 identifies some screening methods appropriate for different classes of organic chemicals in certain matrices.

2.2.5 Quantitation or monitoring

The strategy for quantitation of compounds in environmental or process samples may be contrasted with the strategy for collecting monitoring data. When there is little information available about the composition of the sample source (e.g., a well or process stream), mass spectral identification of organic analytes leads to fewer false positive results. Thus, the most practical form of quantitation for organic analytes is often mass spectral identification. However, where the sensitivity requirements exceed those that can be achieved using mass spectral methods (e.g., gas chromatography/mass spectrometry (GC/MS) or high performance liquid chromatography (HPLC)/MS), it may be necessary to employ a more sensitive quantitation method (e.g., electron capture). In these instances, the risk of false positive results may be minimized by confirming the results through a second analysis with a dissimilar detector or chromatographic column. Thus, the choice of technique for organic analytes may be governed by the sensitivity requirements and potential interferants.

Similarly, the choice of technique for metals may be governed by the sensitivity requirements and potential interferants.

In contrast, monitoring samples are analyzed to confirm existing and ongoing conditions, tracking the presence or absence of known constituents in an environmental or process matrix. In well-defined matrices and under stable analytical conditions, less compound-specific quantitation modes may be used, as the risk of false positive results is less.

2.2.6 Sample preservation and holding times

Table 2-40 provides information regarding recommended sample preservation techniques, sample holding times, and other information. Similar information may be found in Table 3-1 of Chapter Three (inorganic analytes) and Table 4-1 of Chapter Four (organic analytes). Samples

need to be extracted and analyzed within the recommended holding times for the results to be considered reflective of native concentrations as collected. Analytical data generated outside of the recommended holding times should typically be considered as minimum values only. Such data may be used to demonstrate that a waste is hazardous where it shows the concentration of a constituent to be above the regulatory threshold, but cannot be used to demonstrate that a waste is not hazardous. However, regarding the information in Table 2-40, a longer holding time may be appropriate if it can be demonstrated that reported concentrations are not adversely affected from preservation, storage and analyses performed outside the recommended holding times.

2.3 CHOOSING PROCEDURES FOR ORGANIC ANALYSES

Table 2-1 summarizes the organic analysis options available in SW-846.

2.3.1 Extraction and sample preparation procedures for organic analytes

SW-846 methods for preparing samples for organic analytes are shown in Table 2-41. Method 3500 and associated methods should be consulted for further details on preparing the sample for analysis.

2.3.1.1 Aqueous samples

Methods 3510, 3520, and 3535 may be used for extraction of the semivolatile organic compounds (SVOCs) from aqueous samples. The choice of a preparative method depends on the sample. Method 3510, a separatory funnel liquid-liquid extraction technique, is appropriate for samples which will not form a persistent emulsion interface between the sample and the extraction solvent. The formation of an emulsion that cannot be broken up by mechanical techniques will prevent proper extraction of the sample. Method 3520, a continuous liquid-liquid extraction technique, may be used for any aqueous sample and will minimize emulsion formation.

Method 3535 is solid-phase extraction technique that has been tested for organochlorine pesticides, phthalate esters, polychlorinated biphenyls (PCBs), organophosphorus pesticides, nitroaromatics and nitramines, and some explosive compounds, and may be applicable to other semivolatile and extractable compounds as well. The aqueous sample is passed through a solid sorbent material which traps the analytes. They are then eluted from the solid-phase sorbent with a small volume of organic solvent. This technique may be used to minimize the volumes of organic solvents that are employed, but may not be appropriate for aqueous samples with high suspended solids contents.

2.3.1.1.1 Acidic extraction of phenols and acid analytes

The solvent extract obtained by performing Method 3510, 3520, or 3535 at a pH less than or equal to 2 will contain the phenols and acid/neutral extractable organics of interest, and may contain some mildly basic compounds. The particular pH extraction conditions needs to be defined during the project planning process based on the desired target analytes and performance goals.

2.3.1.1.2 Basic or neutral extraction of semivolatile analytes

The solvent extract obtained by performing Method 3510, 3520, or 3535 at a basic pH will contain the organic bases of interest, if acid extraction is performed first. It will also contain the neutral compounds of interest, if acid extraction is not performed. Refer to Table 1 in the extraction methods (3510 and/or 3520) for guidance on the requirements for pH adjustment prior to extraction and analysis.

2.3.1.2 Solid samples

Soxhlet extraction (Methods 3540, 3541 and 3542), pressurized fluid extraction (Method 3545), microwave extraction (Method 3546) and ultrasonic extraction (Method 3550) may be used with solid samples. Consolidated samples should be ground finely enough to pass through a 1-mm sieve. In limited applications, waste dilution (Methods 3580 and 3585) may be used if the entire sample is soluble in the specified solvent.

Methods 3540, 3541, 3542, 3545, 3546 and 3550 are neutral-pH extraction techniques and therefore, depending on the analysis requirements, acid-base partition cleanup (Method 3650) may be necessary. Method 3650 will only be needed if chromatographic interferences are severe enough to prevent quantitation of the analytes of interest. This separation will be most important if a gas chromatography (GC) method is chosen for analysis of the sample. If GC/MS is used, the ion selectivity of the technique may compensate for chromatographic interferences.

There are three extraction procedures for solid samples that employ supercritical fluid extraction (SFE). Method 3560 is a technique for the extraction of petroleum hydrocarbons from various solid matrices using carbon dioxide at elevated temperature and pressure. Method 3561 may be used to selectively extract polynuclear aromatic hydrocarbons (PAHs) from solid matrices using supercritical carbon dioxide and appropriate modifiers, based on the determinative procedure to be used. Method 3562 may be used to selectively extract organochlorine pesticides or PCBs from solid matrices using supercritical carbon dioxide.

2.3.1.3 Oils and organic liquids

Method 3580, waste dilution, may be used to prepare oils and organic liquid samples for analysis of semivolatile and extractable organic analytes by GC or GC/MS. Method 3585 may be employed for the preparation of these matrices for volatiles analysis by GC or GC/MS. To avoid overloading the analytical detection system, care must be exercised to ensure that proper dilutions are made. Methods 3580 and 3585 give guidance on performing waste dilutions.

To remove interferences for semivolatiles and extractables, Method 3611 (alumina cleanup) may be performed on an oil sample directly, without prior sample preparation.

Method 3650 is the only other preparative procedure for oils and other organic liquids. This procedure is a back extraction into an aqueous phase. It is generally introduced as a cleanup procedure for extracts rather than as a preparative procedure. Oils generally have a high concentration of semivolatile compounds and, therefore, preparation by Method 3650 should be done on a relatively small aliquot of the sample. Generally, extraction of 1 mL of oil will be sufficient to obtain a saturated aqueous phase and avoid emulsions.

NOTE: The use of traditional extraction techniques (i.e., 3510, 3520, 3535, 3540, 3541, 3545, 3546, and 3550), is neither suitable nor recommended for use in these matrices due to a high potential for hydrocarbon interferences and decreased determinative method sensitivity (i.e., poor analytical performance).

2.3.1.4 Sludge samples

Determining the appropriate methods for analysis of sludges is complicated because of the lack of precise definitions of sludges with respect to the relative percent of liquid and solid components. There is no set ratio of liquid to solid that enables the analyst to determine which of the three extraction methods cited is the most appropriate. Sludges may be classified into three categories: liquid sludges, solid sludges, and emulsions, but with appreciable overlap.

If the sample is an organic sludge (solid material and organic liquid, as opposed to an aqueous sludge), the sample should be handled as a multiphase sample.

2.3.1.4.1 Liquid sludges

Method 3510 or Method 3520 may be applicable to sludges that behave like, and have the consistency of, aqueous liquids. Ultrasonic extraction (Method 3550) and Soxhlet-type (Method 3540 series) procedures will, most likely, be ineffective because of the overwhelming presence of the liquid aqueous phase.

2.3.1.4.2 Solid sludges

Soxhlet extraction (Methods 3540 and 3541), pressurized fluid extraction (Method 3545), microwave extraction (Method 3546), and ultrasonic extraction (Method 3550) will be more effective when applied to sludge samples that resemble solids. Samples may be dried or centrifuged to form solid materials for subsequent determination of semivolatile compounds.

Using Method 3650, Acid-Base Partition Cleanup, on the extract may be necessary, depending on whether chromatographic interferences prevent determination of the analytes of interest.

2.3.1.4.3 Emulsions

Attempts should be made to break up and separate the phases of an emulsion. Several techniques are effective in breaking emulsions or separating the phases of emulsions, including:

1. Freezing/thawing -- Certain emulsions will separate if exposed to temperatures below 0 °C.

2. Salting out -- Addition of a salt to make the aqueous phase of an emulsion too polar to support a less polar phase promotes separation.

3. Centrifugation -- Centrifugal force may separate emulsion components by density.

4. Addition of water or ethanol -- Emulsion polymers may be destabilized when a preponderance of the aqueous phase is added.

5. Forced filtering through glass wool -- Many emulsions can be broken by forcing the emulsion through a pad of Pyrex glass wool in a drying column using a slight amount of air pressure (using a rubber bulb usually provides sufficient pressure).

If techniques for breaking emulsions fail, use Method 3520. If the emulsion can be broken, the different phases (aqueous, solid, or organic liquid) may then be analyzed separately.

2.3.1.5 Multiphase samples

Choice of the procedure for separating multiphase samples is highly dependent on the objective of the analysis. With a sample in which some of the phases tend to separate rapidly, the percent weight or volume of each phase should be calculated and each phase should be individually analyzed for the required analytes.

An alternate approach is to obtain a homogeneous sample and attempt a single analysis on the combination of phases. This approach will give no information on the abundance of the analytes in the individual phases other than what can be implied by solubility.

A third alternative is to select phases of interest and to analyze only those selected phases. This tactic must be consistent with the sampling/analysis objectives or it will yield insufficient information for the time and resources expended. The phases selected should be compared with Figure 2-1 and Table 2-41 for further guidance.

2.3.2 Cleanup procedures

Cleanup procedure selection is determined by the analytes of interest within the extract. Each analyte type in Table 2-42, Cleanup Methods for Organic Analyte Extracts, corresponds to one or more of the possible determinative methods available in the manual. However, the necessity of performing cleanup may also depend upon the matrix from which the extract was developed. Cleanup of a sample may be done exactly as instructed in the cleanup method for some of the analytes. There are some instances when cleanup using one of the methods may only proceed after the procedure is modified to optimize recovery and separation. Several cleanup techniques may be possible for each analyte category. The information provided is not meant to imply that any or all of these methods must be used for the analysis to be acceptable. Extracts with components which interfere with spectral or chromatographic determinations are expected to be subjected to cleanup procedures.

The analyst, in consultation with the regulator, customer, and other project planning participants as necessary, must determine the necessity for cleanup procedures, as there are no clear-cut criteria for indicating their use. Method 3600 and associated methods should be consulted for further details on extract cleanup.

2.3.3 Determinative procedures

In Table 2-43, the determinative methods for organic analytes are divided into four categories, specifically: GC/MS (this category includes single quadrupole MS, triple quadrupole (MS/MS), and time-of-flight instruments); GC with electromagnetic spectrometric (ES) detectors (i.e., Fourier Transform infrared (FT-IR) or atomic emission (AES)); specific quantitation methods (i.e., GC with specific non-MS detectors); and HPLC, including any HPLC-MS methods. This division is intended to help an analyst choose which determinative method will apply. Under each analyte column, SW-846 method numbers are indicated, if appropriate, for the determination of the analyte. A blank has been left if no chromatographic determinative method is available.

Generally, the MS procedures are more specific but less sensitive than the appropriate gas chromatographic/specific quantitation or ES method.

Method 8000 gives a general description of the techniques of GC and HPLC. Method 8000 should be consulted prior to application of any of the GC or HPLC methods.

Method 8081 (organochlorine pesticides), Method 8082 (PCBs), Method 8141 (organophosphorus pesticides), and Method 8151 (chlorinated herbicides), are preferred over GC/MS because of the combination of selectivity and sensitivity of the flame photometric, nitrogen-phosphorus, and electron capture detectors.

Method 8260 is a GC/MS method for volatile analytes. A variety of sample introduction techniques may be used with Method 8260, including Methods 5021, 5030, 5031, 5035, 5041, and 3585. A GC with a selective detector is also useful for the determination of volatile organic compounds in a monitoring scenario, as described in Sec. 2.2.5.

Method 8270 is a GC/MS method for semivolatile analytes. Method 8410 is another GC method for semivolatile analytes which uses a FT-IR detector. Method 8085 is a GC method for pesticides which uses an AES detector.

Table 2-43 lists several GC and HPLC methods that apply to only a small number of analytes. Methods 8031 and 8033 are GC methods for acrolein, acrylonitrile, and acetonitrile. Methods 8315 and 8316 are HPLC methods for these three analytes. Method 8316 also addresses acrylamide, which may be analyzed by Method 8032. Method 8325 is an HPLC coupled with particle beam MS for the determination of benzidines and nitrogen-containing pesticides in water and wastewater. Method 8520 measures formaldehyde in ambient air primarily for non-occupational exposure monitoring. Method 8540 is used for field-testing of soil samples for pentachlorophenol (PCP).

HPLC methods have been developed for other types of analytes, most notably N-methyl carbamates (Method 8318); azo dyes, phenoxy acid herbicides, carbamates, and organophosphorus pesticides (Method 8321); PAHs (Method 8310); explosives (Methods 8330, 8331, and 8332); and some volatile organics (Methods 8315 and 8316).

Method 8430 utilizes a FT-IR spectrometer coupled to a gas chromatograph to determine bis(2-chloroethyl) ether and its hydrolysis products. The sample is introduced by direct aqueous injection. Method 8440 may be employed for the determination of total recoverable petroleum hydrocarbons (TRPH) in solid samples by infrared (IR) spectrophotometry. The samples may be extracted with supercritical carbon dioxide, using Method 3560.

2.4 CHOOSING PROCEDURES FOR CHARACTERISTIC ANALYSES

2.4.1 Figure 2-2 outlines a sequence for determining if a waste exhibits one or more of the characteristics of a hazardous waste.

2.4.2 SPLP, EP and TCLP extracts

The leachate obtained from using either the Synthentic Precipitation Leaching procedure (SPLP), EP (Figure 2-3A) or the TCLP (Figure 2-3B) is an aqueous sample, and therefore, requires further solvent extraction prior to the analysis of semivolatile compounds.

The SPLP or TCLP leachate is solvent extracted with methylene chloride at a pH <2 and at a pH >11 by either Method 3510 or 3520. The leachate may also be extracted as received for organochlorine pesticides and semivolatiles and at pH <1.0 for phenoxyacid herbicides using the solid phase extraction (SPE) disk option in Method 3535. The best recoveries are usually obtained using either Method 3520 or Method 3535.

The solvent extract obtained by performing either Method 3510 or 3520 at an acidic pH will contain the acid/neutral compounds of interest. Refer to the specific determinative method for guidance on the pH requirements for extraction prior to analysis. Method 5031 (azeotropic distillation) may be used as an effective preparative method for pyridine.

Due to the high concentration of acetate in the TCLP extract, it is recommended that purge-and-trap be used to introduce the volatile sample into the gas chromatograph.

The SPLP, EP and/or TCLP extracts can also be digested using acids (Method 3010, 3015, or 3020) and analyzed for metals using a 6000 or 7000 series method (Figures 2-3A and 2-3B).

2.5 CHOOSING PROCEDURES FOR GROUNDWATER ANALYSES

Appropriate analysis schemes for the determination of analytes in groundwater are presented in Figures 2-4A, 2-4B, and 2-4C. Quantitation limits (LLOQs) for the inorganic analytes should correspond to the drinking water limits, where such limits are available.

2.5.1 Special techniques for inorganic analytes

All atomic absorption (AA) analyses should employ appropriate background correction systems whenever spectral interferences could be present. Several background correction techniques are employed in modern AA spectrometers. Matrix modification can complement background correction in some cases. Since no approach to interference correction is completely effective in all cases, the analyst should attempt to verify the adequacy of correction. If the interferant is known (e.g., high concentrations of iron in the determination of selenium), accurate analyses of synthetic solutions of the interferant (with and without analyte) could establish the efficacy of the background correction. If the nature of the interferant is not established, good agreement of analytical results using two substantially different wavelengths could substantiate the adequacy of the background correction.

To reduce matrix interferences, all graphite furnace atomic absorption (GFAA) analyses should be performed using techniques which maximize an isothermal environment within the furnace cell. Data indicate that two such techniques, L'vov platform and the delayed atomization cuvette (DAC), are equivalent in this respect, and produce high quality results.

All GFAA analysis should be carried out using the best matrix modifier for the analysis. Some examples of modifiers are listed below. (See also the appropriate methods.)

Element(s)	Modifier(s)
As and Se	Nickel nitrate, palladium
Pb	Phosphoric acid, ammonium phosphate, palladium
Cd	Ammonium phosphate, palladium
Sb	Ammonium nitrate, palladium
Tl	Platinum, palladium

Inductively coupled plasma (ICP), AA, and GFAA calibration standards need to match the acid composition and strength of the acids contained in the samples. Acid strengths of the calibration standards should be stated in the raw data. When using a method which permits the use of internal standardization, and the internal standardization option is being used, matrix matching is not required.

2.6 CHOOSING PROCEDURES FOR INORGANIC ANALYSES

Methods for preparing different sample matrices for inorganic analyses are shown in Table 2-44. Guidance regarding the use of leaching and digestive methods for inorganic analysis is provided in Table 2-45.

2.7 REFERENCES

1. M. J. Barcelona, "TOC Determinations in Ground Water," Ground Water 1984, 22(1), 18-24.

2. R. Riggin, et al.; Development and Evaluation of Methods for Total Organic Halide and Purgeable Organic Halide in Wastewater; U.S. Environmental Protection Agency; Office of Research and Development; Environmental Monitoring and Support Laboratory; ORD Publication Offices of Center for Environmental Research Information; Cincinnati, OH, 1984; EPA-600/4-84-008.

3. G. McKee, et al.; Determination of Inorganic Anions in Water by Ion Chromatography (Technical addition to Methods for Chemical Analysis of Water and Wastewater, EPA 600/4-79-020); U.S. Environmental Protection Agency; Environmental Monitoring and Support Laboratory; ORD Publication Offices of Center for Environmental Research Information; Cincinnati, OH, 1984; EPA-600/4-84-017.

TABLE 2-1

DETERMINATIVE METHODS FOR ORGANIC ANALYTES

Analytes are listed in alphabetical order and alternative analyte names are in parenthesis. The applicable method listing does not include immunoassay or screening methods.

Analyte	Applicable Method
Abate (Temephos)	8085
Acenaphthene	8100, 8270, 8275, 8310, 8410
Acenaphthylene	8100, 8270, 8275, 8310, 8410
Acetaldehyde	8315
Acetone	8015, 8260, 8261, 8315
Acetonitrile	8015, 8033, 8260, 8261
Acetophenone	8261, 8270
2-Acetylaminofluorene	8270
1-Acetyl-2-thiourea	8270
Acifluorfen	8085, 8151
Acrolein (Propenal)	8015, 8260, 8261, 8315, 8316
Acrylamide	8032, 8316
Acrylonitrile	8015, 8031, 8260, 8261, 8316
Alachlor	8081, 8085
Aldicarb (Temik)	8318, 8321
Aldicarb sulfone	8318, 8321
Aldicarb sulfoxide	8321
Aldrin	8081, 8085, 8270
Allyl alcohol	8015, 8260
Allyl chloride	8021, 8260, 8261
Ametryn	8085
2-Aminoanthraquinone	8270
Aminoazobenzene	8270
4-Aminobiphenyl	8270
Aminocarb	8321
2-Amino-4,6-dinitrotoluene (2-Am-DNT)	8095, 8330
4-Amino-2,6-dinitrotoluene (4-Am-DNT)	8095, 8330
3-Amino-9-ethylcarbazole	8270
t-Amyl alcohol (TAA)	8015
t-Amyl ethyl ether (TAEE, 4,4-Dimethyl-3-oxahexane)	8015, 8260, 8261
t-Amyl methyl ether (TAME)	8015, 8260, 8261
Anilazine	8270
Aniline	8131, 8261, 8270
o-Anisidine	8270
Anthracene	8100, 8270, 8275, 8310, 8410
Aramite	8270
Aroclor-1016 (PCB-1016)	8082, 8270
Aroclor-1221 (PCB-1221)	8082, 8270
Aroclor-1232 (PCB-1232)	8082, 8270
Aroclor-1242 (PCB-1242)	8082, 8270
Aroclor-1248 (PCB-1248)	8082, 8270
Aroclor-1254 (PCB-1254)	8082, 8270

Aroclor-1260 (PCB-1260)..... 8082, 8270
Aspon 8141
Asulam..... 8321
Atraton 8085
Atrazine..... 8041, 8085, 8141
Azinphos-ethyl (Ethyl guthion)..... 8085, 8141
Azinphos-methyl (Guthion)..... 8085, 8141, 8270
Barban 8270, 8321
Baygon (Propoxur)..... 8318, 8321
Bendiocarb..... 8141, 8318, 8321
Benefin 8091
Benfluralin..... 8085
Benomyl..... 8321
Bentazon..... 8151
Benzal chloride 8121
Benzaldehyde 8315
Benz(a)anthracene 8100, 8270, 8275, 8310, 8410
Benzene..... 8015, 8021, 8260, 8261
Benzenethiol (Thiophenol) 8270
Benzidine..... 8270, 8325
Benzo(b)fluoranthene..... 8100, 8270, 8275, 8310
Benzo(j)fluoranthene..... 8100
Benzo(k)fluoranthene..... 8100, 8270, 8275, 8310
Benzoic acid 8270, 8410
Benzo(g,h,i)perylene..... 8100, 8270, 8275, 8310
Benzo(a)pyrene 8100, 8270, 8275, 8310, 8410
p-Benzoquinone..... 8270
Benzotrichloride 8121
Benzoylprop ethyl 8325
Benzyl alcohol..... 8270
Benzyl chloride..... 8021, 8121, 8260
α-BHC (α-Hexachlorocyclohexane)..... 8081, 8085, 8121, 8270
β-BHC (β-Hexachlorocyclohexane)..... 8081, 8085, 8121, 8270
δ-BHC (δ-Hexachlorocyclohexane)..... 8081, 8085, 8121, 8270
γ-BHC (Lindane, γ-Hexachlorocyclohexane)..... 8081, 8085, 8121, 8270
Bis(2-n-butoxyethyl)phthalate..... 8061
Bis(2-chloroethoxy)methane 8111, 8270, 8410
Bis(2-chloroethyl)ether 8111, 8270, 8410, 8430
Bis(2-chloroethyl)sulfide..... 8260
Bis(2-chloro-1-methylethyl)ether 8021, 8111, 8270, 8410
Bis(2-ethoxyethyl)phthalate..... 8061
Bis(2-ethylhexyl)phthalate..... 8061, 8270, 8410
Bis(2-methoxyethyl)phthalate..... 8061
Bis(4-methyl-2-pentyl)phthalate 8061
Bolstar (Sulprofos) 8085, 8141
Bromacil..... 8085, 8321
Brominal (Bromoxynil)..... 8085, 8270
Bromoacetone..... 8021, 8260
4-Bromoaniline..... 8131
Bromobenzene..... 8021, 8260
Bromochloromethane..... 8021, 8260, 8261

2-Bromo-6-chloro-4-nitroaniline....8131
Bromodichloromethane....8021, 8260, 8261
2-Bromo-4,6-dinitroaniline....8131
Bromoform....8021, 8260, 8261
Bromomethane....8021, 8260, 8261
4-Bromophenyl phenyl ether....8111, 8270, 8275, 8410
Bromoxynil (Brominal)....8085, 8270
Butachlor....8085
Butanal....8315
n-Butanol (1-Butanol, *n*-Butyl alcohol)....8260
2-Butanone (Methyl ethyl ketone, MEK)....8015, 8260, 8261
Butifos (DEF)....8085
Butralin....8091
t-Butyl alcohol....8015, 8260
Butyl benzyl phthalate....8061, 8270, 8410
Butylate....8085, 8141, 8321
n-Butylbenzene....8021, 8260, 8261
sec-Butylbenzene....8021, 8260, 8261
tert-Butylbenzene....8021, 8260, 8261
2-*sec*-Butyl-4,6-dinitrophenol (DNBP, Dinoseb)....8041, 8085, 8151, 8270, 8321
Captafol....8081, 8085, 8270
Captan....8085, 8270
Carbaryl (Sevin)....8270, 8318, 8321, 8325
Carbendazim....8321
Carbofuran (Furaden)....8270, 8318, 8321
Carbofuran phenol....8321
Carbon disulfide....8260, 8261
Carbon tetrachloride....8021, 8260, 8261, 8535
Carbophenothion....8081, 8085, 8141, 8270
Carbosulfan....8321
Carboxin....8085
Casoron (Dichlobenil)....8085
Chloral hydrate....8260
Chloramben....8151
Chlordane (NOS)....8081, 8270
cis-Chlordane....8081
trans-Chlordane....8085, 8081
Chlorfenvinphos....8141, 8270
Chloroacetonitrile....8260
2-Chloroaniline....8131
3-Chloroaniline....8131
4-Chloroaniline....8131, 8270, 8410
Chlorobenzene....8021, 8260, 8261
Chlorobenzilate....8081, 8270
2-Chlorobiphenyl....8082, 8275
2-Chloro-1,3-butadiene (Chloroprene)....8021, 8260
1-Chlorobutane....8260
Chlorodibromomethane (Dibromochloromethane)....8021, 8260, 8261
2-Chloro-4,6-dinitroaniline....8131
1-Chloro-2,4-dinitrobenzene....8091
1-Chloro-3,4-dinitrobenzene....8091

Chloroethane 8021, 8260, 8261
2-Chloroethanol 8021, 8260, 8430
2-(2-Chloroethoxy) ethanol..... 8430
2-Chloroethyl vinyl ether 8021, 8260
Chloroform 8021, 8260, 8261
1-Chlorohexane 8260
Chloromethane 8021, 8260, 8261
5-Chloro-2-methylaniline 8270
Chloromethyl methyl ether 8021
2-Chloro-5-methylphenol..... 8041
4-Chloro-2-methylphenol..... 8041
4-Chloro-3-methylphenol..... 8041, 8270, 8410
3-(Chloromethyl) pyridine hydrochloride..... 8270
1-Chloronaphthalene..... 8270, 8275
2-Chloronaphthalene..... 8121, 8270, 8410
Chloroneb 8081
2-Chloro-4-nitroaniline..... 8131
4-Chloro-2-nitroaniline..... 8131
1-Chloro-2-nitrobenzene 8091
1-Chloro-4-nitrobenzene 8091
2-Chloro-6-nitrotoluene 8091
4-Chloro-2-nitrotoluene 8091
4-Chloro-3-nitrotoluene 8091
2-Chlorophenol 8041, 8270, 8410
3-Chlorophenol 8041
4-Chlorophenol 8410
2-Chlorophenyl 4-nitrophenyl ether 8111
3-Chlorophenyl 4-nitrophenyl ether 8111
4-Chlorophenyl 4-nitrophenyl ether 8111
4-Chlorophenyl phenyl ether 8111, 8270, 8410
o-Chlorophenyl thiourea..... 8325
4-Chloro-1,2-phenylenediamine 8270
4-Chloro-1,3-phenylenediamine 8270
Chloroprene (2-Chloro-1,3-butadiene) 8021, 8260
Chloropropham 8085, 8321
Chloropropylate..... 8081
Chlorothalonil..... 8081
2-Chlorotoluene 8021, 8260, 8261
4-Chlorotoluene 8021, 8260, 8261
Chloroxuron 8321
Chlorpyrifos..... 8085, 8141
Chlorpyrifos methyl 8141
Chlorthalonil (Daconil)..... 8085
Chrysene 8100, 8270, 8275, 8310, 8410
Coumaphos 8085, 8141, 8270
p-Cresidine 8270
o-Cresol (2-Methylphenol)..... 8041, 8270, 8410
m-Cresol (3-Methylphenol)..... 8041, 8270
p-Cresol (4-Methylphenol)..... 8041, 8270, 8410
Crotonaldehyde..... 8015, 8260, 8315
Crotoxyphos..... 8141, 8270

m-Cumenyl methylcarbamate 8318, 8321
Cyanazine 8085
Cycloate 8085
Cyclohexane 8260
Cyclohexanone 8315
2-Cyclohexyl-4,6-dinitrophenol 8041, 8270
2,4-D 8151, 8321
2,4-D (acid) 8085
2,4-D (butoxyethanol ester) 8321
2,4-D (ethylhexyl ester) 8321
Daconil (Chlorthalonil) 8085
Dacthal (DCPA) 8081, 8085
Dalapon 8151, 8321
2,4-DB 8151, 8321
2,4-DB (acid) 8085
DBCP (1,2-Dibromo-3-chloropropane) 8011, 8021, 8081, 8260, 8261, 8270
DCM (Dichloromethane, Methylene chloride) 8021, 8260, 8261
DCPA (Dacthal) 8081, 8085
DCPA diacid 8151
2,4'-DDD 8085
4,4'-DDD 8081, 8085, 8270
2,4'-DDE 8085
4,4'-DDE 8081, 8085, 8270
2,4'-DDT 8085
4,4'-DDT 8081, 8085, 8270
DDVP (Dichlorvos, Dichlorovos) 8085, 8141, 8270, 8321
2,2',3,3'4,4'5,5',6,6'-Decachlorobiphenyl 8275
Decanal 8315
DEF (Butifos) 8085
Demeton-O, and Demeton-S 8085, 8141, 8270
Diallate 8081, 8085, 8270
2,4-Diaminotoluene 8270
Diamyl phthalate 8061
Diazinon 8085, 8141
Dibenz(*a,h*)acridine 8100
Dibenz(*a,j*)acridine 8100, 8270
Dibenz(*a,h*)anthracene 8100, 8270, 8275, 8310
7H-Dibenzo(*c,g*)carbazole 8100
Dibenzofuran 8270, 8275, 8410
Dibenzo(*a,e*)pyrene 8100, 8270
Dibenzo(*a,h*)pyrene 8100
Dibenzo(*a,i*)pyrene 8100
Dibenzothiophene 8275
Dibromochloromethane (Chlorodibromomethane) 8021, 8260, 8261
1,2-Dibromo-3-chloropropane (DBCP) 8011, 8021, 8081, 8260, 8261, 8270
Dibromomethane 8021, 8260, 8261
1,2-Dibromoethane (EDB, Ethylene dibromide) 8011, 8021, 8260
2,6-Dibromo-4-nitroaniline 8131
2,4-Dibromophenyl 4-nitrophenyl ether 8111
Dibutyltin dichloride 8323
Di-*n*-butyl phthalate 8061, 8270, 8410

Dicamba 8085, 8151, 8321
Dichlobenil (Casoron) 8085
Dichlone 8081, 8270
Dichloran 8081
3,4-Dichloroaniline 8131
1,2-Dichlorobenzene 8021, 8121, 8260, 8261, 8270, 8410
1,3-Dichlorobenzene 8021, 8121, 8260, 8261, 8270, 8410
1,4-Dichlorobenzene 8021, 8121, 8260, 8261, 8270, 8410
3,3'-Dichlorobenzidine 8270,8325
3,5-Dichlorobenzoic acid 8085, 8151
2,3-Dichlorobiphenyl 8082
3,3'-Dichlorobiphenyl 8275
cis-1,4-Dichloro-2-butene 8260, 8261
trans-1,4-Dichloro-2-butene 8260, 8261
Dichlorodifluoromethane 8021, 8260, 8261
1,1-Dichloroethane 8021, 8260, 8261
1,2-Dichloroethane 8021, 8260, 8261
1,1-Dichloroethene (Vinylidene chloride) 8021, 8260, 8261
cis-1,2-Dichloroethene 8021, 8260, 8261
trans-1,2-Dichloroethene 8021, 8260, 8261
Dichlorofenthion 8141
Dichloromethane (DCM, Methylene chloride) 8021, 8260, 8261
2,6-Dichloro-4-nitroaniline 8131
2,3-Dichloronitrobenzene 8091
2,4-Dichloronitrobenzene 8091
2,5-Dichloronitrobenzene 8091
3,4-Dichloronitrobenzene 8091
3,5-Dichloronitrobenzene 8091
2,3-Dichlorophenol 8041
2,4-Dichlorophenol 8041, 8270, 8410
2,5-Dichlorophenol 8041
2,6-Dichlorophenol 8041, 8270
3,4-Dichlorophenol 8041
3,5-Dichlorophenol 8041
2,4-Dichlorophenol 3-methyl-4-nitrophenyl ether 8111
2,3-Dichlorophenyl 4-nitrophenyl ether 8111
2,4-Dichlorophenyl 4-nitrophenyl ether 8111
2,5-Dichlorophenyl 4-nitrophenyl ether 8111
2,6-Dichlorophenyl 4-nitrophenyl ether 8111
3,4-Dichlorophenyl 4-nitrophenyl ether 8111
3,5-Dichlorophenyl 4-nitrophenyl ether 8111
Dichloroprop (Dichlorprop) 8085, 8151, 8321
1,2-Dichloropropane 8021, 8260, 8261
1,3-Dichloropropane 8021, 8260, 8261
2,2-Dichloropropane 8021, 8260, 8261
1,3-Dichloro-2-propanol 8021, 8260
1,1-Dichloropropene 8021, 8260, 8261
cis-1,3-Dichloropropene 8021, 8260, 8261
trans-1,3-Dichloropropene 8021, 8260, 8261
Dichlorovos (DDVP, Dichlorvos) 8085, 8141, 8270, 8321
Dichlorprop (Dichloroprop) 8085, 8151, 8321

Diclofol (Kelthane)..... 8085
Diclofop-methyl 8085
Dicofol 8081
Dicrotophos..... 8141, 8270
Dicyclohexyl phthalate 8061
Dieldrin 8081, 8085, 8270
1,2,3,4-Diepoxybutane 8260
Diesel range organics (DRO) 8015
Diethyl ether..... 8015, 8260, 8261
Diethyl phthalate 8061, 8270, 8410
Diethyl sulfate 8270
Diethylene glycol 8430
Diethylstilbestrol 8270
Dihexyl phthalate 8061
Diisobutyl phthalate..... 8061
Diisopropyl ether (DIPE) 8015, 8260, 8261
Dimethoate 8141, 8270, 8085, 8321
3,3'-Dimethoxybenzidine 8270, 8325
Dimethyl phthalate 8061, 8270, 8410
Dimethylaminoazobenzene 8270
2,5-Dimethylbenzaldehyde..... 8315
7,12-Dimethylbenz(a)anthracene 8270
3,3'-Dimethylbenzidine 8270, 8325
4,4-Dimethyl-3-oxahexane (*t*-Amyl ethyl ether, TAEE) 8015, 8260, 8261
α,α-Dimethylphenethylamine..... 8270
2,3-Dimethylphenol 8041
2,4-Dimethylphenol 8041, 8270
2,5-Dimethylphenol 8041
2,6-Dimethylphenol 8041
3,4-Dimethylphenol 8041
Dinitramine..... 8091
2,4-Dinitroaniline 8131
3,5-Dinitroaniline 8095, 8330
1,2-Dinitrobenzene..... 8091, 8270
1,3-Dinitrobenzene (1,3-DNB)..... 8091, 8095, 8270, 8330
1,4-Dinitrobenzene..... 8091, 8270
4,6-Dinitro-2-methylphenol 8270, 8410
2,4-Dinitrophenol..... 8041, 8270, 8410
2,5-Dinitrophenol..... 8041
2,4-Dinitrotoluene (2,4-DNT)..... 8091, 8095, 8270, 8330, 8410
2,6-Dinitrotoluene (2,6-DNT)..... 8091, 8095, 8270, 8330, 8410
Dinocap..... 8270
Dinonyl phthalate 8061
Dinoseb (2-*sec*-Butyl-4,6-dinitrophenol, DNBP) 8041, 8085, 8151, 8270, 8321
Di-*n*-octyl phthalate 8061, 8270, 8410
Dioxacarb..... 8318
1,4-Dioxane 8260, 8261
Dioxathion 8085, 8141
DIPE (Diisopropyl ether) 8015, 8261
Diphenamid..... 8085
Diphenylamine 8270

5,5-Diphenylhydantoin 8270
1,2-Diphenylhydrazine 8270
Diphenyltin dichloride 8323
Di-*n*-propyl phthalate 8410
Disperse Blue 3 8321
Disperse Blue 14 8321
Disperse Brown 1 8321
Disperse Orange 3 8321
Disperse Orange 30 8321
Disperse Red 1 8321
Disperse Red 5 8321
Disperse Red 13 8321
Disperse Red 60 8321
Disperse Yellow 5 8321
Disulfoton 8085, 8141, 8270, 8321
Diuron 8085, 8321, 8325
1,3-DNB (1,3-Dinitrobenzene) 8091, 8095, 8270, 8330
DNBP (2-*sec*-Butyl-4,6-dinitrophenol, Dinoseb) 8041, 8085, 8151, 8270, 8321
2,4-DNT (2,4-Dinitrotoluene) 8091, 8095, 8270, 8330, 8410
2,6-DNT (2,6-Dinitrotoluene) 8091, 8270, 8330, 8410
EDB (1,2-Dibromoethane, Ethylene dibromide) 8011, 8021, 8260
Endosulfan I 8081, 8085, 8270
Endosulfan II 8081, 8085, 8270
Endosulfan sulfate 8081, 8085, 8270
Endrin 8081, 8085, 8270
Endrin aldehyde 8081, 8085, 8270
Endrin ketone 8081, 8085, 8270
Epichlorohydrin 8021, 8260
EPN 8141, 8085, 8270
Eptam (EPTC) 8085, 8141, 8321
EPTC (Eptam) 8085, 8141, 8321
ETBE (Ethyl *tert*-butyl ether) 8015, 8261
Ethalfluralin (Sonalan) 8085
Ethanol 8015, 8260, 8261
Ethion 8085, 8141, 8270
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Ethyl acetate 8015, 8260, 8261
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1,2,3,4,7,8,9-HpCDF 8280, 8290
HpCDF, total 8280, 8290
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1,2,3,7,8-PeCDF 8280, 8290
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2-Propanol (Isopropyl alcohol) 8015, 8260
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n-Propylamine..... 8260
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Prosulfocarb..... 8141, 8321
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Pyridine..... 8015, 8260, 8261
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Sulfotepp..... 8085, 8141
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2,3,7,8-TCDF..... 8280, 8290
TCDF, total..... 8280, 8290
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1,2,3,5-Tetrachlorobenzene..... 8121
1,2,4,5-Tetrachlorobenzene..... 8121, 8270
2,2',3,5'-Tetrachlorobiphenyl..... 8082, 8275
2,2',4,5'-Tetrachlorobiphenyl..... 8275
2,2',5,5'-Tetrachlorobiphenyl..... 8082, 8275
2,3',4,4'-Tetrachlorobiphenyl..... 8082, 8275
1,1,1,2-Tetrachloroethane..... 8021, 8260
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2,3,5,6-Tetrachloronitrobenzene..... 8091
2,3,4,5-Tetrachlorophenol..... 8041, 8085
2,3,4,6-Tetrachlorophenol..... 8041, 8085, 8270
2,3,5,6-Tetrachlorophenol..... 8041
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Tetraethyl pyrophosphate (TEPP)..... 8141, 8270
Tetrahydrofuran (THF)..... 8261
Tetrazene..... 8331
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THF (Tetrahydrofuran)..... 8261
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Thiofanox..... 8321
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Thiophanate-methyl..... 8321
Thiophenol (Benzenethiol)..... 8270

1,3,5-TNB (1,3,5-Trinitrobenzene)..... 8095, 8270, 8330
2,4,6-TNT (2,4,6-Trinitrotoluene)..... 8095, 8330
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o-Tolualdehyde..... 8315
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Toluene..... 8015, 8021, 8260, 8261
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Toxaphene..... 8081, 8270, 8272, 8276
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Treflan (Trifluralin)..... 8081, 8085, 8091, 8270
Triademefon..... 8085
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2,4,6-Trichloroaniline..... 8131
1,2,3-Trichlorobenzene..... 8021, 8121, 8260, 8261
1,2,4-Trichlorobenzene..... 8021, 8121, 8260, 8261, 8270, 8275, 8410
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2,2',5-Trichlorobiphenyl..... 8082, 8275
2,3',5-Trichlorobiphenyl..... 8275
2,4',5-Trichlorobiphenyl..... 8082, 8275
1,1,1-Trichloroethane..... 8021, 8260, 8261
1,1,2-Trichloroethane..... 8021, 8260, 8261
Trichloroethene (Trichloroethylene)..... 8021, 8260, 8261, 8535
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Trichloronate..... 8141
1,2,3-Trichloro-4-nitrobenzene..... 8091
1,2,4-Trichloro-5-nitrobenzene..... 8091
2,4,6-Trichloronitrobenzene..... 8091
2,3,4-Trichlorophenol..... 8041
2,3,5-Trichlorophenol..... 8041
2,3,6-Trichlorophenol..... 8041
2,4,5-Trichlorophenol..... 8041, 8085, 8270, 8410
2,4,6-Trichlorophenol..... 8041, 8085, 8270, 8410
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2,3,6-Trichlorophenyl 4-nitrophenyl ether..... 8111
2,4,5-Trichlorophenyl 4-nitrophenyl ether..... 8111
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3,4,5-Trichlorophenyl 4-nitrophenyl ether..... 8111
1,2,3-Trichloropropane..... 8021, 8260, 8261
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Tri-*o*-cresylphosphate (TOCP)..... 8141
O,O,O-Triethyl phosphorothioate..... 8270
Triethylamine..... 8015
Trifluralin (Treflan)..... 8081, 8085, 8091, 8270
Trihalomethanes..... 8535

Trimethyl phosphate 8270
2,4,5-Trimethylaniline 8270
1,2,4-Trimethylbenzene 8021, 8260, 8261
1,3,5-Trimethylbenzene 8021, 8260, 8261
1,3,5-Trinitrobenzene (1,3,5-TNB) 8095, 8270, 8330
2,4,6-Trinitrophenylmethylnitramine 8095
2,4,6-Trinitrotoluene (2,4,6-TNT) 8095, 8330
Triphenyltin chloride 8323
Tris-BP (Tris(2,3-dibromopropyl) phosphate) 8270, 8321
Tris(2,3-dibromopropyl) phosphate (Tris-BP) 8270, 8321
Tri-*p*-tolyl phosphate 8270
Valeraldehyde (Pentanal) 8315
Vernolate 8085
Vinyl acetate 8260
Vinyl chloride 8021, 8260, 8261
Vinylidene chloride (1,1-Dichloroethene) 8021, 8260, 8261
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o-Xylene 8015, 8021, 8260, 8261
p-Xylene 8015, 8021, 8260, 8261
Zinophos (Thionazin) 8141, 8270

TABLE 2-2

METHOD 8011 (MICROEXTRACTION AND GAS CHROMATOGRAPHY)

1,2-Dibromo-3-chloropropane (DBCP)
1,2-Dibromoethane (EDB)

TABLE 2-3

METHOD 8015 (GC/FID) - NONHALOGENATED VOLATILES

Acetone	Ethylene oxide
Acetonitrile	Gasoline range organics (GRO)
Acrolein	Isopropyl alcohol
Acrylonitrile	Methanol
Allyl alcohol	Methyl ethyl ketone (MEK, 2-Butanone)
t-Amyl alcohol (TAA)	*N*-Nitroso-di-*n*-butylamine
t-Amyl ethyl ether (TAEE)	Paraldehyde
t-Amyl methyl ether (TAME)	2-Pentanone
Benzene	2-Picoline
t-Butyl alcohol	1-Propanol (*n*-Propyl alcohol)
Crotonaldehyde	Propionitrile
Diesel range organics (DRO)	Pyridine
Diethyl ether	Toluene
Diisopropyl ether (DIPE)	*o*-Toluidine
Ethanol	*m*-Xylene
Ethyl acetate	*o*-Xylene
Ethyl benzene	*p*-Xylene
Ethyl *tert*-butyl ether (ETBE)	Triethylamine

TABLE 2-4

METHOD 8021 (GC, PHOTOIONIZATION AND ELECTROLYTIC CONDUCTIVITY DETECTORS) - AROMATIC AND HALOGENATED VOLATILES

Allyl chloride	*cis*-1,2-Dichloroethene
Benzene	*trans*-1,2-Dichloroethene
Benzyl chloride	1,2-Dichloropropane
Bis(2-chloro-1-methylethyl) ether	1,3-Dichloropropane
Bromoacetone	2,2-Dichloropropane
Bromobenzene	1,3-Dichloro-2-propanol
Bromochloromethane	1,1-Dichloropropene
Bromodichloromethane	*cis*-1,3-Dichloropropene
Bromoform	*trans*-1,3-Dichloropropene
Bromomethane	Epichlorhydrin
n-Butylbenzene	Ethylbenzene
sec-Butylbenzene	Hexachlorobutadiene
tert-Butylbenzene	Isopropylbenzene
Carbon tetrachloride	*p*-Isopropyltoluene
Chlorobenzene	Methylene chloride
Chlorodibromomethane	Naphthalene
Chloroethane	*n*-Propylbenzene
2-Chloroethanol	Styrene
2-Chloroethyl vinyl ether	1,1,1,2-Tetrachloroethane
Chloroform	1,1,2,2-Tetrachloroethane
Chloromethane	Tetrachloroethene
Chloromethyl methyl ether	Toluene
Chloroprene	1,2,3-Trichlorobenzene
2-Chlorotoluene	1,2,4-Trichlorobenzene
4-Chlorotoluene	1,1,1-Trichloroethane
1,2-Dibromo-3-chloropropane	1,1,2-Trichloroethane
1,2-Dibromoethane	Trichloroethene
Dibromomethane	Trichlorofluoromethane
1,2-Dichlorobenzene	1,2,3-Trichloropropane
1,3-Dichlorobenzene	1,2,4-Trimethylbenzene
1,4-Dichlorobenzene	1,3,5-Trimethylbenzene
Dichlorodifluoromethane	Vinyl chloride
1,1-Dichloroethane	*o*-Xylene
1,2-Dichloroethane	*m*-Xylene
1,1-Dichloroethene	*p*-Xylene

TABLE 2-5

METHODS 8031 AND 8033 (GC WITH NITROGEN-PHOSPHORUS DETECTION)
AND METHOD 8032 (GC WITH ELECTRON CAPTURE DETECTION)

Method 8031: Acrylonitrile
Method 8032: Acrylamide
Method 8033: Acetonitrile

TABLE 2-6

METHOD 8041 (GC) - PHENOLS

2-Chloro-5-methylphenol	2,5-Dinitrophenol
4-Chloro-2-methylphenol	Dinoseb (2-*sec*-butyl-4,6-dinitro phenol)
4-Chloro-3-methylphenol	2-Methyl-4,6-dinitrophenol
2-Chlorophenol	2-Methylphenol (*o*-Cresol)
3-Chlorophenol	3-Methylphenol (*m*-Cresol)
4-Chlorophenol	4-Methylphenol (*p*-Cresol)
2-Cyclohexyl-4,6-dinitrophenol	2-Nitrophenol
2,3-Dichlorophenol	3-Nitrophenol
2,4-Dichlorophenol	4-Nitrophenol
2,5-Dichlorophenol	Pentachlorophenol
2,6-Dichlorophenol	Phenol
3,4-Dichlorophenol	2,3,4,5-Tetrachlorophenol
3,5-Dichlorophenol	2,3,4,6-Tetrachlorophenol
2,3-Dimethylphenol	2,3,5,6-Tetrachlorophenol
2,4-Dimethylphenol	2,3,4-Trichlorophenol
2,5-Dimethylphenol	2,3,5-Trichlorophenol
2,6-Dimethylphenol	2,3,6-Trichlorophenol
3,4-Dimethylphenol	2,4,5-Trichlorophenol
2,4-Dinitrophenol	2,4,6-Trichlorophenol

TABLE 2-7

METHOD 8061 (GC/ECD) - PHTHALATE ESTERS

Bis(2-*n*-butoxyethyl) phthalate	Diethyl phthalate
Bis(2-ethoxyethyl) phthalate	Dihexyl phthalate
Bis(2-ethylhexyl) phthalate	Diisobutyl phthalate
Bis(2-methoxyethyl) phthalate	Di-*n*-butyl phthalate
Bis(4-methyl-2-pentyl) phthalate	Dimethyl phthalate
Butyl benzyl phthalate	Di-*n*-octyl phthalate
Diamyl phthalate	Dinonyl phthalate
Dicyclohexyl phthalate	Hexyl 2-ethylhexyl phthalate

TABLE 2-8

METHOD 8070 (GC) - NITROSAMINES

N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosodi-*n*-propylamine

TABLE 2-9

METHOD 8081 (GC) - ORGANOCHLORINE PESTICIDES

Alachlor	4,4'-DDE	Halowax-1051
Aldrin	4,4'-DDT	Halowax-1099
α-BHC	Diallate	Heptachlor
β-BHC	Dichlone	Heptachlor epoxide
δ-BHC	Dichloran	Hexachlorobenzene
γ-BHC (Lindane)	Dicofol	Hexachlorocyclopentadiene
Captafol	Dieldrin	Isodrin
Carbophenothion	Endosulfan I	Methoxychlor
Chlordane (NOS)	Endosulfan II	Mirex
cis-Chlordane	Endosulfan sulfate	Nitrofen
trans-Chlordane	Endrin	*trans*-Nonachlor
Chlorobenzilate	Endrin aldehyde	Pentachloronitrobenzene (PCNB)
Chloroneb	Endrin ketone	Permethrin (*cis* + *trans*)
Chloropropylate	Etridiazole	Perthane
Chlorothalonil	Halowax-1000	Propachlor
Dacthal (DCPA)	Halowax-1001	Strobane
DBCP	Halowax-1013	Toxaphene
4,4'-DDD	Halowax-1014	Trifluralin

TABLE 2-10

METHOD 8082 (GC) - POLYCHLORINATED BIPHENYLS

Aroclor 1016	2,2',3,4,5,5'-Hexachlorobiphenyl
Aroclor 1221	2,2',3,5,5',6-Hexachlorobiphenyl
Aroclor 1232	2,2',4,4',5,5'-Hexachlorobiphenyl
Aroclor 1242	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl
Aroclor 1248	2,2',3,4,5'-Pentachlorobiphenyl
Aroclor 1254	2,2',4,5,5'-Pentachlorobiphenyl
Aroclor 1260	2,3,3',4',6-Pentachlorobiphenyl
2-Chlorobiphenyl	2,2',3,5'-Tetrachlorobiphenyl
2,3-Dichlorobiphenyl	2,2',5,5'-Tetrachlorobiphenyl
,2',3,3',4,4',5-Heptachlorobiphenyl	2,3',4,4'-Tetrachlorobiphenyl
2,2',3,4,4',5,5'-Heptachlorobiphenyl	2,2',5-Trichlorobiphenyl
2,2',3,4,4',5',6-Heptachlorobiphenyl	2,4',5-Trichlorobiphenyl
2,2',3,4',5,5',6-Heptachlorobiphenyl	

TABLE 2-11

METHOD 8085 (GC/AED) – PESTICIDES

Abate (Temephos)	Cycloate	Diphenamid
Acifluorfen	Coumaphos	Disulfoton (Disyston)
Alachlor	2,4-D acid	Diuron
Aldrin	2,4-DB acid	Endosulfan I
Ametryn	DCPA (Dacthal)	Endosulfan II
Atraton	2,4'-DDD	Endosulfan sulfate
Atrazine	4,4'-DDD	Endrin
Azinphos ethyl (Ethyl guthion)	2,4'-DDE	Endrin aldehyde
Azinphos methyl (Guthion)	4,4'-DDE	Endrin ketone
Benfluralin	2,4'-DDT	EPN
α-BHC	4,4'-DDT	Eptam (EPTC)
β-BHC	DEF (Butifos)	Ethalfluralin (Sonalan)
δ-BHC	Demeton-O	Ethion
γ-BHC (Lindane)	Demeton-S	Ethoprop
Bromacil	Diallate	Fenamiphos
Bromoxynil (Brominal)	Diazinon	Fenarimol
Butachlor	Dicamba	Fenitrothion
Butylate	Dichlobenil (Casoron)	Fensulfothion
Captafol	3,5-Dichlorobenzoic acid	Fenthion
Captan	Dichlorprop	Fluridone
Carbophenothion	Dichlorvos (DDVP)	Fonofos
Carboxin	Diclofol (Kelthane)	Gardona (Tetrachlovinphos)
trans-Chlordane	Diclofop-methyl	Heptachlor
Chlorpropham	Dieldrin	Heptachlor epoxide
Chlorpyrifos	Dimethoate	Hexachlorobenzene
Chlorthalonil (Daconil)	Dinoseb	Hexachlorocyclopentadiene
Cyanazine	Dioxathion	Hexazinone

TABLE 2-11 (continued)

Imidan (Phosmet)	Norflurazon	Sulfotepp
Ioxynil	Oxyfluorfen	Sulprofos (Bolstar)
Malathion	Parathion	Silvex
MCPA acid	Pebulate	2,4,5-T acid
MCPP acid	Pendimethalin	2,4,5-TB
Merphos	Pentachlorophenol (PCP)	Tebuthiuron
Metalaxyl	Phorate	Terbacil
Methoxychlor	Phosphamidon	Terbutryn (Igran)
Methyl chlorpyrifos	Picloram	2,3,4,5-Tetrachlorophenol
Methyl paraoxon	Profluralin	2,3,4,6-Tetrachlorophenol
Methyl parathion	Prometon (Pramitol 5p)	Triademefon
Metolachlor	Prometryn	Triallate
Metribuzin	Pronamide (Kerb)	2,4,5-Trichlorophenol
Mevinphos	Propachlor (Ramrod)	2,4,6-Trichlorophenol
MGK-264	Propargite (S-181)	Triclopyr (Garlon)
Mirex	Propazine	Trifluralin (Treflan)
Molinate	Propetamidophos	Vernolate
Napropamide	Ronnel	
4-Nitrophenol	Simazine	

TABLE 2-12

METHOD 8091 (GC) - NITROAROMATICS AND CYCLIC KETONES

Benefin	2,4-Dinitrotoluene
Butralin	2,6-Dinitrotoluene
1-Chloro-2,4-dinitrobenzene	Isopropalin
1-Chloro-3,4-dinitrobenzene	1,2-Naphthoquinone
1-Chloro-2-nitrobenzene	1,4-Naphthoquinone
1-Chloro-4-nitrobenzene	Nitrobenzene
2-Chloro-6-nitrotoluene	2-Nitrotoluene
4-Chloro-2-nitrotoluene	3-Nitrotoluene
4-Chloro-3-nitrotoluene	4-Nitrotoluene
2,3-Dichloronitrobenzene	Penoxalin [Pendimethalin]
2,4-Dichloronitrobenzene	Pentachloronitrobenzene
2,5-Dichloronitrobenzene	Profluralin
3,4-Dichloronitrobenzene	2,3,4,5-Tetrachloronitrobenzene
3,5-Dichloronitrobenzene	2,3,5,6-Tetrachloronitrobenzene
Dinitramine	1,2,3-Trichloro-4-nitrobenzene
1,2-Dinitrobenzene	1,2,4-Trichloro-5-nitrobenzene
1,3-Dinitrobenzene	2,4,6-Trichloronitrobenzene
1,4-Dinitrobenzene	Trifluralin

TABLE 2-13

METHOD 8095 (GC) - EXPLOSIVES

2-Amino-4,6-dinitrotoluene	2-Nitrotoluene
4-Amino-2,6-dinitrotoluene	3-Nitrotoluene
3,5-Dinitroaniline	4-Nitrotoluene
1,3-Dinitrobenzene	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
2,4-Dinitrotoluene	Pentaerythritoltetranitrate
2,6-Dinitrotoluene	1,3,5-Trinitrobenzene
Hexahydro-1,3,5-trinitro-1,3,5-triazine	2,4,6-Trinitrophenylmethylnitramine
Nitrobenzene	2,4,6-Trinitrotoluene
Nitroglycerine	

TABLE 2-14

METHOD 8100 - POLYNUCLEAR AROMATIC HYDROCARBONS

Acenaphthene	Dibenz(*a,h*)anthracene
Acenaphthylene	7H-Dibenzo(*c,g*)carbazole
Anthracene	Dibenzo(*a,e*)pyrene
Benz(*a*)anthracene	Dibenzo(*a,h*)pyrene
Benzo(*b*)fluoranthene	Dibenzo(*a,i*)pyrene
Benzo(*j*)fluoranthene	Fluoranthene
Benzo(*k*)fluoranthene	Fluorene
Benzo(*g,h,i*)perylene	Indeno(1,2,3-*cd*)pyrene
Benzo(*a*)pyrene	3-Methylcholanthrene
Chrysene	Naphthalene
Dibenz(*a,h*)acridine	Phenanthrene
Dibenz(*a,j*)acridine	Pyrene

TABLE 2-15

METHOD 8111 (GC) - HALOETHERS

Bis(2-chloroethoxy)methane	2,5-Dichlorophenyl 4-nitrophenyl ether
Bis(2-chloroethyl) ether	2,6-Dichlorophenyl 4-nitrophenyl ether
Bis(2-chloro-1-methylethyl) ether	3,4-Dichlorophenyl 4-nitrophenyl ether
4-Bromophenyl phenyl ether	3,5-Dichlorophenyl 4-nitrophenyl ether
4-Chlorophenyl phenyl ether	4-Nitrophenyl phenyl ether
2-Chlorophenyl 4-nitrophenyl ether	2,3,4-Trichlorophenyl 4-nitrophenyl ether
3-Chlorophenyl 4-nitrophenyl ether	2,3,5-Trichlorophenyl 4-nitrophenyl ether
4-Chlorophenyl 4-nitrophenyl ether	2,3,6-Trichlorophenyl 4-nitrophenyl ether
2,4-Dibromophenyl 4-nitrophenyl ether	2,4,5-Trichlorophenyl 4-nitrophenyl ether
2,4-Dichlorophenyl 3-methyl-4-nitrophenyl ether	2,4,6-Trichlorophenyl 4-nitrophenyl ether
2,3-Dichlorophenyl 4-nitrophenyl ether	3,4,5-Trichlorophenyl 4-nitrophenyl ether
2,4-Dichlorophenyl 4-nitrophenyl ether	

TABLE 2-16

METHOD 8121 (GC) - CHLORINATED HYDROCARBONS

Benzal chloride	δ-Hexachlorocyclohexane (δ-BHC)
Benzotrichloride	γ-Hexachlorocyclohexane (γ-BHC)
Benzyl chloride	Hexachlorocyclopentadiene
2-Chloronaphthalene	Hexachloroethane
1,2-Dichlorobenzene	Pentachlorobenzene
1,3-Dichlorobenzene	1,2,3,4-Tetrachlorobenzene
1,4-Dichlorobenzene	1,2,3,5-Tetrachlorobenzene
Hexachlorobenzene	1,2,4,5-Tetrachlorobenzene
Hexachlorobutadiene	1,2,3-Trichlorobenzene
α-Hexachlorocyclohexane (α-BHC)	1,2,4-Trichlorobenzene
β-Hexachlorocyclohexane (β-BHC)	1,3,5-Trichlorobenzene

TABLE 2-17

METHOD 8131 (GC) - ANILINE AND SELECTED DERIVATIVES

Aniline	2,6-Dibromo-4-nitroaniline
4-Bromoaniline	3,4-Dichloroaniline
2-Bromo-6-chloro-4-nitroanilne	2,6-Dichloro-4-nitroaniline
2-Bromo-4,6-dintroaniline	2,4-Dinitroaniline
2-Chloroaniline	2-Nitroaniline
3-Chloroaniline	3-Nitroaniline
4-Chloroaniline	4-Nitroaniline
2-Chloro-4,6-dinitroaniline	2,4,5-Trichloroaniline
2-Chloro-4-nitroaniline	2,4,6-Trichloroaniline
4-Chloro-2-nitroaniline	

TABLE 2-18

METHOD 8141 (GC) - ORGANOPHOSPHORUS COMPOUNDS

Aspon	Disulfoton	Parathion, methyl
Atrazine	EPN	Pebulate
Azinphos-ethyl	EPTC	*o*-Phenylenediamine
Azinphos-methyl	Ethion	Phorate
Bendiocarb	Ethoprop	Phosmet
Bolstar (Sulprofos)	Famphur	Phosphamidon
Butylate	Fenitrothion	Propham
Carbophenothion	Fensulfothion	Prosulfocarb
Chlorfenvinphos	Fenthion	Ronnel
Chlorpyrifos	Fonophos	Simazine
Chlorpyrifos methyl	Hexamethyl phosphoramide (HMPA)	Stirophos (Tetrachlorvinphos, Gardona)
Coumaphos	Leptophos	Sulfotepp
Crotoxyphos	Malathion	Terbufos
Demeton-O, and -S	Merphos	Tetraethyl pyrophosphate (TEPP)
Diazinon	Methiocarb	Thionazin (Zinophos)
Dichlorofenthion	Mevinphos	Tokuthion (Prothiofos)
Dichlorvos (DDVP)	Molinate	Triallate
Dicrotophos	Monocrotophos	Trichlorfon
Dimethoate	Naled	Trichloronate
Dioxathion	Parathion, ethyl	Tri-*o*-cresyl phosphate (TOCP)

TABLE 2-19

METHOD 8151 (GC USING METHYLATION OR PENTAFLUOROBENZYLATION DERIVATIZATION) - CHLORINATED HERBICIDES

Acifluorfen	Dicamba	MCPP
Bentazon	3,5-Dichlorobenzoic acid	4-Nitrophenol
Chloramben	Dichloroprop	Pentachlorophenol
2,4-D	Dinoseb	Picloram
Dalapon	5-Hydroxydicamba	2,4,5-T
2,4-DB	MCPA	2,4,5-TP (Silvex)
DCPA diacid		

TABLE 2-20

METHOD 8260 (GC/MS) - VOLATILE ORGANIC COMPOUNDS

Acetone	2-Chloroethyl vinyl ether	Diisopropyl ether (DIPE)
Acetonitrile	Chloroform	1,4-Dioxane
Acrolein (Propenal)	1-Chlorohexane	Epichlorohydrin
Acrylonitrile	Chloromethane	Ethanol
Allyl alcohol	Chloroprene	Ethyl acetate
Allyl chloride	2-Chlorotoluene	Ethyl t-butyl ether (ETBE)
t-Amyl ethyl ether (TAEE)	4-Chlorotoluene	Ethyl methacrylate
t-Amyl methyl ether (TAME)	Crotonaldehyde	Ethylbenzene
Benzene	Cyclohexane	Ethylene oxide
Benzyl chloride	1,2-Dibromo-3-chloropropane	Hexachlorobutadiene
Bis(2-chloroethyl)sulfide	1,2-Dibromoethane	Hexachloroethane
Bromoacetone	Dibromomethane	2-Hexanone
Bromobenzene	1,2-Dichlorobenzene	Iodomethane
Bromochloromethane	1,3-Dichlorobenzene	Isobutyl alcohol
Bromodichloromethane	1,4-Dichlorobenzene	Isopropylbenzene
Bromoform	cis-1,4-Dichloro-2-butene	p-Isopropyltoluene
Bromomethane	trans-1,4-Dichloro-2-butene	Malononitrile
n-Butanol	Dichlorodifluoromethane	Methacrylonitrile
2-Butanone (MEK)	1,1-Dichloroethane	Methanol
t-Butyl alcohol	1,2-Dichloroethane	Methyl acrylate
n-Butylbenzene	1,1-Dichloroethene	Methyl-t-butyl ether (MTBE)
sec-Butylbenzene	cis-1,2-Dichloroethene	Methyl methacrylate
tert-Butylbenzene	trans-1,2-Dichloroethene	Methylcyclohexane
Carbon disulfide	1,2-Dichloropropane	Methylene chloride
Carbon tetrachloride	1,3-Dichloropropane	4-Methyl-2-pentanone (MIBK)
Chloral hydrate	2,2-Dichloropropane	Naphthalene
Chloroacetonitrile	1,3-Dichloro-2-propanol	Nitrobenzene
Chlorobenzene	1,1-Dichloropropene	2-Nitropropane
1-Chlorobutane	cis-1,3-Dichloropropene	N-Nitroso-di-n-butylamine
Chlorodibromomethane	trans-1,3-Dichloropropene	Paraldehyde
Chloroethane	1,2,3,4-Diepoxybutane	Pentachloroethane
2-Chloroethanol	Diethyl ether	Pentafluorobenzene

TABLE 2-20 (continued)

2-Pentanone	Styrene	Trichloroethene
2-Picoline	1,1,1,2-Tetrachloroethane	Trichlorofluoromethane
1-Propanol	1,1,2,2-Tetrachloroethane	1,2,3-Trichloropropane
2-Propanol	Tetrachloroethene	1,2,4-Trimethylbenzene
Propargyl alcohol	Toluene	1,3,5-Trimethylbenzene
ß-Propiolactone	o-Toluidine	Vinyl acetate
Propionitrile (Ethyl cyanide)	1,2,3-Trichlorobenzene	Vinyl chloride
n-Propylamine	1,2,4-Trichlorobenzene	o-Xylene
n-Propylbenzene	1,1,1-Trichloroethane	m-Xylene
Pyridine	1,1,2-Trichloroethane	p-Xylene

TABLE 2-21

METHOD 8261 (VD/GC/MS) - VOLATILE ORGANIC COMPOUNDS

Acetone	1,3-Dichlorobenzene	Methacrylonitrile
Acetonitrile	1,4-Dichlorobenzene	Methyl *t*-butyl ether (MTBE)
Acetophenone	*cis*-1,4-Dichloro-2-butene	Methyl methacrylate
Acrolein	*trans*-1,4-Dichloro-2-butene	Methylene chloride
Acrylonitrile	Dichlorodifluoromethane	1-Methylnaphthalene
Allyl Chloride	1,1-Dichloroethane	2-Methylnaphthalene
t-Amyl ethyl ether (TAEE) (4,4-Dimethyl-3-oxahexane)	1,2-Dichloroethane	4-Methyl-2-pentanone
t-Amyl methyl ether (TAME)	1,1-Dichloroethene	Naphthalene
Aniline	*cis*-1,2-Dichloroethene	*N*-Nitrosodibutylamine
Benzene	*trans*-1,2-Dichloroethene	*N*-Nitrosodiethylamine
Bromochloromethane	1,2-Dichloropropane	*N*-Nitrosodimethylamine
Bromodichloromethane	1,3-Dichloropropane	*N*-Nitrosodi-*n*-propylamine
Bromoform	2,2-Dichloropropane	*N*-Nitrosomethylethylamine
Bromomethane	1,1-Dichloropropene	Pentachloroethane
2-Butanone	*cis*-1,3-Dichloropropene	2-Picoline
n-Butylbenzene	*trans*-1,3-Dichloropropene	Propionitrile
sec-Butylbenzene	Diethyl ether	*n*-Propylbenzene
tert-Butylbenzene	Diisopropyl ether (DIPE)	Pyridine
Carbon disulfide	1,4-Dioxane	Styrene
Carbon tetrachloride	Ethanol	1,1,2,2-Tetrachloroethane
Chlorobenzene	Ethyl acetate	Tetrachloroethene
Chlorodibromomethane	Ethyl *t*-butyl ether (ETBE)	Tetrahydrofuran
Chloroethane	Ethyl methacrylate	Toluene
Chloroform	Ethylbenzene	*o*-Toluidine
Chloromethane	Hexachlorobutadiene	1,2,3-Trichlorobenzene
2-Chlorotoluene	2-Hexanone	1,2,4-Trichlorobenzene
4-Chlorotoluene	Iodomethane	1,1,1-Trichloroethane
1,2-Dibromo-3-chloropropane	Isobutyl alcohol	1,1,2-Trichloroethane
Dibromomethane	Isopropylbenzene	Trichloroethene
1,2-Dichlorobenzene	*p*-Isopropyltoluene	Trichlorofluoromethane

TABLE 2-21 (continued)

1,2,3-Trichloropropane	Vinyl chloride	*p*-Xylene
1,2,4-Trimethylbenzene	*o*-Xylene	
1,3,5-Trimethylbenzene	*m*-Xylene	

TABLE 2-22

METHOD 8270 (GC/MS) - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	Aroclor-1260
Acenaphthylene	Azinphos-methyl
Acetophenone	Barban
2-Acetylaminofluorene	Benz(a)anthracene
1-Acetyl-2-thiourea	Benzidine
Aldrin	Benzo(b)fluoranthene
2-Aminoanthraquinone	Benzo(k)fluoranthene
Aminoazobenzene	Benzoic acid
4-Aminobiphenyl	Benzo(g,h,i)perylene
3-Amino-9-ethylcarbazole	Benzo(a)pyrene
Anilazine	*p*-Benzoquinone
Aniline	Benzyl alcohol
o-Anisidine	α-BHC
Anthracene	β-BHC
Aramite	δ-BHC
Aroclor-1016	γ-BHC (Lindane)
Aroclor-1221	Bis(2-chloroethoxy)methane
Aroclor-1232	Bis(2-chloroethyl)ether
Aroclor-1242	Bis(2-chloro-1-methylethyl)ether
Aroclor-1248	Bis(2-ethylhexyl)phthalate
Aroclor-1254	4-Bromophenyl phenyl ether

Table 2-22 (continued)

Bromoxynil	Demeton-S
Butyl benzyl phthalate	Diallate (*cis* or *trans*)
Captafol	2,4-Diaminotoluene
Captan	Dibenz(*a,j*)acridine
Carbaryl	Dibenz(*a,h*)anthracene
Carbofuran	Dibenzofuran
Carbophenothion	Dibenzo(*a,e*)pyrene
Chlordane (NOS)	1,2-Dibromo-3-chloropropane
Chlorfenvinphos	Di-*n*-butyl phthalate
4-Chloroaniline	Dichlone
Chlorobenzilate	1,2-Dichlorobenzene
5-Chloro-2-methylaniline	1,3-Dichlorobenzene
4-Chloro-3-methylphenol	1,4-Dichlorobenzene
3-(Chloromethyl)pyridine hydrochloride	3,3'-Dichlorobenzidine
1-Chloronaphthalene	2,4-Dichlorophenol
2-Chloronaphthalene	2,6-Dichlorophenol
2-Chlorophenol	Dichlorovos
4-Chloro-1,2-phenylenediamine	Dicrotophos
4-Chloro-1,3-phenylenediamine	Dieldrin
4-Chlorophenyl phenyl ether	Diethyl phthalate
Chrysene	Diethyl sulfate
Coumaphos	Diethylstilbestrol
p-Cresidine	Dimethoate
Crotoxyphos	3,3'-Dimethoxybenzidine
2-Cyclohexyl-4,6-dinitrophenol	Dimethyl phthalate
4,4'-DDD	Dimethylaminoazobenzene
4,4'-DDE	7,12-Dimethylbenz(*a*)anthracene
4,4'-DDT	3,3'-Dimethylbenzidine
Demeton-O	α,α-Dimethylphenethylamine

Table 2-22 (continued)

2,4-Dimethylphenol
1,2-Dinitrobenzene
1,3-Dinitrobenzene
1,4-Dinitrobenzene
4,6-Dinitro-2-methylphenol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Dinocap
Dinoseb
Di-*n*-octyl phthalate
Diphenylamine
5,5-Diphenylhydantoin
1,2-Diphenylhydrazine
Disulfoton
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Endrin ketone
EPN
Ethion
Ethyl carbamate
Ethyl methanesulfonate
Famphur
Fensulfothion
Fenthion
Fluchloralin
Fluoranthene
Fluorene
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Hexachlorophene
Hexachloropropene
Hexamethylphosphoramide
Hydroquinone
Indeno(1,2,3-cd)pyrene
Isodrin
Isophorone
Isosafrole
Kepone
Leptophos
Malathion
Maleic anhydride
Mestranol
Methapyrilene
Methoxychlor
Methyl methanesulfonate
Methyl parathion
3-Methylcholanthrene
4,4'-Methylenebis(2-chloroaniline)

Table 2-22 (continued)

4,4'-Methylenebis(N,N-dimethylaniline)	N-Nitrosodimethylamine
2-Methylnaphthalene	N-Nitrosodiphenylamine
2-Methylphenol	N-Nitrosodi-n-propylamine
3-Methylphenol	N-Nitrosomethylethylamine
4-Methylphenol	N-Nitrosomorpholine
Mevinphos	N-Nitrosopiperidine
Mexacarbate	N-Nitrosopyrrolidine
Mirex	5-Nitro-o-toluidine
Monocrotophos	Octamethyl pyrophosphoramide
Naled	4,4'-Oxydianiline
Naphthalene	Parathion
1,4-Naphthoquinone	Pentachlorobenzene
1-Naphthylamine	Pentachloronitrobenzene
2-Naphthylamine	Pentachlorophenol
Nicotine	Phenacetin
5-Nitroacenaphthene	Phenanthrene
2-Nitroaniline	Phenobarbital
3-Nitroaniline	Phenol
4-Nitroaniline	1,4-Phenylenediamine
5-Nitro-o-anisidine	Phorate
Nitrobenzene	Phosalone
4-Nitrobiphenyl	Phosmet
Nitrofen	Phosphamidion
2-Nitrophenol	Phthalic anhydride
4-Nitrophenol	2-Picoline (2-methylpyridine)
Nitroquinoline-1-oxide	Piperonyl sulfoxide
N-Nitrosodi-n-butylamine	Pronamide
N-Nitrosodiethylamine	Propylthiouracil

Table 2-22 (continued)

Pyrene	Toluene diisocyanate
Resorcinol	o-Toluidine
Safrole	Toxaphene
Strychnine	1,2,4-Trichlorobenzene
Sulfallate	2,4,5-Trichlorophenol
Terbufos	2,4,6-Trichlorophenol
1,2,4,5-Tetrachlorobenzene	O,O,O-Triethylphosphorothioate
2,3,4,6-Tetrachlorophenol	Trifluralin
Tetrachlorvinphos	Trimethyl phosphate
Tetraethyl dithiopyrophosphate	2,4,5-Trimethylaniline
Tetraethyl pyrophosphate	1,3,5-Trinitrobenzene
Thionazine	Tris(2,3-dibromopropyl)phosphate
Thiophenol (Benzenethiol)	Tri-p-tolyl phosphate

TABLE 2-23

METHOD 8275 (TE/GC/MS) - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	2,2',3,4',5,5',6- Heptachlorobiphenyl
Acenaphthylene	Hexachlorobenzene
Anthracene	2,2',3,3',4,4'- Hexachlorobiphenyl
Benz(*a*)anthracene	2,2',3,4,4',5'- Hexachlorobiphenyl
Benzo(*k*)fluoranthene	Indeno(1,2,3-*cd*)pyrene
Benzo(*b*)fluoranthene	Naphthalene
Benzo(*g,h,i*)perylene	2,2',3,3'4,4',5,5',6- Nonachlorobiphenyl
Benzo(*a*)pyrene	2,2',3,3',4,4',5,5'- Octachlorobiphenyl
4-Bromophenyl phenyl ether	2,2',4,5,5'-Pentachlorobiphenyl
2-Chlorobiphenyl	2,3',4,4',5-Pentachlorobiphenyl
1-Chloronaphthalene	Phenanthrene
Chrysene	Pyrene
2,2',3,3'4,4',5,5',6,6'- Decachlorobiphenyl	2,2'3,5'-Tetrachlorobiphenyl
Dibenz(*a,h*)anthracene	2,2'4,5'-Tetrachlorobiphenyl
Dibenzofuran	2,2',5,5'-Tetrachlorobiphenyl
Dibenzothiophene	2,3',4,4'-Tetrachlorobiphenyl
3,3'-Dichlorobiphenyl	1,2,4-Trichlorobenzene
Fluoranthene	2,2',5-Trichlorobiphenyl
Fluorene	2,3',5-Trichlorobiphenyl
2,2',3,3',4,4',5- Heptachlorobiphenyl	2,4',5-Trichlorobiphenyl
2,2',3,4,4',5,5'- Heptachlorobiphenyl	

TABLE 2-23A

METHOD 8276 (GC-NICI/MS) - TOXAPHENE AND TOXAPHENE CONGENERS

2-endo,3-exo,5-endo,6-exo,8,9,10-Heptachlorobornane (Hp-Sed)
2-exo,3-endo,6-exo,8,9,10-Hexachlorobornane (Hx-Sed)
2,2,5,5,8,9,9,10,10-Nonachlorobornane (P62)
2-endo,3-exo,5-endo,6-exo,8,8,9,10,10-Nonachlorobornane (P50)
2-endo,3-exo,5-endo,6-exo,8,8,10,10-Octachlorobornane (P26)
2-endo,3-exo,5-endo,6-exo,8,9,10,10-Octachlorobornane (P40)
2-exo,3-endo,5-exo,8,9,9,10,10-Octachlorobornane (P41)
2-exo,5,5,8,9,9,10,10-Octachlorobornane (P44)
Toxaphene

TABLE 2-24

METHODS 8280 (HRGC/LRMS) AND 8290 (HRGC/HRMS) - POLYCHLORINATED DIBENZO-*p*-DIOXINS (PCDDs) AND POLYCHLORINATED DIBENZOFURANS (PCDFs)

1,2,3,4,6,7,8-HpCDD	2,3,4,6,7,8-HxCDF
HpCDD, total	HxCDF, total
1,2,3,4,6,7,8-HpCDF	OCDD
1,2,3,4,7,8,9-HpCDF	OCDF TCDF, total
HpCDF, total	1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD	PeCDD, total
1,2,3,6,7,8-HxCDD	1,2,3,7,8-PeCDF
1,2,3,7,8,9-HxCDD	2,3,4,7,8-PeCDF
HxCDD, total	PeCDF, total
1,2,3,4,7,8-HxCDF	2,3,7,8-TCDD
1,2,3,6,7,8-HxCDF	TCDD, total
1,2,3,7,8,9-HxCDF	2,3,7,8-TCDF

TABLE 2-25

METHOD 8310 (HPLC) - POLYNUCLEAR AROMATIC HYDROCARBONS

Acenaphthene	Chrysene
Acenaphthylene	Dibenzo(*a,h*)anthracene
Anthracene	Fluoranthene
Benz(*a*)anthracene	Fluorene
Benzo(*b*)fluoranthene	Indeno(1,2,3-*cd*)pyrene
Benzo(*k*)fluoranthene	Naphthalene
Benzo(*g,h,i*)perylene	Phenanthrene
Benzo(*a*)pyrene	Pyrene

TABLE 2-26

METHOD 8315 - CARBONYL COMPOUNDS

Acetaldehyde	Decanal	Octanal
Acetone	2,5-Dimethylbenzaldehyde	Pentanal (Valeraldehyde)
Acrolein	Formaldehyde	Propanal (Propionaldehyde)
Benzaldehyde	Heptanal	*m*-Tolualdehyde
Butanal (Butyraldehyde)	Hexanal (Hexaldehyde)	*o*-Tolualdehyde
Crotonaldehyde	Isovaleraldehyde	*p*-Tolualdehyde
Cyclohexanone	Nonanal	

TABLE 2-27

METHOD 8316 (HPLC)

Acrolein
Acrylamide
Acrylonitrile

TABLE 2-28

METHOD 8318 (HPLC) - *N*-METHYLCARBAMATES

Aldicarb (Temik)	Dioxacarb	Mexacarbate
Aldicarb sulfone	Formetanate hydrochloride	Oxamyl
Bendiocarb	3-Hydroxycarbofuran	Promecarb
Carbaryl (Sevin)	Methiocarb (Mesurol)	Propoxur (Baygon)
Carbofuran (Furadan)	Methomyl (Lannate)	Thiodicarb
m-Cumenyl methylcarbamate	Metolcarb	

TABLE 2-29

METHOD 8321 (HPLC/TS/MS) - NONVOLATILE ORGANIC COMPOUNDS

Azo Dyes	Organophosphorus Compounds
Disperse Brown 1	Asulam
Disperse Orange 3	Dichlorvos (DDVP)
Disperse Orange 30	Dimethoate
Disperse Red 1	Disulfoton
Disperse Red 5	Famphur
Disperse Red 13	Fensulfothion
Disperse Yellow 5	Merphos
Solvent Red 3	Methomyl
Solvent Red 23	Monocrotophos
	Naled
Anthraquinone Dyes	Parathion methyl
Disperse Blue 3	Phorate
Disperse Blue 14	Thiofanox
Disperse Red 60	Trichlorfon
	Tris(2,3-dibromopropyl) phosphate (Tris-BP)
Chlorinated Phenoxyacid Compounds	
2,4-D	Silvex (2,4,5-TP)
2,4-D, butoxyethanol ester	2,4,5-T
2,4-D, ethylhexyl ester	2,4,5-T, butyl ester
Dalapon	2,4,5-T, butoxyethanol ester
2,4-DB	
Dicamba	
Dichlorprop	
Dinoseb	
MCPA	
MCPP	

Table 2-29 (continued)

Carbamates	
Aldicarb	Linuron
Aldicarb sulfone	Methiocarb
Aldicarb sulfoxide	Methomyl
Aminocarb	Metolcarb
Barban	Mexacarbate
Bendiocarb	Molinate
Benomyl	Monuron
Bromacil	Neburon
Butylate	Oxamyl
Carbaryl	Pebulate
Carbendazim	*o*-Phenylenediamine
Carbofuran	Physostigmine
Carbofuran phenol	Physostigmine salicylate
Carbosulfan	Promecarb
Chloropropham	Propham
Chloroxuron	Propoxur
m-Cumenyl methyl carbamate	Prosulfocarb
Diuron	Siduron
EPTC	Tebuthiuron
Fenuron	Thiodicarb
Fluometuron	Thiophanate-methyl
Formetanate hydrochloride	Triallate
3-Hydroxycarbofuran	

TABLE 2-29A

METHOD 8323 (MS) - ORGANOTINS BY MICRO-LIQUID CHROMATOGRAPHY-ELECTROSPRAY ION TRAP MASS SPECTROMETRY

Dibutyltin dichloride	Monophenyltin trichloride
Diphenyltin dichloride	Tributyltin chloride
Monobutyltin trichloride	Triphenyltin chloride

TABLE 2-30

METHOD 8325 (HPLC/PB/MS) - NONVOLATILE ORGANIC COMPOUNDS

Benzidine	3,3'-Dimethylbenzidine
Benzoylprop ethyl	Diuron
Carbaryl	Linuron (Lorox)
o-Chlorophenyl thiourea	Monuron
3,3'-Dichlorobenzidine	Rotenone
3,3'-Dimethoxybenzidine	Siduron

TABLE 2-31

METHOD 8330 (HPLC) - NITROAROMATICS AND NITRAMINES

2-Amino-4,6-dinitrotoluene (2-Am-DNT)	2-Nitrotoluene (2-NT)
4-Amino-2,6-dinitrotoluene (4-Am-DNT)	3-Nitrotoluene (3-NT)
3,5-Dinitroanaline (3,5-DNA)	4-Nitrotoluene (4-NT)
1,3-Dinitrobenzene (1,3-DNB)	Nitroglycerin
2,4-Dinitrotoluene (2,4-DNT)	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)
2,6-Dinitrotoluene (2,6-DNT)	Pentaerythritol tetranitrate (PETN)
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	1,3,5-Trinitrobenzene (1,3,5-TNB)
Methyl-2,4,6-trinitrophenyl-nitramine (Tetryl)	2,4,6-Trinitrotoluene (2,4,6-TNT)
Nitrobenzene (NB)	

TABLE 2-32

METHOD 8331 (HPLC)

Tetrazene

TABLE 2-33

METHOD 8332 (HPLC)

Nitroglycerine

TABLE 2-34

METHOD 8410 - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	1,2-Dichlorobenzene
Acenaphthylene	1,3-Dichlorobenzene
Anthracene	1,4-Dichlorobenzene
Benzo(*a*)anthracene	2,4-Dichlorophenol
Benzo(*a*)pyrene	Diethyl phthalate
Benzoic acid	Dimethyl phthalate
Bis(2-chloroethoxy)methane	4,6-Dinitro-2-methylphenol
Bis(2-chloroethyl)ether	2,4-Dinitrophenol
Bis(2-chloro-1-methylethyl)ether	2,4-Dinitrotoluene
Bis(2-ethylhexyl) phthalate	2,6-Dinitrotoluene
4-Bromophenyl phenyl ether	Di-*n*-octyl phthalate
Butyl benzyl phthalate	Di-*n*-propyl phthalate
4-Chloroaniline	Fluoranthene
4-Chloro-3-methylphenol	Fluorene
2-Chloronaphthalene	Hexachlorobenzene
2-Chlorophenol	1,3-Hexachlorobutadiene
4-Chlorophenol	Hexachlorocyclopentadiene
4-Chlorophenyl phenyl ether	Hexachloroethane
Chrysene	Isophorone
Dibenzofuran	2-Methylnaphthalene
Di-*n*-butyl phthalate	2-Methylphenol

Table 2-34 (continued)

4-Methylphenol	*N*-Nitrosodiphenylamine
Naphthalene	*N*-Nitroso-di-*n*-propylamine
2-Nitroaniline	Pentachlorophenol
3-Nitroaniline	Phenanthrene
4-Nitroaniline	Phenol
	Pyrene
2-Nitrophenol	1,2,4-Trichlorobenzene
4-Nitrophenol	2,4,5-Trichlorophenol
N-Nitrosodimethylamine	2,4,6-Trichlorophenol

TABLE 2-35

METHOD 8430 (GC/FT-IR) - BIS(2-CHLOROETHYL) ETHER AND ITS HYDROLYSIS PRODUCTS

Bis(2-chloroethyl) ether
2-Chloroethanol
2-(2-Chloroethoxy) ethanol
Diethylene glycol
Ethylene glycol

TABLE 2-35A

METHOD 8440 - TOTAL RECOVERABLE PETROLEUM HYDROCARBONS BY INFRARED SPECTROPHOTOMETRY

This method does not give a specific compound list but is applicable to total recoverable petroleum hydrocarbons.

TABLE 2-36

METHOD 8510 (COLORIMETRIC SCREENING) - RDX AND HMX

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)

TABLE 2-36A

METHOD 8520 (CONTINUOUS MEASUREMENT OF FORMALDEHYDE IN AMBIENT AIR)

Formaldehyde

TABLE 2-37

METHOD 8535 (COLORIMETRIC SCREENING) - VOLATILE ORGANIC HALIDES

Carbon tetrachloride
Perchloroethylene (Tetrachloroethene)
Trichloroethylene
Trihalomethanes

TABLE 2-38

METHOD 8540 (UV-INDUCED COLORIMETRY) - PENTACHLOROPHENOL

Pentachlorophenol

TABLE 2-39

DETERMINATIVE METHODS FOR INORGANIC ANALYTES

Analyte	Applicable Methods
Aluminum	6010, 6020, 7000, 7010
Antimony	6010, 6020, 6200, 6800, 7000, 7062
Arsenic	6010, 6020, 6200, 7010, 7061, 7062, 7063
Barium	6010, 6020, 6200, 6800, 7000, 7010
Beryllium	6010, 6020, 7000, 7010
Boron	6010, 6800
Bromide	6500, 9056, 9211
Cadmium	6010, 6020, 6200, 6800, 7000, 7010
Calcium	6010, 6020, 6200, 6800, 7000
Chloride	6500, 9056, 9057, 9212, 9250, 9251, 9253
Chromium	6010, 6020, 6200, 6800, 7000, 7010
Chromium, hexavalent	6800, 7195, 7196, 7197, 7198, 7199
Cobalt	6010, 6020, 6200, 7000, 7010
Copper	6010, 6020, 6200, 6800, 7000, 7010
Cyanide	9010, 9012, 9013, 9014, 9015, 9016, 9213
Fluoride	6500, 9056, 9214
Iron	6010, 6020, 6200, 6800, 7000, 7010
Lead	6010, 6020, 6200, 6800, 7000, 7010
Lithium	6010, 7000
Magnesium	6010, 6020, 6800, 7000
Manganese	6010, 6020, 6200, 7000, 7010
Mercury	6010, 6020, 6200, 6800, 7470, 7471, 7472, 7473, 7474
Molybdenum	6010, 6200, 6800, 7000, 7010
Nickel	6010, 6020, 6200, 6800, 7000, 7010
Nitrate	6500, 9056, 9210
Nitrite	6500, 9056, 9216
Osmium	7000
Perchlorate	6850, 6860
Phosphate	6500, 9056
Phosphorus	6010
Phosphorus, white	7580
Potassium	6010, 6020, 6200, 6800, 7000
Rubidium	6200
Selenium	6010, 6020, 6200, 6800, 7010, 7741, 7742
Silica	6010
Silver	6010, 6020, 6200, 6800, 7000, 7010
Sodium	6010, 6020, 7000
Strontium	6010, 6200, 6800, 7000
Sulfate	6500, 9035, 9036, 9038, 9056
Sulfide	9030, 9031, 9215
Thallium	6010, 6020, 6200, 6800, 7000, 7010
Thorium	6200
Tin	6010, 6200, 7000
Titanium	6010, 6200

TABLE 2-39 (cont)

Vanadium.....6010, 6020, 6200, 6800, 7000, 7010
Zinc.....6010, 6020, 6200, 6800, 7000, 7010
Zirconium.....6200

R000115

TABLE 2-40A

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

(Note: Footnotes are located on the last page of the table.)

VOLATILE ORGANICS

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Concentrated waste samples	Method 5035: See the method. Method 5021: See the method. Methods 5031 and 5032: See the methods. Use PTFE-lined lids for all procedures.	Cool to 0 - 6 °C.	14 days
Aqueous samples with no residual chlorine present	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Cool to 0 - 6 °C and adjust pH to less than 2 with H_2SO_4, HCl, or solid $NaHSO_4$	14 days
		If carbonaceous materials are present, or if MTBE and other fuel oxygenate ethers are present and a high temperature sample preparative method is to be used, do not acid preserve the samples.	*7 days*
		If the reactive compound 2-chloroethyl vinyl ether[b] is an analyte of interest, collect a second set of samples without acid preservatives and analyze immediately.	*7 days*

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

R000116

VOLATILE ORGANICS (continued)

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Aqueous samples WITH residual chlorine present	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Collect sample in a 125-mL container which has been pre-preserved with 4 drops of 10% sodium thiosulfate solution. Gently swirl to mix sample and transfer to a 40-mL VOA vial. Cool to 0 - 6 °C and adjust pH to less than 2 with H_2SO_4, HCl, or solid $NaHSO_4$.	14 days
		If carbonaceous materials are present, or if MTBE and other fuel oxygenate ethers are present and a high temperature sample preparative method is to be used, do not acid preserve the samples.	*7 days*
		If the reactive compound 2-chloroethyl vinyl ether[b] is an analyte of interest, collect a second set of samples without acid preservatives and analyze immediately.	*7 days*
Acrolein and acrylonitrile in aqueous samples	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Adjust to pH 4-5. Cool to 0 - 6 °C. *These compounds are highly reactive and should be analyzed as soon as possible.*	7 days
Solid samples (e.g., soils, sediments, sludges, ash)	Method 5035: See the method. Method 5021: See the method. Methods 5031 and 5032: See the methods.	See the individual methods.	14 days
		If vinyl chloride, styrene, or 2-chloroethyl vinyl ether are analytes of interest, collect a second set of samples without acid preservatives and analyze as soon as possible.	7 days

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

R000117

SEMIVOLATILE ORGANICS/ORGANOCHLORINE PESTICIDES AND HERBICIDES

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Concentrated waste samples	125-mL wide-mouth glass with PTFE-lined lid	None	Samples extracted within 14 days and extracts analyzed within 40 days following extraction.
Aqueous samples with no residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Cool to 0 - 6 °C.	Samples extracted within 7 days and extracts analyzed within 40 days following extraction.
Aqueous samples WITH residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Add 3 mL 10% sodium thiosulfate solution per gallon (or 0.008%). Addition of sodium thiosulfate solution to sample container may be performed in the laboratory prior to field use. Cool to 0 - 6 °C.	Samples extracted within 7 days and extracts analyzed within 40 days following extraction.
Solid samples (e.g., soils, sediments, sludges, ash)	250-mL wide-mouth glass container with PTFE-lined lid	Cool to 0 - 6 °C.	Samples extracted within 14 days and extracts analyzed within 40 days following extraction.

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

R000118

POLYCHLORINATED BIPHENYLS, POLYCHLORINATED DIBENZO-*p*-DIOXINS, AND POLYCHLORINATED DIBENZOFURANS

Sample Matrix	Container	Preservative[1]	Holding Time[2]
Concentrated waste samples	125-mL wide-mouth glass with PTFE-lined lid	None	None
Aqueous samples with no residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Cool to 0 - 6 °C.	None
Aqueous samples WITH residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Add 3 mL 10% sodium thiosulfate solution per gallon (or 0.008%). Addition of sodium thiosulfate solution to sample container may be performed in the laboratory prior to field use. Cool to 0 - 6 °C	None
Solid samples (e.g., soils, sediments, sludges, ash)	250-mL wide-mouth glass container with PTFE-lined lid.	Cool to 0 - 6 °C.	None

[a] The information presented in this table does not represent EPA requirements, but rather is intended solely as guidance. Selection of containers, preservation techniques, and applicable holding times should be based on the stated project-specific DQOs.

[1] The exact sample, extract, and standard storage temperature should be based on project-specific requirements and/or manufacturer's recommendations for commercially available standards. Furthermore, alternative storage temperatures may be appropriate based on demonstrated analyte stability in a given matrix, provided the stated DQOs for a project-specific application are still attainable.

[2] A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected from preservation, storage, and analyses performed outside the recommended holding times.

R000119

TABLE 2-40B

RECOMMENDED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR INORGANIC AND OTHER ANALYTES IN AQUEOUS MATRICES
(SEE CHAPTER THREE FOR MORE DETAILED GUIDANCE, INCLUDING REGARDING SOLID MATRICES)
(Footnotes are located on the next page.)

Name	Container[1]	Preservation[2]	Holding Time[3]
Inorganic Tests:			
Chloride	P, G	None required	28 days
Cyanide, total and amenable to chlorination	P, G	Cool to 0 - 6 °C; if oxidizing agents present add 5 mL 0.1N $NaAsO_2$ per L or 0.06 g of ascorbic acid per L; adjust pH>12 with 50% NaOH. See Method 9010 for other interferences.	14 days
Hydrogen ion (pH)	P, G	None required	As soon as possible
Nitrate	P, G	Cool to 0 - 6 °C.	48 hours
Sulfate	P, G	Cool to 0 - 6 °C.	28 days
Sulfide	P, G	Cool to 0 - 6 °C , add zinc acetate, NaOH to pH >9	7 days
Metals:			
Chromium VI	P, G	Cool to 0 - 6 °C.	24 hours
Mercury	P, G	HNO_3 to pH<2	28 days
Mercury (soil/sediment)	P, G	Cool to 0 - 6 °C.	28 days
Mercury Species in soil/sediment	P, G	Cool to 0 - 6 °C.	5 days
All Other Metals	P, G	HNO_3 to pH<2	6 months
Hexane Extractable Material (HEM; Oil and grease)	G	Cool to 0 - 6 °C,HCl or H_2SO_4 to pH<2	28 days
Organic carbon, total (TOC)	P, G	Cool to 0 - 6°C, store in dark; HCl or H_2SO_4 to pH<2	28 days
Radiological Tests:			

Name	Container[1]	Preservation[2]	Holding Time[3]
Alpha, beta and radium	P, G	HNO_3 to pH<2	6 months

[a] The information presented in this table does not represent EPA requirements, but rather is intended solely as guidance. Selection of containers, preservation techniques and applicable holding times should be based on the stated project-specific DQOs. See Chapter Three, Chapter Four, or the individual methods for more information.

[1] Polyethylene (P) or glass (G)

[2] The exact sample, extract, and standard storage temperature should be based on project-specific requirements and/or manufacturer's recommendations for commercially available standards. Furthermore, alternative storage temperatures may be appropriate based on demonstrated analyte stability in a given matrix, provided the stated DQOs for a project-specific application are still attainable.

[3] A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected by preservation, storage, and analyses performed outside the recommended holding times.

TABLE 2-41
PREPARATION METHODS FOR ORGANIC ANALYTES
(Note: Footnotes are located on the last page of the table.)

	Matrix			
Analyte Type	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils
Acid Extractable	35103520 (pH ≤ 2)	3540 3541 3542[13] 3545 3546 3550	3520 (pH ≤ 2)	3650 3580[3]
Acrolein[12], Acrylonitrile[12], and Acetonitrile	5031 5032[12]	5031 5032[12]	5031 5032[12]	3585
Acrylamide	8032[4]			
Aniline and Selected Derivatives	3510 3520 (pH >11) 5031[11]	3540 3541 3545 3550	3520 (pH >11)	3580[3]
Aromatic Volatiles	5021 5030 5032	5021 5032 5035	5030 5032	3585
Base/Neutral Extractable	3510 3511 3520 (pH >11)	3540 3541 3542[13] 3545 3546 3550	3520 (pH >11)	3650 3580[3]
Carbamates	8318[5] 8321	8318[5] 8321	8318[5]	8318[5]
Chlorinated Herbicides	3535 (pH < 1) 8151[6] (pH ≤ 2) 8321	3545 3546 8151[6] 8321	8151[6] (pH ≤ 2)	3580[3]
Chlorinated Hydrocarbons	3510 3520 (pH as received)	3540 3541 3550	3520 (pH as received)	3580[3]
Dyes	3510 3520	3540 3541 3545 3550		

TABLE 2-41 (continued)
PREPARATION METHODS FOR ORGANIC ANALYTES

Analyte Type	Matrix			
	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils
Explosives	3535 8330[7] 8331[8]	8330[7] 8331[8]		
Formaldehyde	8315[9]	8315[9]		
Haloethers			3510 3520	3540 3541 3545 3550
Halogenated Volatiles	5021 5030 5032	5021 5032 5035	5030	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Nitroaromatics and Cyclic Ketones	3510 3520 (pH 5-9) 3535	3540 3541 3545 3550	3520 (pH 5-9)	3580[3]
Nitrosamines	3510 3520	3540 3541 3545 3550		
Non-halogenated Volatiles	5021 5030 5031 5032	5021 5031 5032 5035	5021 5031 5032	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Organochlorine Pesticides	3510 3520 3535 (pH 5-9)	3540 3541 3545 3546 3550 3562	3520 (pH 5-9)	3580[3]
Organophosphorus Pesticides	3510 3520 (pH 5-8) 3535	3540 3541 3545 3546	3520 (pH 5-8)	3580[3]

TABLE 2-41 (continued)
PREPARATION METHODS FOR ORGANIC ANALYTES

	Matrix			
	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils 3650 3580[3]
Phenols	3510 3520 (pH ≤ 2) 3535	3540 3541 3545 3546 3550 3562	3520 (pH ≤ 2)	3650 3580[3]
Phthalate Esters	3510 3520 3535 (pH 5-7)	3540 3541 3545 3546 3550	3520 (pH 5- 7)	3580[3]
Polychlorinated Biphenyls	3510 3520 3535 (pH 5-9)	3540 3541 3545 3546 3562	3520 (pH 5-9)	3580[3]
PCDDs and PCDFs	8280[10] 8290[10]	3545 3546 8280[10] 8290[10]	8280[10] 8290[10]	8280[10] 8290[10]
Polynuclear Aromatic Hydrocarbons	3510 3511 3520 (pH as received)	3540 3541 3545 3546 3550 3561	3520 (pH as received)	3580[3]
Volatile Organics	5021 5030 5031 5032	5021 5031 5032 5035	5021 5030 5031 5032	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Wipes (Chemical Agents only)		3572		

[1] The pH at which extraction should be performed is shown in parentheses.
[2] If attempts to break an emulsion are unsuccessful, these methods may be used.
[3] Method 3580 is only appropriate if the sample is soluble in the specified solvent.
[4] Method 8032 contains the extraction, cleanup, and determinative procedures for this analyte.

[5] Method 8318 contains the extraction, cleanup, and determinative procedures for these analytes.
[6] Method 8151 contains the extraction, cleanup, and determinative procedures for these analytes.
[7] Method 8330 contains the extraction, cleanup, and determinative procedures for these analytes.
[8] Method 8331 is for Tetrazene only, and contains the extraction, cleanup, and determinative procedures for this analyte.
[9] Method 8315 contains the extraction, cleanup, and determinative procedures for this analyte.
[10] Methods 8280 and 8290 contain the extraction, cleanup, and determinative procedures for these analytes.
[11] Method 5031 may be used when only aniline is to be determined.
[12] Method 5032 may be used for acrolein and acrylonitrile.
[13] Method 3542 is used for extraction of semivolatiles from stack samples collected using Method 0010.

TABLE 2-42

CLEANUP METHODS FOR ORGANIC ANALYTE EXTRACTS

Analyte Type	Method
Acid Extractable	3650, 3640
Base/Neutral Extractable	3650, 3640
Carbamates	8318[1]
Chlorinated Herbicides	8151[2]
Chlorinated Hydrocarbons	3620, 3640
Haloethers	3620, 3640
Nitroaromatics & Cyclic Ketones	3620, 3640
Nitrosamines	3610, 3620, 3640
Organochlorine Pesticides	3620, 3630, 3640 3660
Organophosphorus Pesticides	3620
Phenols	3630, 3640, 3650 8041[3]
Phthalate Esters	3610, 3611, 3620 3640
Polychlorinated Biphenyls	3620, 3630, 3640 3660, 3665
Polychlorinated Dibenzo-*p*-Dioxins and Polychlorinated Dibenzofurans	8280[4] 8290[4]
Polynuclear Aromatic Hydrocarbons	3610, 3611 3630, 3640, 3650

[1] Method 8318 contains the extraction, cleanup, and determinative procedures for these analytes.
[2] Method 8151 contains the extraction, cleanup, and determinative procedures for these analytes.
[3] Method 8041 includes a derivatization technique followed by GC/ECD analysis, if interferences are encountered using GC/FID.
[4] Methods 8280 and 8290 contain the extraction, cleanup, and determinative procedures for these analytes.

TABLE 2-43

DETERMINATIVE METHODS ORGANIC ANALYTES

Analyte Type	GC/MS Method	Specific GC Method[6]	HPLC Method
Acid Extractable	8270	8410[6]	
Acrolein, Acrylonitrile, Acetonitrile	8260, 8261	8015, 8031, 8033[1]	8315[2], 8316
Acrylamide	8260	8032	8316
Aniline and Selected Derivatives	8270	8131	
Aromatic Volatiles	8260, 8261	8021	
Base/Neutral Extractable	8270	8410[6]	8325[4]
Carbamates			8318, 8321
Chlorinated Herbicides	8270[3]	8151	8321
Chlorinated Hydrocarbons	8270	8121	
Diesel Range Organics (DRO)		8015, 8440[7]	
Dyes			8321
Explosives		8095	8330, 8331, 8332
Formaldehyde			8315
Gasoline Range Organics (GRO)		8015	
Haloethers	8270	8111, 8430	
Halogenated Volatiles	8260, 8261	8011, 8021	
Nitroaromatics and Cyclic Ketones	8270	8091	8330[5]
Nitrosoamines	8270	8070	
Non-halogenated Volatiles	8260	8015	8315
Organochlorine Pesticides	8270[3], 8276	8081, 8085[6]	
Organophosphorus Pesticides	8270[3]	8141, 8085[6]	8321
Phenols	8270	8041, 8410[6]	
Phthalate Esters	8270	8061, 8410[6]	
Polychlorinated Biphenyls	8270[3]	8082	
PCDDs and PCDFs	8280, 8290		
Polynuclear Aromatic Hydrocarbons	8270	8100, 8410[6]	8310
Volatile Organics	8260, 8261	8011, 8015, 8021, 8031, 8032, 8033	8315, 8316

[1] Of these analytes, Method 8033 is for acetonitrile only.
[2] Of these analytes, Method 8315 is for acrolein only.
[3] This method is an alternative confirmation method, not the method of choice.
[4] Benzidines and related compounds.
[5] Nitroaromatics (see "Explosives").
[6] Includes GC/ES methods, e.g., Methods 8085 and 8410.
[7] FT-IR determinative method only. Does not use GC.

TABLE 2-44

PREPARATION METHODS FOR INORGANIC ANALYSES [1]

Matrix	Method
Surface water	3005, 3010, 3015, 3020
Groundwater	3005, 3010, 3015, 3020
Extracts	3010, 3015, 3020
Aqueous samples containing suspended solids	3010, 3015, 3020
Oils	3031, 3040, 3051, 3052[2]
Oil sludges	3031, 3052[2]
Tars	3031, 3052[2]
Waxes	3031, 3040, 3052[2]
Paints	3031, 3052[2]
Paint sludges	3031, 3052[2]
Petroleum products	3031, 3040, 3052[2]
Sediments	3050, 3051, 3052[2], 3060[3], 3200[4]
Sludges	3050, 3051, 3052[2], 3060[3]
Soil samples	3050, 3051, 3052[2], 3060[3], 3200[4]
Ashes	3052[2]
Biological tissues	3052[2]

[1]It is the responsibility of the analyst to refer to each analytical method to determine applicability of the chosen method to a specific waste type and target analyte.

[2]For total decomposition analysis ONLY.

[3]For the analysis of samples for hexavalent chromium ONLY.

[4]For the analysis of samples for mercury or mercury species ONLY.

R000128

TABLE 2-45

USE OF LEACHING, EXTRACTION AND DIGESTION METHODS
FOR INORGANIC ANALYSIS (In order of increasing strength)

Method	Method Name	Reagents & Conditions	Use
1310	Extraction Procedure (EP) Toxicity Test Method and Structural Integrity Test	Dilute acetic acid	Simulate leaching that would result from codisposal of a solid waste and municipal waste in a sanitary landfill[1]
1311	Toxicity Characteristic Leaching Procedure	Extraction Fluid # 1 -- Dilute glacial acetic acid and NaOH, pH 4.93 ± 0.05 Extraction Fluid # 2 -- Dilute glacial acetic acid, pH 2.88 ± 0.05	Simulate leaching that would result from codisposal of a solid waste and municipal waste in a sanitary landfill[1]
1312	Synthetic Precipitation Leaching Procedure	Dilute H_2SO_4 and HNO_3 (synthetic acid rain)	Simulate acid rain leaching of a waste
1313	Liquid-Solid Partitioning as a Function of Extract pH Batch Extraction Procedure	Dilute HNO_3, KOH	Industrial wastes, soils, sludges, combustion residues, sediments, stabilized materials, construction materials, and mining wastes
1316	Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio in Solid Materials Using a Parallel Batch Procedure	None	Industrial wastes, soils, sludges, combustion residues, sediments, stabilized materials, construction materials, and mining wastes
1320	Multiple Extraction Procedure	Dilute H_2SO_4 and HNO_3 (synthetic acid rain)	Simulate long-term acid rain leaching of a waste
3005	Acid Digestion of Waters for Total Recoverable or Dissolved Metals Analysis by FLAA or ICP Spectroscopy	HNO_3, heat	Surface water and groundwater
3010	Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by FLAA or ICP Spectroscopy	HNO_3, HCl, heat	Aqueous samples and extracts
3015	Microwave Assisted Acid Digestion of Aqueous Samples and Extracts	HNO_3 or alternatively HNO_3 and HCl, (pressure, heat)	Aqueous samples and extracts

TABLE 2-45 (continued)

USE OF LEACHING, EXTRACTION AND DIGESTION METHODS
FOR INORGANIC ANALYSIS (In order of increasing strength)

Method	Method Name	Reagents & Conditions	Use
3020	Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by GFAA Spectroscopy	HNO_3, heat	Aqueous samples and extracts for GFAA work only
3031	Acid Digestion of Oils for Metals Analysis by Atomic Absorption or ICP Spectrometry	Potassium permanganate, H_2SO_4, HNO_3, HCl, heat	Oils, oily sludges, tars, waxes, paint, paint sludge, and other viscous petroleum products
3040	Dissolution Procedure for Oils, Greases, or Waxes	Solvent (e.g., xylene, kerosene, or MIBK)	Dissolution of oils, oily wastes, greases and waxes
3050	Acid Digestion of Sediments, Sludges, and Soils	HNO_3 and H_2O_2, heat (for GFAA or ICPMS) HNO_3, H_2O_2, and HCl, heat (for ICP-AES or FLAA)	Sediments, soils, and sludges
3051	A Microwave Assisted Acid Digestion of Sediments Sludges, Soils, and Oils	HNO_3, or alternatively HNO_3 and HCl, microwave assisted (pressure, heat)	Sludges, sediments, soils and oils
3052	Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices	HNO_3, HF, HCl (optional) H_2O_2 (optional), heat, pressure	Siliceous, organic and other complex matrices for total sample decomposition
3060A	Alkaline Digestion for Hexavalent Chromium	Na_2CO_3/NaOH, heat	Soils, sludges, sediments and some industrial wastes for the analysis of hexavalent chromium only.

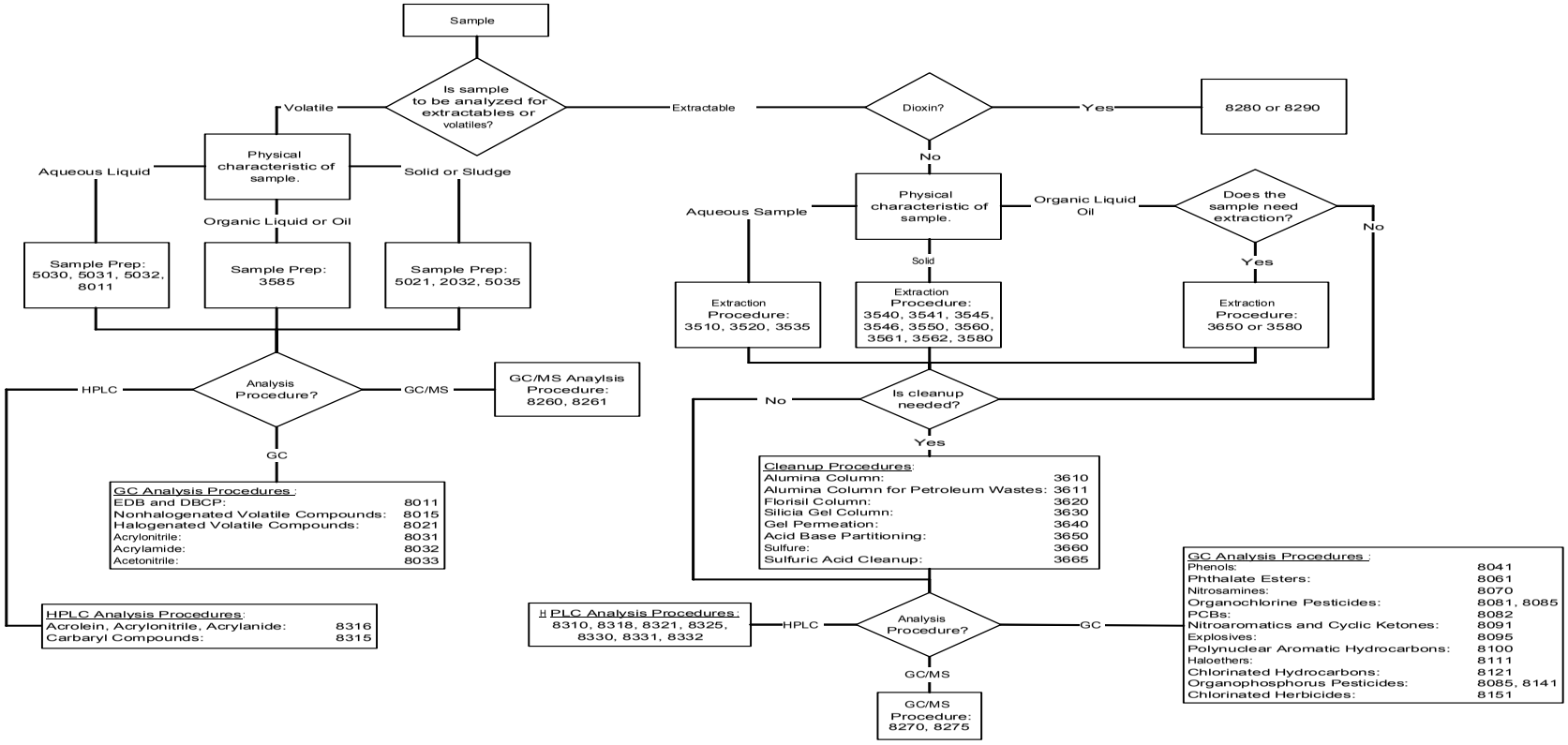
[1] As described in the respective background documents developed in support of the rulemakings, which added required use of these methods to the Toxicity Characteristic regulation (Method 1311 replaced Method 1310 for Toxicity Characteristic determinations on March 29, 1990, 55 FR 11862).

TABLE 2-46
SCREENING METHODS FOR ORGANIC ANALYTES

Analyte Type	Matrix			
	Aqueous	Solids	Sludges and Emulsions	Organic Liquids, Tars, Oils
Chlordane		4041		
2,4-Dichlorophenoxyacetic acid	4015	4015		
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)		4051 8510		
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)		8510		
Pentachlorophenol	4010	4010 8540	4010	
Petroleum Hydrocarbons		4030		
Poly-Chlorinated Biphenyls (PCBs)	4425 (coplanar)	4020 4425 (coplanar)		4020 (non-aqueous)
Polychlorinated Dibenzodioxins	4425	4425		
Polychlorinated Dibenzofurans	4425	4425		
Polynuclear Aromatic Hydrocarbons (PAHs)	4425	4035 4425		
Toxaphene		4040		
Triazine Pesticides	4670 (quantitative)			
1,1,1,-Trichloro-2,2-bis(chlorophenyl)ethane (DDT) and breakdown products		4042		
Trinitrotoluene (TNT)		4050 8515		

R000131

FIGURE 2-1
ORGANIC ANALYSIS OPTIONS FOR SOLID AND LIQUID MATRICES



For illustrative purposes only.

See the disclaimer and Sec. 2.1 for information on the flexibility inherent in SW-846 methods.

NOTE: Not all clean-up methods are applicable to all listed methods. Consult the individual methods for further information on what clean-up methods are applicable and appropriate.

FIGURE 2-2
SCHEMATIC OF SEQUENCE TO DETERMINE
IF A WASTE IS HAZARDOUS BY CHARACTERISTIC

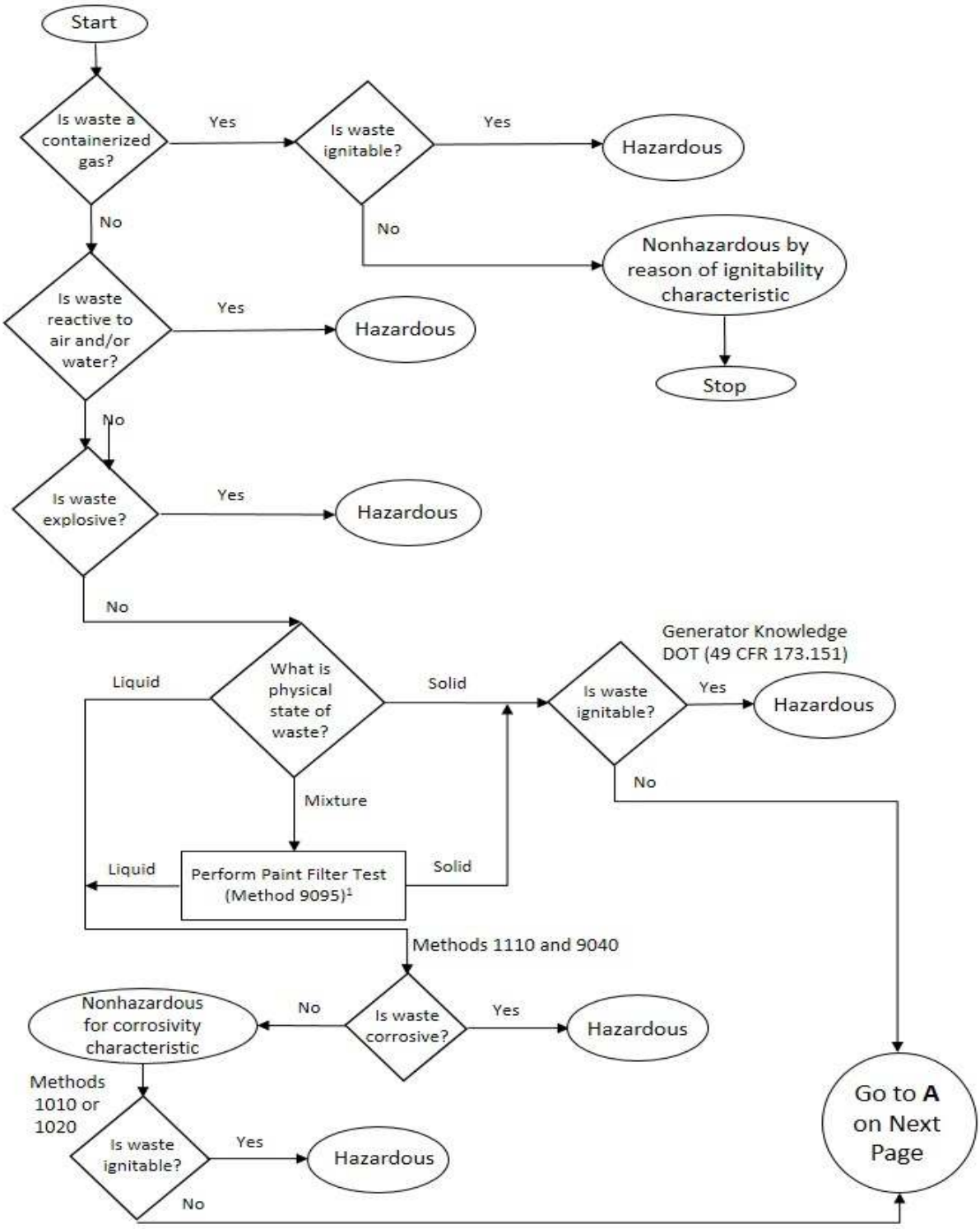
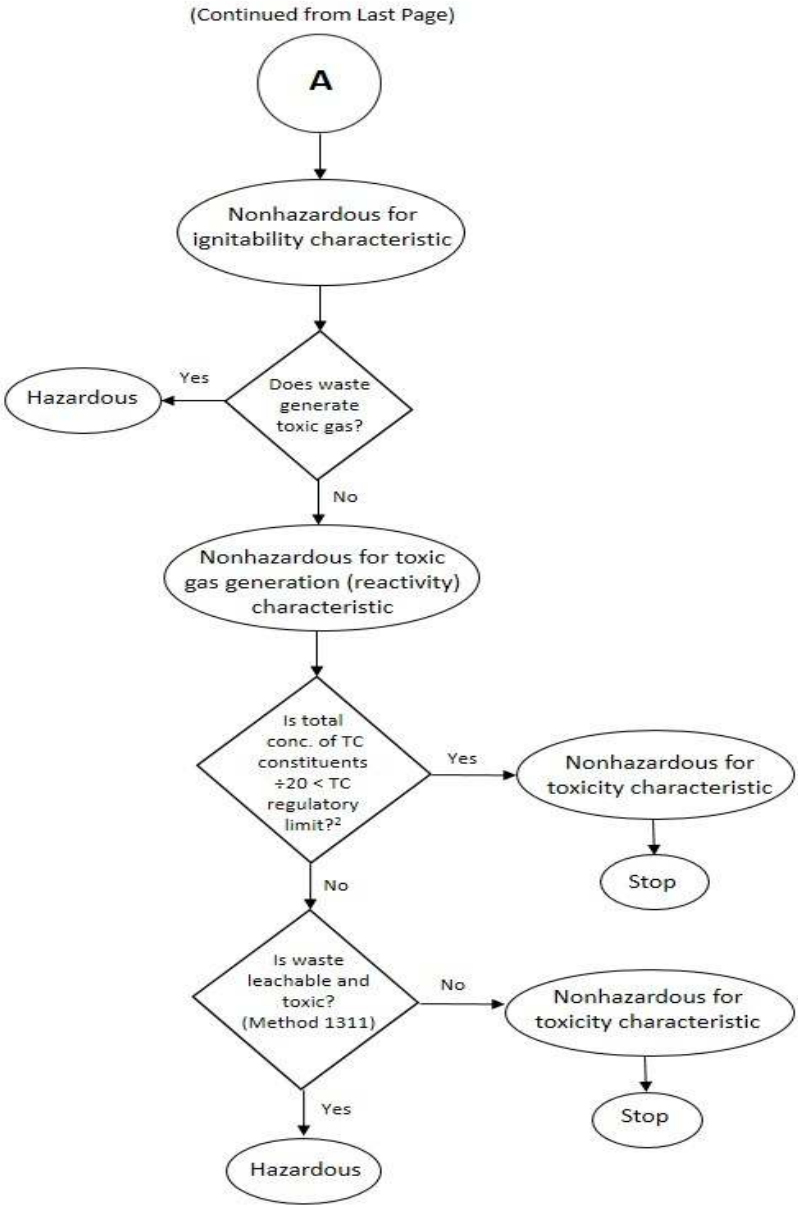


FIGURE 2-2 (continued)



1. Users can find information regarding the corrosivity characteristic for samples in a gel matrix at:http://yosemite.epa.gov/osw/rcra.nsf/0/7D573EA3E0F1576D8525670F006BEA5F/$file/11719.pdf.
2. Biphasic or multiphasic waste can present a unique challenge. More information can be found on this topic in the Federal Register (Dec 21, 1995 FR (page 66389). This can be found online at: http://nepis.epa.gov/Exe/ZyNET.exe/10001E3Y.txt?ZyActionD=ZyDocument&Client=EPA&Index=1995%20Thru%201999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A\ZYFILES\INDEX%20DATA\95THRU99\TXT\00000000\10001E3Y.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h|-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p|f&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=48

FIGURE 2-3A
RECOMMENDED SW-846 METHODS FOR ANALYSIS OF EP LEACHATES

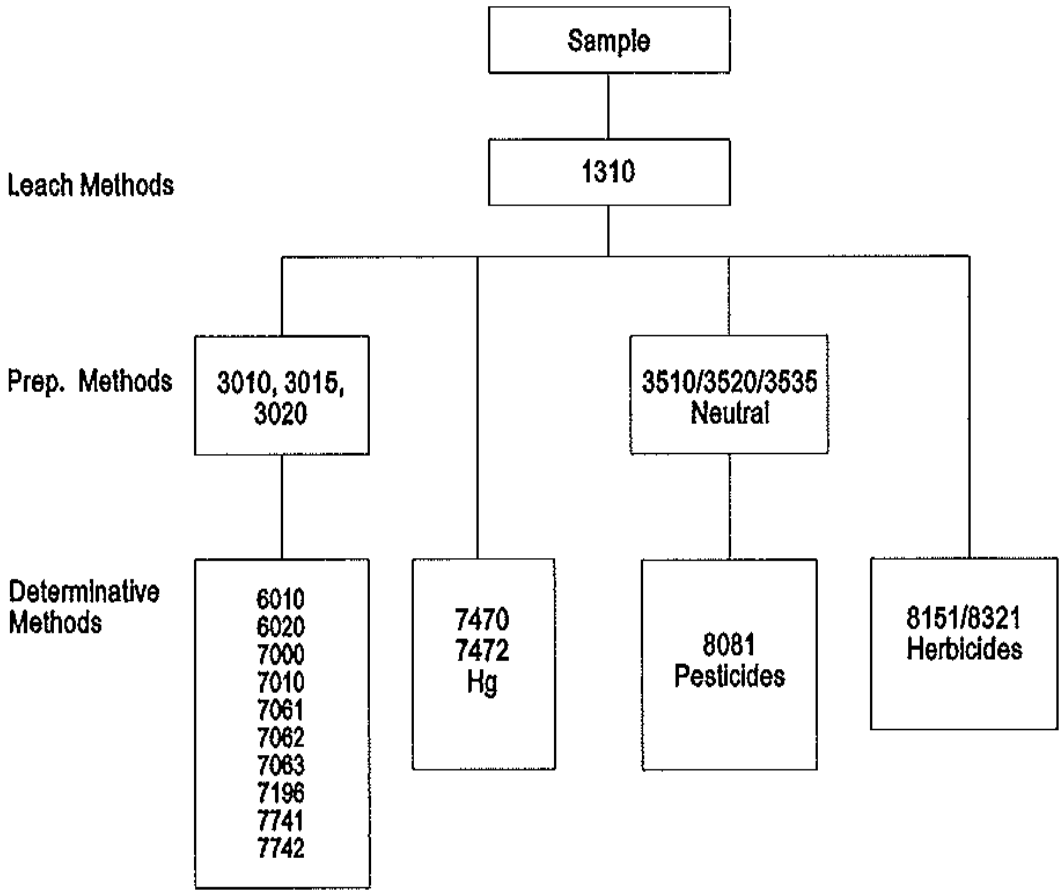


FIGURE 2-3B

RECOMMENDED SW-846 METHODS FOR ANALYSIS OF TCLP LEACHATES

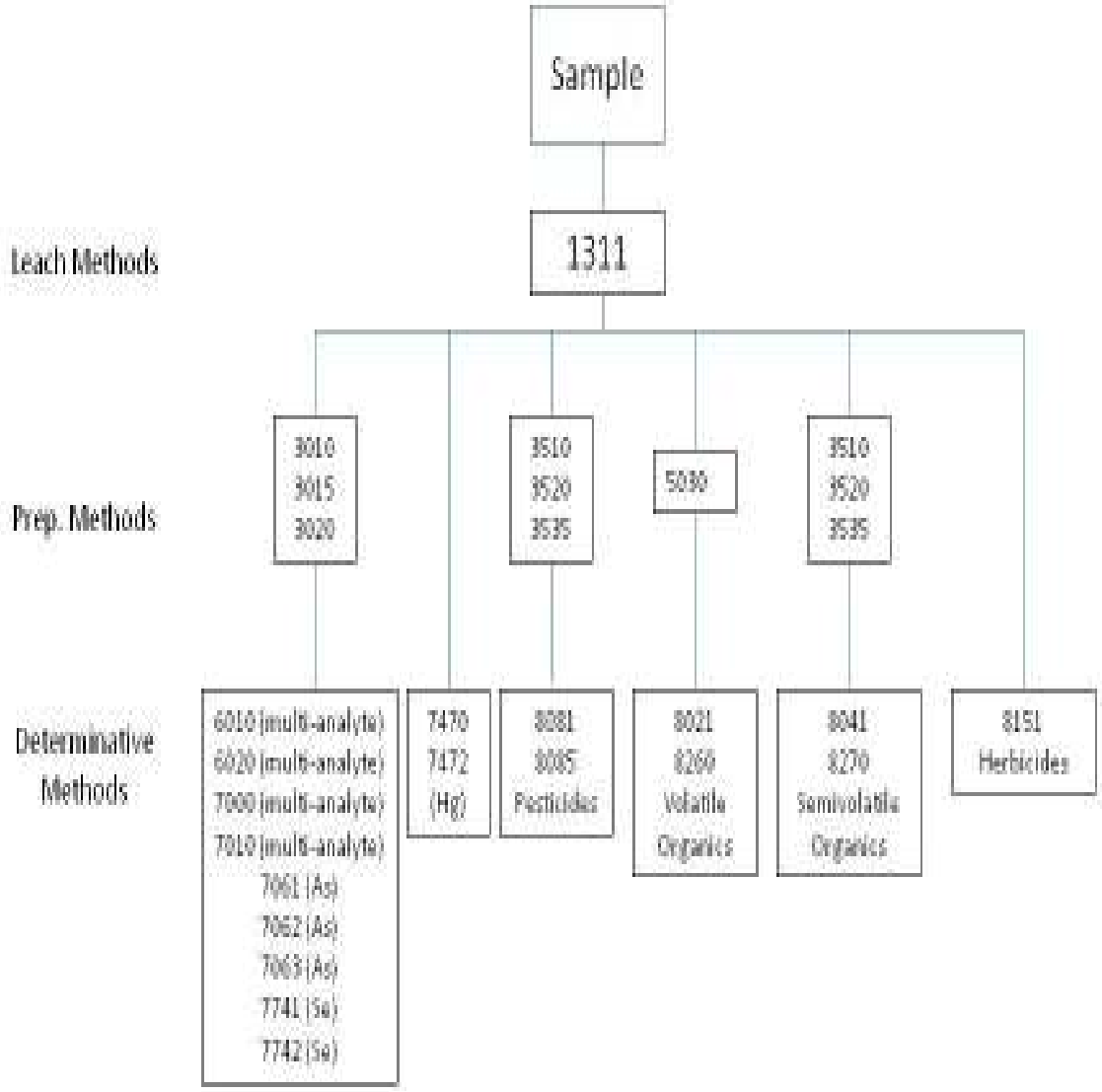
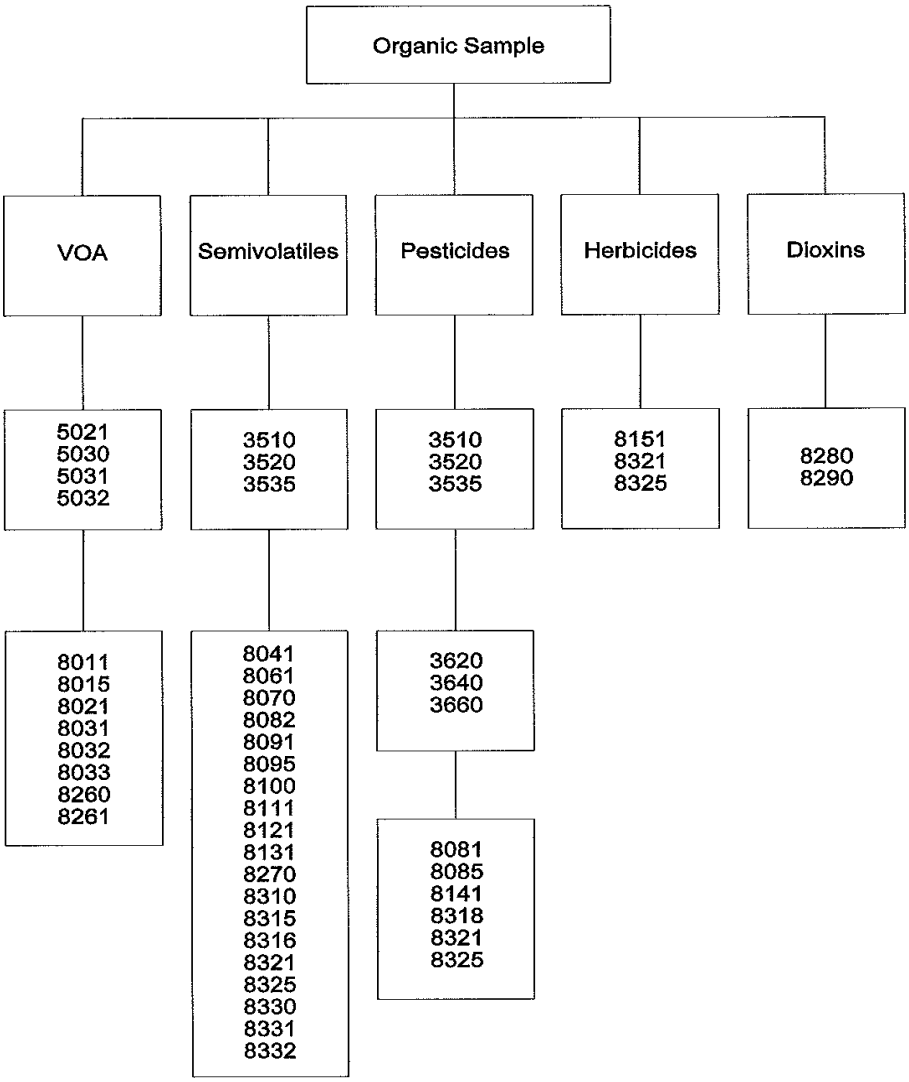


FIGURE 2-4A
GROUNDWATER ANALYSIS - ORGANIC ANALYTES



For illustrative purposes only.
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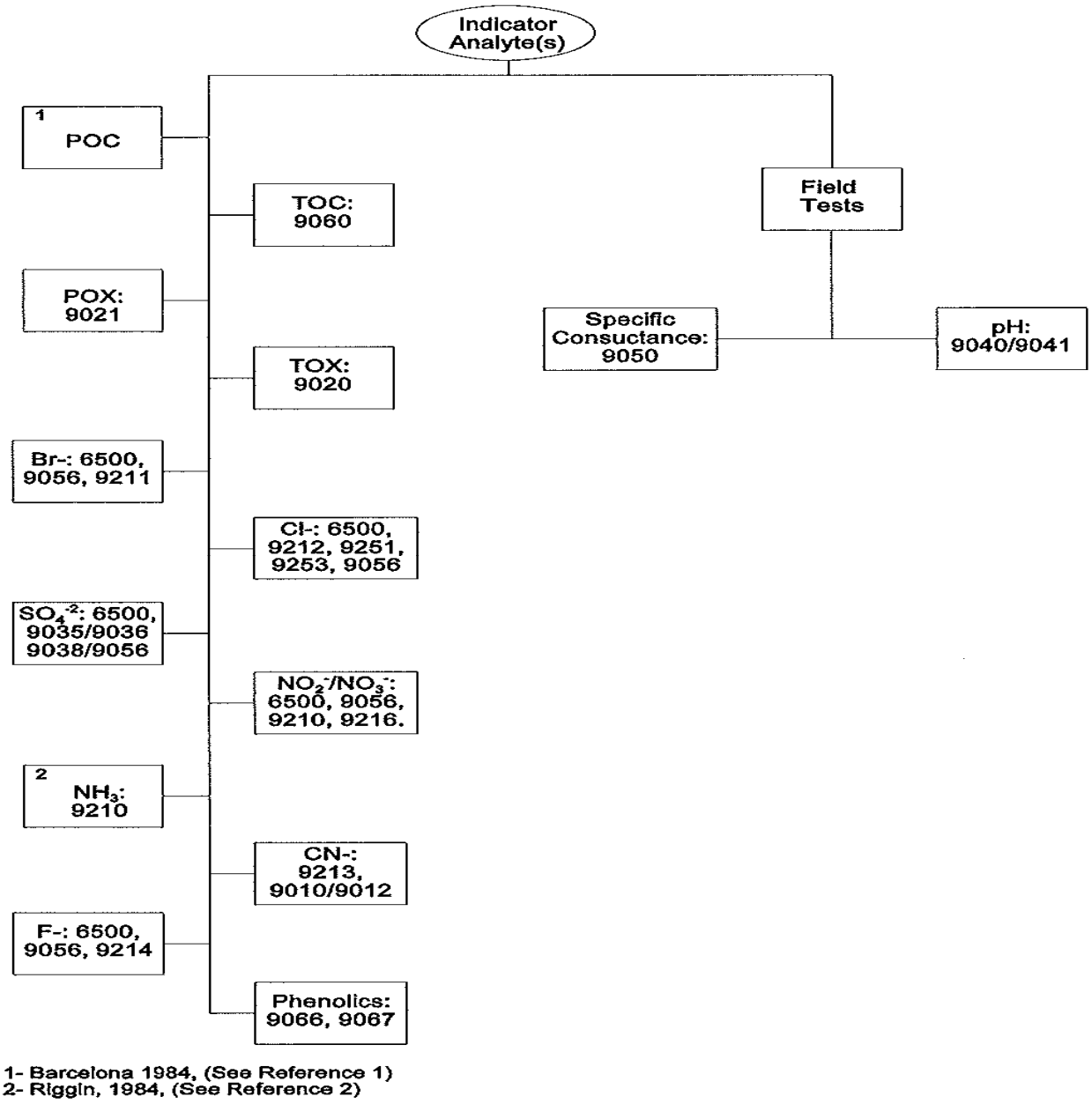
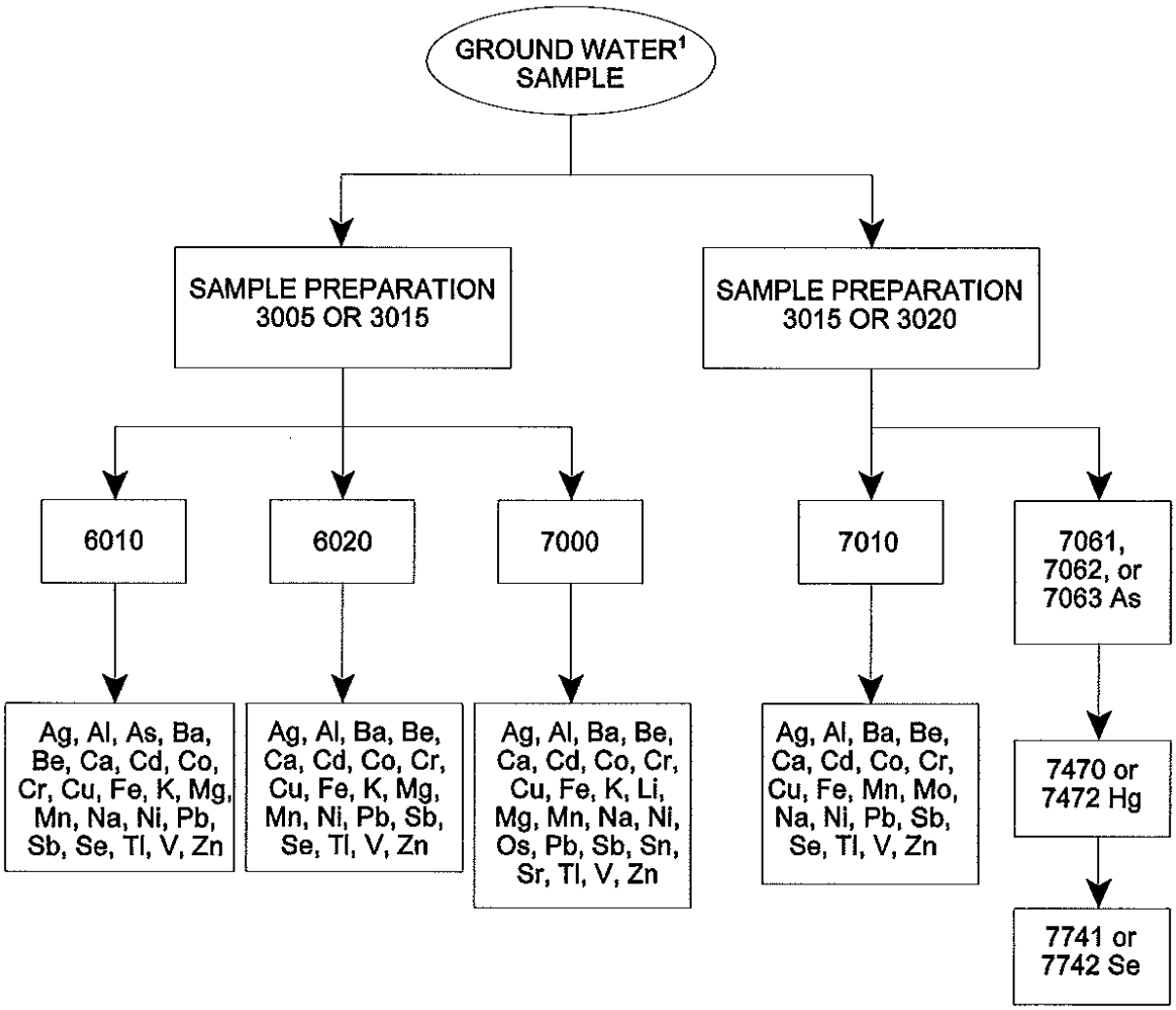
FIGURE 2-4B
GROUNDWATER ANALYSIS - INDICATOR ANALYTES



For illustrative purposes only. See the disclaimer and Sec. 2.1 regarding the flexibility inherent in SW-846 methods.

FIGURE 2-4C

GROUNDWATER ANALYSIS - INORGANIC ANALYTES



For illustrative purposes only. See the disclaimer and Sec. 2.1 regarding the flexibility inherent in SW-846 methods.

Appendix A: Summary of Updates/Changes in Chapter 2

1. Improved overall method formatting for consistency with new SW-846 methods style guidance. The entire document was reformatted in Microsoft Word.docx format from the original .WPD and .PDF files.
2. The revision number was changed to five and the published date to July 2014.
3. A Table of Contents was compiled and added to make finding information easier.
4. Minor editorial and grammatical changes (e.g., removing extra spaces between words, adding commas, etc.) were made throughout Sections 1.0 to 2.7. The disclaimer statement in Section 1.0 was numbered to keep the format consistent, as it started at Section 2.0 originally.
5. Graphics in the Figures Section were modified from Corel Drawing Objects V.10 to .jpg graphical images where needed to remove artifacts from the conversion process. The text titles of each figure was centered and formatted.
6. This appendix was added to document non-significant changes made during the editorial process.
7. Bis(2-chloroisopropyl) ether was corrected to Bis(2-chloro-1-methylethyl) ether in Tables 2-1, 2-4, 2-15, 2-22, and 2-34.
8. Revised Table 2-40A to reflect current sample preservation guidance for styrene and vinyl chloride in aqueous samples (i.e., deletion of previously recommended practice of collecting a second set of samples without acid preservatives and analyze immediately, if styrene and vinyl chloride are analytes of interest).
9. Revised Table 2-41.
10. Revised Table 2-45 to include Methods 1313 and 1316.
11. Added Table 2-46.
12. Added Figure(s) for new leaching procedure(s).
13. Revised Table 2-40B to include Mercury Speciation hold times in addition to totals.
14. All other tables were updated with the target compound list in the current published methods.

DOCUMENT 6

METHOD 1315[1]

MASS TRANSFER RATES OF CONSTITUENTS IN MONOLITHIC OR COMPACTED GRANULAR MATERIALS USING A SEMI-DYNAMIC TANK LEACHING PROCEDURE

SW-846 is not intended to be an analytical training manual. Therefore, method procedures are written based on the assumption that they will be performed by analysts who are formally trained in at least the basic principles of chemical analysis and in the use of the subject technology.

In addition, SW-846 methods, with the exception of required methods used for the analysis of method-defined parameters, are intended to be guidance methods that contain general information on how to perform an analytical procedure or technique, which a laboratory can use as a basic starting point for generating its own detailed standard operating procedure (SOP), either for its own general use or for a specific project application. Performance data included in this method are for guidance purposes only and must not be used as absolute quality control (QC) acceptance criteria for purposes of laboratory QC or accreditation.

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[1] This method has been derived from the MT001 and MT002 procedures (Ref. 12). The method is analogous to the monolithic mass transfer methods NEN 7345 (Ref. 9) developed under Dutch regulation and CEN/TS 15863 (Ref. 13) developed for the Comité Européen de Normalisation (CEN).

1.0 SCOPE AND APPLICATION

1.1 This method is designed to provide the mass transfer rates (release rates) of inorganic analytes contained in a monolithic or compacted granular material, under diffusion-controlled release conditions, as a function of leaching time. Observed diffusivity and tortuosity may be estimated through analysis of the resulting leaching test data.

1.2 This method is suitable to a wide range of solid materials which may be in monolithic form (e.g., cements, solidified wastes) or may be compacted granular materials (e.g., soils, sediments and stacked granular wastes) which behave as a monolith, in that the predominant water flow is around the material and release is controlled by diffusion to the boundary. The method is not required by federal regulations to determine whether waste passes or fails the toxicity characteristic as defined at 40 CFR 261.24.

1.3 This leaching characterization method provides intrinsic material parameters for release of inorganic species under mass transfer controlled leaching conditions. This test method is intended as a means for obtaining a series of eluents which may be used to estimate the diffusivity of constituents and physical retention parameters of the solid material under specified laboratory conditions.

1.4 This method is not applicable to characterize the release of organic analytes with the exception of general dissolved organic carbon.

1.5 This method is a characterization method and does not provide a solution considered to be representative of eluate under field conditions. This method is similar in structure and use to predecessor methods such as MT001.1 (see Ref. 12), NEN 7345 (see Ref. 9), ANSI/ANS 16.1 (see Ref. 15), and ASTM C1308 (see Ref. 11). However, this method differs from previous methods in that: 1) leaching intervals are modified to improve QC; 2) sample preparation accounts for mass transfer from compacted granular samples; and, 3) mass transfer may be interpreted by more complex release models that account for physical retention of the porous medium and chemical retention at the pore wall through geochemical speciation modeling.

1.6 The geometry of monolithic samples may be rectangular (e.g., bricks or tiles), cubes, wafers or cylinders. Samples may also have a variety of faces exposed to eluent, forming anything from 1-dimensional (1-D) through 3-dimensional (3-D) mass transfer cases. In all cases, a minimum sample size of 5 cm in the direction of mass transfer must be employed and the liquid-surface-area ratio (L/A) must be maintained at 9 ± 1 mL/cm^2.

Monolithic samples should be suspended or held in the leaching fluid such that at least 98% of the entire sample surface area is exposed to eluent and the bulk of the eluent (e.g., a minimum of 2 cm between any exposed surface and the vessel wall) is in contact with the exposed sample surface. Figure 1 provides examples of appropriate sample holders and leaching configurations for 3-D and 1-D cases.

1.7 Compacted granular materials are granular solids, screened to pass through a 2-mm sieve, compacted following a modified Proctor compaction effort (see Ref. 10). The sample geometry

must be open-faced cylinders due to limitations of mechanical packing. However, the diameter and height of the sample holder may be altered to correspond appropriately with the diameter and volume of the leaching vessel. In all cases, the sample size of at least 5 cm in the direction of mass transfer must be employed and the L/A must be maintained at 9 ± 1 mL/cm^2.

The sample should be positioned at the bottom of the leaching vessel with a minimum of 5 cm of distance between the solid-liquid interface and the top of the vessel. The distance between the non-leaching faces (i.e., outside of the mold surfaces) and the leaching vessel wall should be minimized to < 0.5 cm, such that the majority of the eluent volume is on top of the sample. Figure 2 shows an example of a holder and leaching configuration for a compacted granular sample.

1.8 The solvent system used in this characterization method is reagent water. Other systems (e.g., groundwater, seawater, and simulated liquids) may be used to infer material performance under specific environmental conditions. However, interaction between the eluent and the solid matrix may result in precipitation and pore blocking, which may interfere with characterization or complicate data interpretation.

1.9 Prior to employing this method, analysts are advised to consult the base method for each type of procedure that may be employed in the overall analysis (e.g., Methods 9040, 9045 and 9050, and the determinative methods for the target analytes) for additional information on QC procedures, development of QC acceptance criteria, calculations, and general guidance. Analysts also should consult the disclaimer statement at the front of the manual and the information in Chapter Two for: 1) guidance on the intended flexibility in the choice of methods, apparatus, materials, reagents, and supplies; and, 2) the responsibilities of the analyst for demonstrating that the techniques employed are appropriate for the analytes of interest, in the matrix of interest, and at the levels of concern.

In addition, analysts and data users are advised that, except where explicitly specified in a regulation, the use of SW-846 methods is *not* mandatory in response to federal testing requirements. The information contained in this method is provided by the Environmental Protection Agency (EPA or the Agency) as guidance to be used by the analyst and the regulated community in making judgments necessary to generate results that meet the data quality objectives for the intended application.

1.10 This method is restricted to use by, or under supervision of, properly experienced and trained personnel. Each analyst must demonstrate the ability to generate acceptable results with this method.

2.0 SUMMARY OF METHOD

This method comprises leaching of continuously water-saturated monolithic or compacted granular material in an eluent-filled tank with periodic renewal of the leaching solution. The vessel and sample dimensions are chosen such that the sample is fully immersed in the leaching solution. Monolithic samples may be cylinders or parallelepipeds, while granular materials are compacted into cylindrical molds at optimum moisture content using modified Proctor compaction methods (see Ref. 10). In either case, the exposure of a regular geometric area to the eluent is recommended. Samples are contacted with reagent water at a specified L/A. The leaching solution is exchanged with fresh reagent water at nine pre-determined intervals (see NOTE below). The sample is freely drained and the mass is recorded to monitor the amount of eluent absorbed into the solid matrix at the end of each leaching interval. The eluate pH and specific conductance is measured for each time interval and

analytical samples are collected and preserved accordingly based on the determinative methods to be performed. Eluate concentrations are plotted as a function of time, as a mean interval flux, and as a cumulative release as a function of time. These data are used to estimate mass transfer parameters (i.e., observed diffusivity) for each constituent of potential concern (COPC). A flowchart for performing this method is shown in Figure 3.

NOTE: The leaching schedule may be extended for additional exchanges with individual intervals of 14 days to provide more information about longer-term release.

3.0 DEFINITIONS

3.1 Constituent of potential concern (COPC) – A chemical species of interest, which may or may not be regulated, but may be characteristic of release-controlling properties of the sample geochemistry.

3.2 Release – The dissolution or partitioning of a COPC from the solid phase to the aqueous phase during laboratory testing (or under field conditions). In this method, mass release is expressed in units of mg COPC/kg dry solid material.

3.3 Liquid-to-surface area ratio (L/A) – The ratio representing the total liquid volume used in the leaching interval to the external geometric surface area of the solid material. L/A is typically expressed in units of mL of eluent/cm^2 of exposed surface area.

3.4 Observed mass diffusivity – The apparent, macroscopic rate of release due to mass transfer from a solid into a liquid as measured using a leaching test under conditions where mass transfer controls release. The observed diffusivity accounts for all physical and chemical retention factors influencing mass transfer and is typically expressed in units of cm^2/s.

3.5 Effective mass diffusivity – The intrinsic rate of mass transfer in a porous medium accounting for physical retention. The effective mass diffusivity is typically expressed in units of cm^2/s.

3.6 Physical retention factor – A mass transfer rate term that describes the retardation of diffusion due to intrinsic physical properties of a porous medium (e.g., effective porosity, tortuosity).

3.7 Chemical retention factor – A mass transfer rate term that describes the chemical processes (e.g., dissolution/precipitation, adsorption/desorption, complexation) occurring at the pore water interface with the solid mineral phases within the porous structure of the solid material.

3.8 Eluent – The solution used to contact the solid material in a leaching test. The eluent is usually free of COPCs but may contain other species used to control the test conditions of the extraction.

3.9 Eluate – The solution collected as an extract from a leaching test that contains the eluent plus constituents leached from the solid phase.

3.10 Refer to Chapter One and Chapter Three, and the manufacturer's instructions for definitions that may be relevant to this procedure.

4.0 INTERFERENCES

4.1 Solvents, reagents, glassware, and other sample processing hardware may yield artifacts and/or interferences to sample analysis. All of these materials must be demonstrated to be free from interferences under the conditions of the analysis by analyzing method blanks. Specific selection of reagents and purification of solvents by distillation in all-glass systems may be necessary. Refer to each method to be used for specific guidance on QC procedures and to Chapters Three and Four for general guidance on glassware cleaning. Also refer to Methods 9040, 9045, and 9050 and the determinative methods to be used for information regarding potential interferences.

4.2 The reaction of atmospheric gases can influence the measured concentrations of constituents in eluates. For example, reaction of carbon dioxide with eluents from highly alkaline or strongly reducing materials will result in neutralization of eluate pH and precipitation of carbonates. Leaching vessels, especially those used when testing highly alkaline materials, should be designed to be airtight in order to minimize the reaction of samples with atmospheric gases.

4.3 Use of certain solvent systems may lead to precipitation at the material surface boundary, which may reduce mass transport rates. For example, exposure of cement-based materials to seawater leads to sealing of the porous block (see Ref. 8).

5.0 SAFETY

5.1 This method does not address all safety issues associated with its use. The laboratory is responsible for maintaining a safe work environment and a current awareness file of Occupational Safety and Health Administration (OSHA) regulations regarding the safe handling of the chemicals specified in this method. A reference file of safety data sheets (SDSs) should be available to all personnel involved in these analyses.

5.2 During preparation and processing of extracts and/or eluents/eluates, some waste materials may generate heat or evolve potentially harmful gases when contacted with acids and bases. Adequate prior knowledge of the material being tested should be used to establish appropriate personal protection and workspace ventilation.

6.0 EQUIPMENT AND SUPPLIES

The mention of trade names or commercial products in this manual is for illustrative purposes only, and does not constitute an EPA endorsement or exclusive recommendation for use. The products and instrument settings cited in SW-846 methods represent those products and settings used during the method development or subsequently evaluated by the Agency. Glassware, reagents, supplies, equipment, and settings other than those listed in this manual may be employed provided that method performance appropriate for the intended application has been demonstrated and documented.

This section does not list common laboratory glassware (e.g., beakers and flasks) that might be used.

6.1 Sample holder

6.1.1 Monolithic samples

6.1.1.1 A mesh or structured holder constructed of an inert material such as high density polyethylene (HDPE) or other material resistant to high and low pH is recommended.

6.1.1.2 The holder should be designed such that at least 98% of the external surface area of the sample may be exposed to eluent.

6.1.1.3 The holder should be designed to match the geometry of the mass transfer such that the bulk of the eluent may be in contact with the sample and the exposed surfaces of the sample centered within the leaching fluid.

NOTE: In the case of 1-D mass transfer from the axial face of a cylindrical sample, the outer diameter (OD) of the holder should be matched as closely as possible to the inner diameter (ID) of the leaching vessel so that the majority of the eluent is above the sample (e.g., in contact with the exposed material surface), while allowing for easy placement and removal of the holder in the leaching vessel (see Figure 1).

6.1.2 Compacted granular samples

6.1.2.1 A cylindrical mold constructed of an inert material such as HDPE or other material resistant to high and low pH is recommended.

6.1.2.2 The holder should be capable of withstanding the compaction force required to prepare the sample (see Sec. 11.3) without breaking or distorting.

NOTE: The outer diameter of the holder for a compacted granular sample should be matched as closely as possible to the inner diameter of the leaching vessel so that the majority of the eluent is above the sample (e.g., in contact with the exposed material surface) while allowing for easy placement and removal of the holder in the leaching vessel.

6.2 Leaching vessel

6.2.1 A straight-sided container constructed of a material resistant to high and low pH is recommended. Jars or buckets composed of HDPE, polycarbonate (PC), polypropylene (PP), or polyvinyl chloride (PVC) are recommended when evaluating the mobility of inorganic species.

6.2.2 The leaching vessel should have an airtight seal that can sustain long periods of standing without gas exchange with the atmosphere.

6.2.3 The container must be of sufficient volume to accommodate both the solid sample and an eluent volume based on an L/A of 9 ± 1 mL /cm^2 sample surface area. Ideally, the vessel should be sized such that the headspace is minimized within the tolerance of the L/A.

6.3 Leaching setup

Example photos of three possible leaching equipment arrangements for monolithic and compacted granular samples are shown in Figures 1 and 2, respectively. The equipment used in the each of these cases is described below.

6.3.1 Figure 1a shows a monolithic sample 3-D configuration with the following accessories:

- Sample holder – PP sink washers, 43-mm OD, 37-mm ID, 6-mm high, with four holes drilled at the quadrants to accept 2-mm OD nylon string knotted at the top
- Sample stand – PVC pipe, 47-mm OD, 51-mm high, cut to have four legs approximately 8-mm wide and 30-mm high
- Leaching Vessel – PP bucket, 140-mm ID at top, 120-mm ID at bottom, 200-mm high (Berry Plastics #T51386CP3, VWR Scientific, or equivalent)

6.3.2 Figure 1b shows a monolithic sample 1-D configuration with the following accessories:

- Sample holder – Polyethylene (PE) mold, 54-mm OD, 100-mm high (MA Industries, Peach Tree City, GA, or equivalent), with the test sample cured in mold and cut to 51-mm high
- Leaching vessel – 250-mL PC jar, 60-mm ID, 100-mm high (Nalgene #2116-0250, Fisher Scientific, or equivalent)

6.3.3 Figure 2 shows a compacted granular sample 1-D Configuration with the following accessories:

- Sample holder – PE mold, 100-mm OD, 200-mm high, (MA Industries, Peach Tree City, GA, or equivalent) cut to 63-mm high with three tabs drilled for 0.7-mm fishing line knotted at the top
- Leaching vessel – 1000-mL PC jar, 110-mm ID at top, 130-mm high (Nalgene #2116-1000, Fisher Scientific, or equivalent)
- Glass beads, borosilicate – 2-mm diameter

6.4 Filtration apparatus – Pressure or vacuum filtration apparatus composed of appropriate materials to maximize the collection of extracts and minimize the loss of COPCs (Nalgene #300-4000 or equivalent)

6.5 Filtration membranes – Composed of hydrophilic polypropylene or equivalent material with an effective pore size of 0.45 µm (e.g., Andwin Scientific GH Polypro 28143-288 or equivalent)

6.6 pH meter – Laboratory model with the capability for temperature compensation (e.g., Accumet 20, Fisher Scientific or equivalent) and a minimum resolution of 0.1 pH units

6.7 pH combination electrode – Composed of chemically resistant materials

6.8 Conductivity meter – Laboratory model (e.g., Accumet 20, Fisher Scientific or equivalent), with a minimum resolution of 5% of the measured value

6.9 Conductivity electrodes – Composed of chemically resistant materials

6.10 Proctor compactor (for compacted granular samples only) – Equipped with a slide hammer capable of dropping a 4.5-kg weight over a 0.46-m interval (see Ref. 10 for further details)

7.0 REAGENTS AND STANDARDS

7.1 Reagent-grade chemicals, at a minimum, should be used in all tests. Unless otherwise indicated, all reagents should conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society (ACS), where such specifications are available. Other grades may be used, provided the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination. Inorganic reagents and extracts should be stored in plastic to prevent interaction of constituents from glass containers.

7.2 Reagent water – Reagent water must be interference-free. All references to water in this method refer to reagent water unless otherwise specified.

7.3 Other reagents may be used in place of reagent water on a case-specific basis.

8.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE

8.1 See Chapter Three, "Inorganic Analytes," and Chapter 4, "Organic Analytes," for sample collection and preservation instructions.

8.2 Both plastic and glass containers are suitable for the collection of samples. All sample containers must be prewashed with a metal-free detergent and triple-rinsed with nitric acid and reagent water, depending on the history of the container. For further information, see Chapter Three.

9.0 QUALITY CONTROL

9.1 Refer to Chapter One for guidance on quality assurance (QA) and quality control (QC) protocols. When inconsistencies exist between QC guidelines, method-specific QC criteria take precedence over both technique-specific criteria and Chapter One criteria, and technique-specific QC criteria take precedence over Chapter One criteria. Any effort involving the collection of analytical data should include development of a structured and systematic planning document, such as a quality assurance project plan (QAPP) or a sampling and analysis plan (SAP), which translates project objectives and specifications into directions for those who will implement the project and assess the results.

Each laboratory should maintain a formal QA program. The laboratory should also maintain records to document the quality of the data generated. Development of in-house QC limits for each method is encouraged. Use of instrument-specific QC limits is encouraged, provided such limits will generate data appropriate for use in the intended application. All data sheets and QC data should be maintained for reference or inspection.

9.2 In order to demonstrate the purity of reagents and sample contact surfaces, method blanks should be tested for each leaching interval. Refer to Chapter One for specific QC procedures.

9.3 The analysis of extracts should follow appropriate QC procedures, as specified in the determinative methods for the COPCs. Refer to Chapter One for specific QC procedures.

9.4 Initial demonstration of proficiency (IDP)

Leachate methods are not amenable to typical IDPs when reference materials with known values are not available. However, prior to using this method an analyst should have documented proficiency in the skills required for successful implementation of the method. For example, skill should be demonstrated in the use of an analytical balance, the determination of pH using Methods 9040 and 9045 and the determination of conductance using Method 9050.

10.0 CALIBRATION AND STANDARDIZATION

10.1 The balance should be calibrated and certified, at a minimum, annually or in accordance with laboratory policy.

10.2 Prior to measurement of eluate pH, the pH meter should be calibrated using a minimum of two standards that bracket the range of pH measurements. Refer to Methods 9040 and 9045 for additional guidance.

10.3 Prior to measurement of eluate conductivity, the meter should be calibrated using at least one standard at a value greater than the range of conductivity measurements. Refer to Method 9050 for additional guidance.

11.0 PROCEDURE

A flowchart of this method is presented in Figure 3. Microsoft Excel® data templates are available to aid in collecting and archiving of laboratory and analytical data.[2]

11.1 Preparatory Procedures – Determination of solids and moisture content

The moisture and solids content of the sample material are used to relate leaching results to dry-material masses. When preparing compacted granular samples for testing, the moisture content or solid content is used to determine the optimum moisture content following the modified Proctor test. This method calculates moisture content on the basis of the "wet" or "as-tested" sample.

WARNING: The drying oven should be contained in a hood or otherwise properly ventilated. Significant laboratory contamination or inhalation hazards may result when drying heavily contaminated samples. Consult the laboratory safety officer for proper handling procedures prior to drying samples that may contain volatile, hazardous, flammable, or explosive materials.

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[2] These Excel® templates form the basis for uploading method data into the data management program, LeachXS Lite™. Both the data templates and LeachXS Lite™ are available at http://vanderbilt.edu/leaching.

11.1.1 Place 5 - 10 g of solid sample material into a tared dish or crucible. Dry the sample to a constant mass at 105 ± 2 °C. Check for constant mass by returning the dish to the drying oven for 24 hours, cooling to room temperature in a desiccator and re-weighing. The two mass readings should agree within the larger of 0.2% or 0.02 g.

NOTE: The oven-dried sample is not used for the extraction and should be properly disposed of once the dry mass is determined.

11.1.2 Calculate and report the solids content as follows:

$$SC = \frac{M_{dry}}{M_{test}}$$

Where: SC = solids content of "as-tested" material (g-dry/g)
M_{dry} = mass of dry material specified in the method (g-dry)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)

11.1.3 Calculate and report the moisture content (wet basis) as follows:

$$MC_{wet} = \frac{M_{test} - M_{dry}}{M_{test}}$$

Where: MC_{wet} = moisture content on a wet basis (g_{H_2O}/g)
M_{dry} = mass of dry material specified in the method (g-dry)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)

11.2 Preparation of monolithic samples

11.2.1 If the material to be tested is granular, disregard this section and proceed to Sec. 11.3.

11.2.2 A representative sample of monolithic material should be obtained by molding material components in place (e.g., cementitious media) or by coring or cutting a sample from a larger existing specimen.

11.2.3 The geometry of monolithic samples may be rectangular (e.g., bricks or tiles), cubes, wafers, or cylinders. Samples may also have a variety of faces exposed to eluent forming 1-, 2-, or 3-D mass transfer cases. Examples of monolithic sample leaching setups are shown in Figure 1.

11.2.4 A minimum sample size of 5 cm in the direction of mass transfer must be employed and the L/A must be maintained at 9 ± 1 mL/cm^2.

NOTE: Since the sample holder and leaching vessel must correspond to the specifications in Sec. 6.1, it is often easier to modify the sample size and geometry rather than the holder and vessel dimensions.

11.2.5 Proceed to Sec. 11.4.

11.3 Preparation of compacted granular samples

Compacted granular materials, in most cases, must be open-faced cylinders due to the limitations of mechanical packing. However, the diameter and height of the sample holder may be altered to work appropriately with the diameter and volume of the leaching vessel. In all cases, a minimum sample size of 5 cm in the direction of mass transfer must be employed and the L/A must be maintained at 9 ± 1 mL/cm^2.

Granular samples are compacted into the sample holder using a variation on the modified Proctor compaction (see Ref. 10) to include the use of 6-cm high-test molds. Shorter or taller molds (or packing depths) may be used as long as the compaction effort of 56,000 ft-lb$_f$/ft^3 is achievable. The number of packing layers should be maintained at the five layers specified in Ref. 10. However, the number of blows per layer in a 4-in diameter mold may be changed according to the follow formula:

$$\frac{56{,}000\,\text{ft - lb}_\text{f}}{\text{ft}^3}\left|\frac{\text{blow}}{1.5\,\text{ft}\times 10\,\text{lb}_\text{f}}\right|\frac{\pi\left(0.\overline{3}/2\ \text{ft}\right)^2\times h\,\text{ft}}{5\,\text{layer}}=\frac{65.2\times h\,\text{blow}}{\text{layer}}$$

Where: *h* is the measured height of the sample mold (ft).

Thus, for the mold height of 4.584 in (0.382 ft) specified in the ASTM procedure, 25 blows per each of 5 layers are required. When a 6-cm (0.196 ft) mold height is used (as suggested in this method), 13 blows per each of 5 layers are required to obtain the same compaction effort.

The granular sample should be compacted at a moisture content corresponding to 90% of the modified Proctor optimum packing density in order to provide a uniform approach to obtaining a sample density that approximates field conditions. Optimum moisture content refers to the amount of moisture or fractional mass of water (g$_{H_2O}$/g material) in the granular sample that is present at the optimum packing density (g-dry material/cm^3). Optimum packing density is defined in Ref. 10. The optimum moisture content of the test material is determined from a pre-test that measures the packing density of granular materials compacted at different levels of moisture content.

11.3.1 Pre-test to determine optimum moisture content

The pre-test is conducted as a series of five batch-wise packing trials with consecutive increases in moisture content until the maximum packing density has been surpassed. The optimum moisture content is determined as the maximum of a third-order polynomial fit through the graph of dry-packing density as a function of moisture content (wet basis).

11.3.1.1 Place 1500 g of "as received" material into a pail or bowl and mix well by hand to homogenize. As an alternative to hand mixing, a mechanical paddle mixer may be used.

NOTE: The pre-test may be conducted from a bulk supply of solid material (e.g., 10 kg total for five batches) as long as the starting mass for each trial is recorded and incremental water additions are used.

11.3.1.2 Mix a known amount of tap water with the bulk material in the pail or bowl until homogenized based on visual inspection. For the first point in the pre-test, no water needs to be added.

NOTE: The amount of water added should be enough to increase the moisture content in approximately 3 - 5% increments. Smaller additions may be needed in order to provide finer resolution of the packing density as a function of the moisture content curve.

11.3.1.3 Calculate the new moisture content (wet basis) for the trial as follows:

$$MC^{i}_{(wet)} = \frac{M_{test} \times MC_{wet} + W_{added}}{M_{test} + W_{added}}$$

Where: $MC^{i}_{(wet)}$ = moisture content on a wet basis of the pre-test trial (g_{H_2O}/g)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)
$MC_{(wet)}$ = moisture content on a wet basis of the "as-tested" material (g_{H_2O}/g)
W_{added} = mass of water added to the "as-tested" material (g_{H_2O}/g)

11.3.1.4 Compact approximately 1000 g of material into a tared 10-cm diameter mold into three consecutive layers of material. The compacted mass should have a level, flat surface as a top face.

11.3.1.5 Measure and record the height, diameter, and mass of the resulting compacted material.

11.3.1.6 Calculate and record the packing density (dry basis) as follows:

$$\rho_{pack} = \frac{m \times SC}{\pi \times h}\left(\frac{2}{d}\right)^2$$

Where: ρ_{pack} = packing density (dry basis) ($g\text{-dry}/cm^3$)
m = mass of the compacted sample (g)
SC = solids content of "as-tested" granular material (g-dry/g)
d = measured diameter of the compacted sample (cm)
h = measured height of the compacted sample (cm)

11.3.1.7 Repeat Sec. 11.3.1.1 - 11.3.1.6 for four subsequent trials until the value of the calculated packing density decreases.

11.3.1.8 Plot the packing density as a function of moisture content. Figure 4 shows an example of a packing density curve.

11.3.1.9 Determine the optimum moisture content at the maximum of the packing density curve. This value may be read directly from the graph or determined by the maximum of a third-order polynomial fit through the five pre-test data points (see the Microsoft Excel® spreadsheet template available at http://www.vanderbilt.edu/leaching/downloads/test-methods/).

11.3.2 Compacted granular test sample preparation

11.3.2.1 Using the optimum moisture content determined in Sec. 11.3.1.9, calculate the amount of "as-received" material that is required to pack the sample holder to within 3 mm of the rim of the holder.

$$M_{test} = \frac{\rho_{opt} \times \pi \times (h - 0.3)}{SC} \left(\frac{d}{2}\right)^2$$

Where: M_{test} = mass of "as tested" solid equivalent to the dry-material mass (g)
ρ_{opt} = optimal packing density (dry basis) (g-dry/cm^3) – determined in Sec. 11.3.1.9
h = measured height of the sample mold (cm)
SC = solids content of "as-tested" granular material (g-dry/g)
d = measured diameter of the sample mold (cm)

11.3.2.2 Adjust the moisture content of the "as-received" material to the optimum moisture content using reagent water and mix until homogenized.

11.3.2.3 Pack the sample material into the sample holder using the modified Proctor compaction as described in Ref. 10.

11.3.2.4 Place a monolayer of borosilicate glass beads (Sec. 6.3.3) on the exposed sample surface to minimize scouring and mass loss during testing.

11.3.2.5 Begin the leach test procedure promptly or cover the sample with plastic wrap to minimize moisture loss to the atmosphere.

11.4 Leaching procedure

This protocol is a semi-dynamic, tank-leaching procedure (see schematic in Figure 5) where the sample is exposed to eluate for a series of leaching intervals interspersed with eluent exchanges. The chemical composition of each eluate is determined and mass transfer from the bulk solid is determined as a function of cumulative leaching time. The schedule of leaching intervals for this method is shown in Table 1.

11.4.1 Pre-test measurements – For the surface area calculation, measure and record the dimensions of the test specimen. This should include the diameter and height for a cylinder; length, width, and depth for a parallelepiped; or diameter of exposed surface for a compacted granular sample.

11.4.2 Measure and record the mass of the specimen. This value should be monitored for each eluent exchange.

11.4.3 If a holder is used, place the specimen in the monolith holder.

11.4.4 Measure and record the mass of the specimen and holder, if applicable.

11.4.5 The recommended temperature for conducting this method is room temperature (20 ± 2 °C). When conducted at temperature readings or variations other than those recommended, record the ambient temperature at each eluent renewal.

11.5 Eluent exchange

11.5.1 Fill a clean leaching vessel with the required volume of reagent water based on an L/A of 9 ± 1 mL/cm^2. Record the amount of eluent used.

11.5.2 Carefully place the specimen or the specimen and holder in the leaching vessel (Figure 6a) so that the sample is centered in the eluent (see Figure 6b). Submersion should be gentle enough so that the physical integrity of the monolith is maintained and scouring of the solid is minimized.

11.5.3 Cover the leaching vessel with the airtight lid and place in a safe location until the end of the leaching interval. Table 1 shows the schedule of leaching intervals and cumulative release times for this method.

NOTE: Eluates of alkaline materials may be susceptible to neutralization through reaction with carbon dioxide. Precautions (e.g., ensuring airtight vessels or purging headspace) should be taken to minimize the effect of carbonation on eluates that may sit stationary for more than one week.

11.5.4 Prior to the end of the leaching interval, repeat Sec. 11.5.1 in order to prepare a vessel for the next leaching interval.

11.5.5 At the end of the leaching interval (see Table 1), carefully remove the specimen or the specimen and holder from the vessel (Figure 6c). Drain the liquid from the surface of the specimen into the eluate for approximately 20 sec.

11.5.6 Measure and record the mass of the specimen or the mass of the specimen and holder (Figure 6d).

NOTE: The change in sample mass between intervals is an indication of the potential absorption of eluent by the matrix (mass gain) or erosion of the matrix (mass loss). In the case where a holder is used, moisture may condense on the holder during the leaching interval and sample absorption may not be evident.

NOTE: Mass gain may also be indicative of carbonate precipitation if the vessel is not tightly sealed and carbon dioxide is absorbed from the atmosphere.

11.5.7 Place the specimen or the specimen and holder into the clean leaching vessel filled with new eluent as prepared in Sec. 11.5.4.

11.5.8 Cover the new leaching vessel with the airtight lid and place in a safe location until the end of the leaching interval.

11.6 Eluate processing

11.6.1 Measure and record the pH, specific conductivity, and oxidation reduction potential (ORP) of the eluate of the decanted eluate from the previous leaching interval (see Methods 9040, 9045, and 9050).

NOTE: Measurement of pH, conductivity, and ORP should be taken within 15 minutes of eluent exchange (Sec. 11.5) to avoid neutralization of the solution due to exposure to carbon dioxide, especially when alkaline materials are tested.

NOTE: The measurement of ORP is optional, but strongly recommended, especially when testing materials where oxidation is likely to change the chemistry of COPCs.

11.6.2 Filter the remaining eluate through a 0.45-µm membrane (Sec. 6.5).

11.6.3 Immediately preserve and store the volume(s) of eluate required for chemical analysis. Preserve all analytical samples in a manner that is consistent with the determinative chemical analyses to be performed.

11.6.4 Collect all subsequent eluate by repeating the eluent exchange and eluate processing procedures in Secs. 11.5 and 11.6.

12.0 DATA ANALYSIS AND CALCULATIONS

12.1 Data reporting

12.1.1 Figure 7 shows an example of a data sheet which may be used to report the concentration results of this method. At a minimum, the basic test report should include the following:

a) Name of the laboratory
b) Laboratory technical contact information
c) Date and time at the start of the test
d) Name or code of the solid material
e) Material description (including monolithic or compacted granular)
f) Moisture content of material used (g_{H_2O}/g)
g) Dimensions (cm) and geometry of sample used
h) Mass of solid material used (g)
i) Mass of sample and holder at start of test (g)
j) Eluate type (e.g., reagent water)
k) Eluate-specific information (see Sec. 12.1.2 below)

12.1.2 The minimum set of data that should be reported for each eluate includes:

a) Eluate sample ID
b) Target eluent exchange date and time
c) Actual eluent exchange date and time
d) Volume of eluent used (mL)
e) Mass of sample and holder (g)
f) Measured eluate pH

g) Measured eluate conductivity (mS/cm)

h) Measured ORP (mV) (optional)

i) Concentration of all COPCs

j) Analytical QC qualifiers as appropriate

12.2 Data presentation

12.2.1 Interval concentrations

12.2.1.1 At the conclusion of the schedule of leaching intervals (see Table 1), the concentration of COPCs in each eluate may be plotted as a function of cumulative leaching time. An example of this is shown in Figure 8 for mass transport from a monolithic field sample of fixated scrubber sludge and lime.

12.2.1.2 If data is available from Method 1313, interval concentrations and Method 1313 data may be plotted on the same graph as a function of eluate pH. This QC step is conducted in order to determine whether the concentration of COPCs approached equilibrium in any leaching interval (i.e., the driving force for mass transport from the matrix may not be constant, which is a common assumption of dynamic-tank leach testing). Figure 9 shows this type of graph for the release from a field sample of fixated scrubber sludge and lime.

12.2.2 Interval mass release

At the conclusion of the schedule of leaching intervals (see Table 1), the interval mass released can be calculated for each leaching interval as follows:

$$M_{t_i} = \frac{C_i \times V_i}{A}$$

Where: M_{t_i} = mass released during the current leaching interval, i (mg/m^2)

C_i = constituent concentration in the eluate for interval i (mg/L)

V_i = eluate volume in interval i (L)

A = specimen external geometric surface area exposed to the eluent (m^2)

12.2.3 Mean interval flux

The flux of a COPC in an interval may be plotted as a function of the generalized mean of the square root of cumulative leaching time ($\sqrt{t}$). An example of a flux graph is show in Figure 10 for the release from a field sample of fixated scrubber sludge with lime. This graph may be used to interpret the mechanism of release (see Ref. 5 for further details).

12.2.3.1 The flux across the exposed surface of the sample can be calculated by dividing the interval mass release by the interval duration as follows:

$$F_i = \frac{M_i}{t_i - t_{i-1}}$$

Where: F_i = flux for interval, i ($mg/m^2 \cdot s$)
M_i = mass released during the current leaching interval, i (mg/m^2)
t_i = cumulative time at the end of the current leaching interval, i (s)
t_{i-1} = cumulative time at the end of the previous leaching interval, i-1 (s)

12.2.3.2 The time used to plot each interval mass is the generalized mean of the square root of the cumulative leaching time using the cumulative time at the end of the ith interval, t_i, and the cumulative time at the end of the previous interval, t_{i-1}.

$$\overline{t_i} = \left(\frac{\sqrt{t_i} + \sqrt{t_{i-1}}}{2} \right)^2$$

Where: $\overline{t_i}$ = generalized mean leaching time for the current interval, i (s)
t_i = cumulative time at the end of the current leaching interval, i (s)
t_{i-1} = cumulative time at the end of the previous leaching interval, i-1 (s)

NOTE: If the concentrations of a COPC in the eluates approach that shown in Method 1313 for liquid-solid equilibrium, the flux curve will show the pattern in Figure 10 with intervals of the same duration having the same flux value. When the eluate concentration approaches saturation, the driving force for mass transfer approaches zero, interval flux is limited, and intervals with like durations will display similar flux limitations.

12.2.4 Cumulative release

12.2.4.1 The interval release calculated in 12.2.2 can be summed to provide the cumulative mass release as a function of leaching time. Figure 11 shows the cumulative release curves for a field sample of fixated scrubber sludge with lime.

12.2.4.2 Interpretation of the cumulative release of constituents is illustrated using the analytical solution for simple radial diffusion from a cylinder into an infinite bath presented by Crank (see Ref. 8).

$$M_t = 2\rho C_o \left(\frac{D^{obs}\, t}{\pi} \right)^{1/2}$$

Where: M_t = cumulative mass released during leaching interval i (mg/m^2)
ρ = density of the "as-tested" sample (kg/m^3)
C_o = concentration of available COPC in the solid matrix (mg/kg)
D^{obs} = observed diffusivity (m^2/s)
t = leaching time (s)

When transformed to a log-log scale, the analytical solution presented by Crank becomes linear with the square root of time.

$$\log\left[M_t\right] = \log\left[2\rho C_o\left(\frac{D^{obs}}{\pi}\right)^{1/2}\right] + \frac{1}{2}t$$

Thus, under the assumptions of the analytical solution presented by Crank, the mass release should be proportional to the square root of time. A line showing the square root of time is plotted in Figure 11 along with the data. Since flux is the derivative of release, a similar treatment of flux as a function of leaching time using the simple diffusion model would be proportional to the negative square root of time as shown in Figure 10.

Models other than the simple diffusion model presented by Crank may also be used to interpret mass release. For example, the Shrinking Unreacted Core Model (see Ref. 2) and the Coupled Dissolution-Diffusion Model (see Ref. 7) incorporate chemical release parameters (e.g., as derived from Method 1313 data) into the model to better estimate release mechanisms and predictions (see Ref. 5 for further details).

12.2.5 Observed diffusivity

An observed diffusivity for each COPC can be determined using the logarithm of the cumulative release plotted versus the logarithm of time. In the case of a diffusion-controlled mechanism, this plot is expected to be a straight line with a slope of 0.5. An observed diffusivity can then be determined for each leaching interval where the slope is 0.50 ± 0.15 (see Ref. 1 and Ref. 14) by the following:

$$D_i^{obs} = \pi\left[\frac{M_{t_i}}{2\rho C_o\left(\sqrt{t_i} - \sqrt{t_{i-1}}\right)}\right]^2$$

Where: D_i^{obs} = observed diffusivity of a COPC for leaching interval i (m^2/s)

M_{t_i} = mass released during leaching interval i (mg/m^2)

t_i = cumulative contact time at the end of the current leaching interval, i (s)

t_{i-1} = cumulative contact time at the end of the previous leaching interval, i−1 (s)

ρ = sample density (dry basis) (kg-dry/m^3)

C_0 = initial leachable content (i.e., available release potential) (mg/kg)

The mean observed diffusivity for each COPC is then determined by taking the average of the interval observed diffusivities. It should be reported with the computed uncertainty (i.e., standard deviation).

NOTE: Since the analysis presented above assumes a diffusion process, only those interval mass transfer coefficients corresponding to leaching intervals with slopes of 0.50 ± 0.15 are included in the overall average mass-transfer coefficient.

12.3 Data representation by constituent

A concise representation of all relevant data for a single constituent may be presented as shown in Figure 12 for arsenic from a field core of fixated scrubber sludge with lime (FSSL) material. The data shows eluate pH generation as a function of leaching time (Figure 12a), comparison between eluate

concentrations and Method 1313 data as a function of eluate pH (Figure 12b), constituent flux as a function of generalized mean cumulative leaching time (Figure 12c), and constituent release as a function of cumulative leaching time (Figure 12d).

12.4 Interpolation/extrapolation to target time values

The collected time dependence data may be interpolated or extrapolated to the nearest target cumulative time (Σt) value for purposes of comparing different data sets (e.g., test replicates of the same or different materials). The most transparent and straightforward method is linear interpolation/extrapolation of data after $\log_{10}$ transformation.

12.4.1 $\log_{10}$ transformation

Collected concentration values are transformed by taking the $\log_{10}$ of the measured concentration at each test position, i:

$$C_i = \log_{10}(c_i)$$

Where: C_i = $\log_{10}$-transformed concentration at test position i ($\log_{10}$[mg/L])
c_i = the concentration measured at test position i (mg/L)

12.4.2 Linear interpolation/extrapolation

Given a set of coordinate data sorted by increasing order according to Σt value (e.g., $\Sigma t_1 < \Sigma t_2 < \cdots < \Sigma t_n$), an interpolated/extrapolated $\log_{10}$-transformed concentration at a known Σt target is calculated as:

$$C_T = a_T + b_T \sum t_T$$

Where: C_T = the concentration at target Σt value, Σt_T ($\log_{10}$[s])
a_T and b_T are coefficients of the linear interpolation/extrapolation equation
Σt_T = a target cumulative time value

Depending on the values of observed Σt values relative to target Σt values, the calculations of the coefficients a_T and b_T in the equation may differ according to the following algorithm:

- If $\Sigma t_T < \Sigma t_1$, then $b_T = (C_2 - C_1) / (\Sigma t_2 - \Sigma t_1)$ and $a_T = C_2 - b_T \cdot \Sigma t_2$ (extrapolation from the two points with closest Σt values)
- If $\Sigma t_T \geq \Sigma t_n$, then $b_T = (C_n - C_{n-1}) / (\Sigma t_n - \Sigma t_{n-1})$ and $a_T = C_n - b_T \cdot \Sigma t_n$ (extrapolation from the two points with closest Σt values)
- If $\Sigma t_{j-1} \leq \Sigma t_T < \Sigma t_j$, then $b_T = (C_j - C_{j-1}) / (\Sigma t_j - \Sigma t_{j-1})$ and $a_T = y_j - b_T \cdot \Sigma t_j$ (interpolation from the two closest points surrounding Σt_T)

NOTE: Interpolation or extrapolation of data should only be conducted within a distance of ±20% of the target Σt value. Since the allowable L/S tolerance about a target L/S value is variable (see Table 1), interpolation/extrapolation should not create data at a target Σt value where collected data is missing.

13.0 METHOD PERFORMANCE

13.1 Performance data and related information are provided in SW-846 methods only as examples and guidance. The data do not represent required performance criteria for users of the methods. Instead, performance criteria should be developed on a project-specific basis, and the laboratory should establish in-house QC performance criteria for the application of this method. Performance data must not be used as absolute QC acceptance criteria for laboratory QC or accreditation.

13.2 Interlaboratory validation of this method was conducted using a solidified waste analog (material code SWA) and a contaminated smelter site soil (material code CFS). Repeatability and reproducibility was determined for mean interval flux excluding the first wash-off interval (see Table 2) and for cumulative mass released after 63 days of leaching (see Table 3). More details on the interlaboratory validation may be found in Ref. 4.

13.3 Ref. 5 and Ref. 12 may provide additional guidance and insight on the use, performance, and application of this method.

14.0 POLLUTION PREVENTION

14.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity and/or toxicity of waste at the point of generation. Numerous opportunities for pollution prevention exist in laboratory operations. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to address their waste generation. When wastes cannot be feasibly reduced at the source, the Agency recommends recycling as the next best option.

14.2 For information about pollution prevention that may be applicable to laboratories and research institutions consult *Less is Better: Laboratory Chemical Management for Waste Reduction*, a free publication available from the ACS, Committee on Chemical Safety, https://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/less-is-better.pdf.

15.0 WASTE MANAGEMENT

The EPA requires that laboratory waste management practices be conducted consistent with all applicable rules and regulations. Laboratories are urged to protect air, water, and land by minimizing and controlling all releases from hoods and bench operations, complying with the letter and spirit of any sewer discharge permits and regulations, and by complying with all solid and hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions. For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* available at: http://www.labsafetyinstitute.org/FreeDocs/WasteMgmt.pdf.

16.0 REFERENCES

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3. A.C. Garrabrants, and D.S. Kosson, "Leaching Processes and Evaluation Tests for Inorganic Constituents Release from Cement-Based Matrices," in *Solidification/Stabilization of Hazardous, Radioactive and Mixed Wastes*, R. Spence, and C. Shi (eds), CRC Press, 2005.

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17.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA

The following pages contain the tables and figures referenced by this method.

TABLE 1

SCHEDULE OF ELUATE RENEWALS

Interval Label	Interval Duration (h)	Interval Duration (d)	Cumulative Leaching Time (d)
T01	2.0 ± 0.25	–	0.08
T02	23.0 ± 0.5	–	1.0
T03	23.0 ± 0.5	–	2.0
T04	–	5.0 ± 0.1	7.0
T05	–	7.0 ± 0.1	14.0
T06	–	14.0 ± 0.1	28.0
T07	–	14.0 ± 0.1	42.0
T08	–	7.0 ± 0.1	49.0
T09	–	14.0 ± 0.1	63.0

NOTE: This schedule may be extended for additional 14-day contact intervals to provide more information regarding longer-term release.

TABLE 2

METHOD PRECISON FOR MEAN INTERVAL FLUX (2nd – 9th Intervals)

Analyte	Symbol	Reapeatability – SWA %RSD_r	Repeatability – CFS %RSD_r	Reproducibility – SWA %RSD_R	Reproducibility – CFS %RSD_R
Aluminum	Al	7.3	13.3	25.3	25.3
Antimony	Sb	9.2	14.8	21.8	23.8
Arsenic	As	19.9	-	31.1	-
Barium	Ba	13.2	7.5	44.8	18.3
Boron	B	10.8	7.2	27.3	27.1
Cadmium	Cd	-	7.6	-	23.2
Calcium	Ca	8.1	6.6	28.7	26.0
Chromium	Cr	10.2	-	23.8	-
Lead	Pb	-	4.3	-	19.8
Potassium	K	12.4	10.8	28.8	40.1
Selenium	Se	10.9	13.3	30.8	32.4
Vanadium	V	8.5	11.3	22.3	30.6

Material	Reapeatability – SWA %RSD_r	Repeatability – CFS %RSD_r	Repeatability – Overall	Reproducibility – SWA %RSD_R	Reproducibility – CFS %RSD_R	Reproducibility – Overall
Mean	11%	10%	11%	29%	27%	28%

NOTE: First interval is removed from mean interval flux because of variances associated with wash-off of surface contaminants that do not pertain to the method precision.

Data taken from Ref. 4.

R000164

TABLE 3

METHOD PRECISON FOR CUMULATIVE RELEASE AFTER 63 DAYS

Analyte	Symbol	Repeatability – SWA %RSD_r	Repeatability – CFS %RSD_r	Reproducibility – SWA %RSD_R	Reproducibility – CFS %RSD_R
Aluminum	Al	5.4	5.3	23.6	22.9
Antimony	Sb	6.9	5.9	19.7	14.4
Arsenic	As	15.9	-	31.0	-
Barium	Ba	7.5	3.9	35.6	16.5
Boron	B	8.4	3.7	22.6	25.7
Cadmium	Cd	-	4.8	-	18.4
Calcium	Ca	4.6	3.2	23.9	24.6
Chromium	Cr	7.7	-	17.7	-
Lead	Pb	-	1.6	-	12.0
Potassium	K	10.8	6.3	24.8	44.4
Selenium	Se	8.7	3.6	26.7	20.5
Vanadium	V	5.7	4.2	21.1	22.8

Material	Repeatability – SWA %RSD_r	Repeatability – CFS %RSD_r	Repeatability – Overall	Reproducibility – SWA %RSD_R	Reproducibility – CFS %RSD_R	Reproducibility – Overall
Mean	8%	4%	6%	25%	22%	23%

Data taken from Ref. 4.

FIGURE 1

EXAMPLES OF MONOLITHIC SAMPLE HOLDERS

3-D Configuration



Sample Holder



Sample, Holder and Stand



3-D Leaching Setup

1-D Configuration



Empty Sample Holder



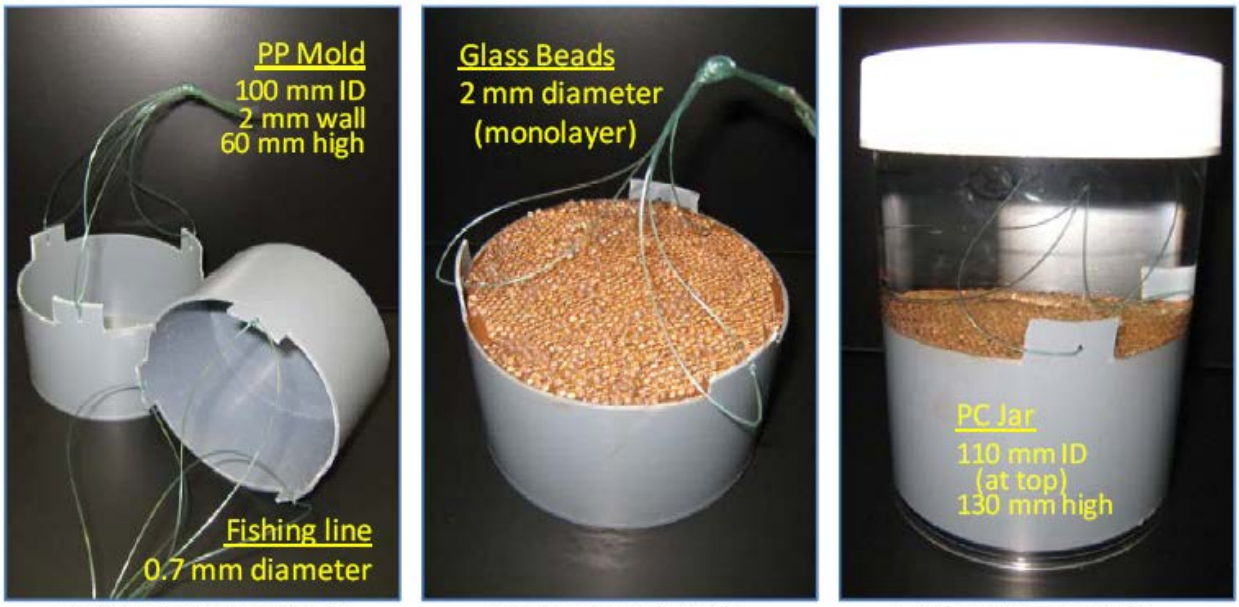
Full Sample Holder



1-D Leaching Setup

FIGURE 2

EXAMPLE COMPACTED GRANULAR SAMPLE HOLDER AND SETUP



Empty Sample Holder | Compacted Sample | 1-D Leaching Setup

FIGURE 3

METHOD FLOWCHART

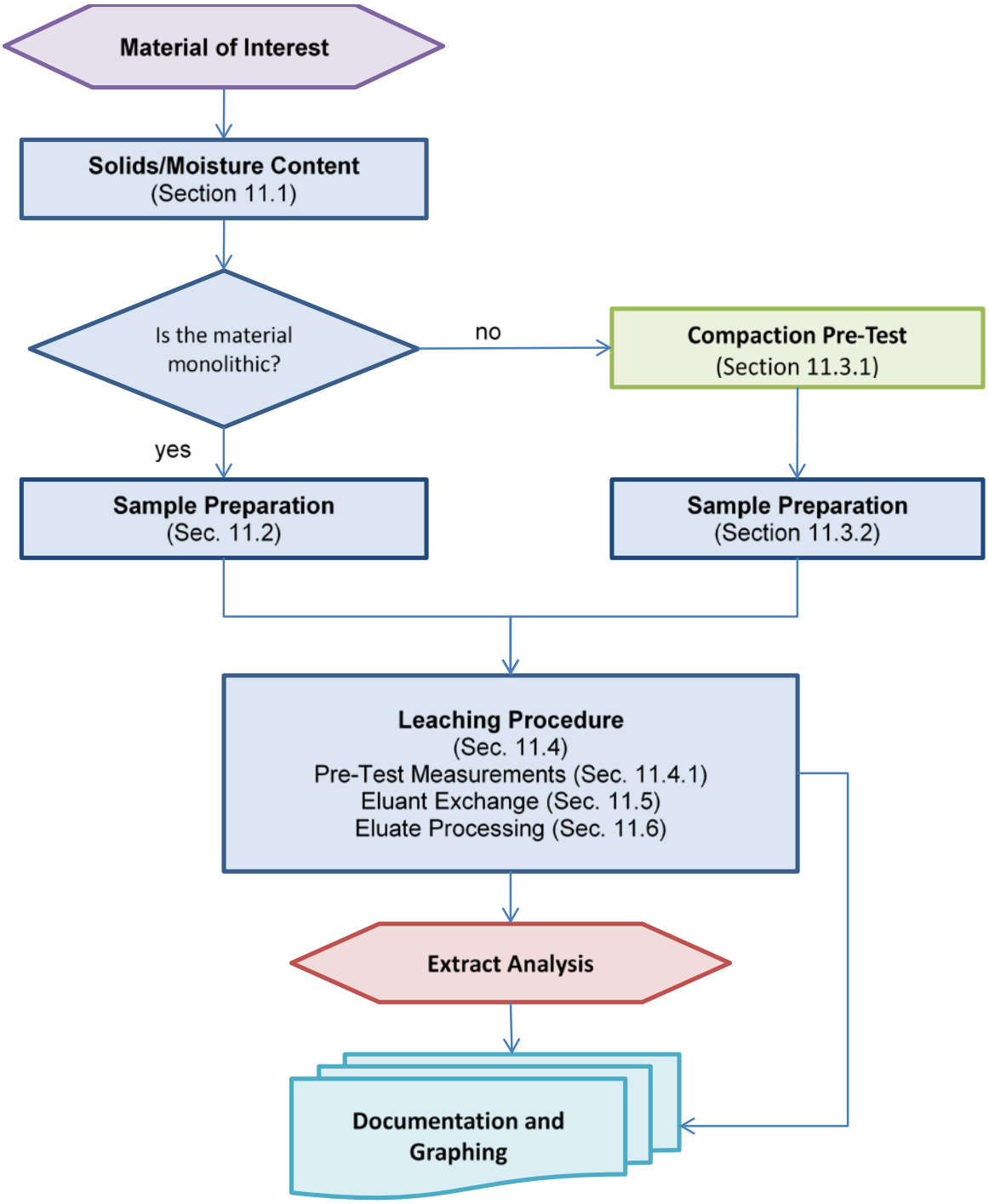


FIGURE 4

EXAMPLE CURVE OF PACKING DENSITY AS A FUNCTION OF MOISTURE CONTENT

$y = 55.975x^3 – 65.036x^2 + 1.8352$

$r^2 = 0.983$

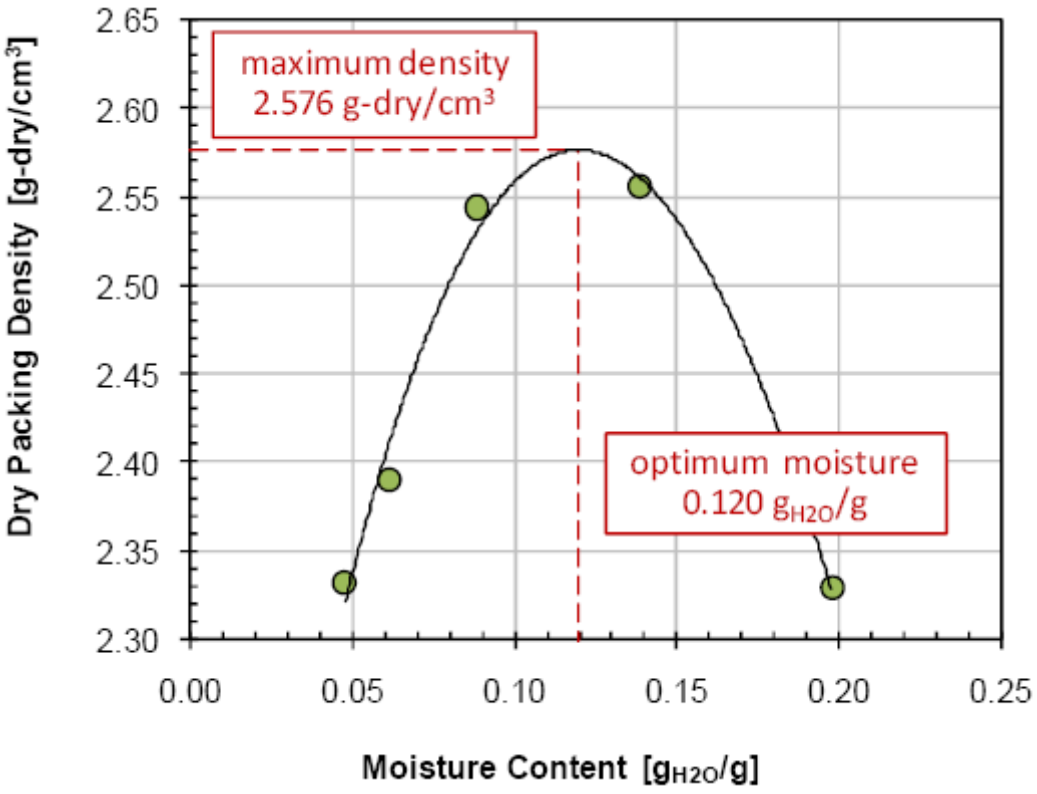


FIGURE 5

SCHEMATIC OF SEMI-DYNAMIC MASS TRANSFER TEST PROCESS

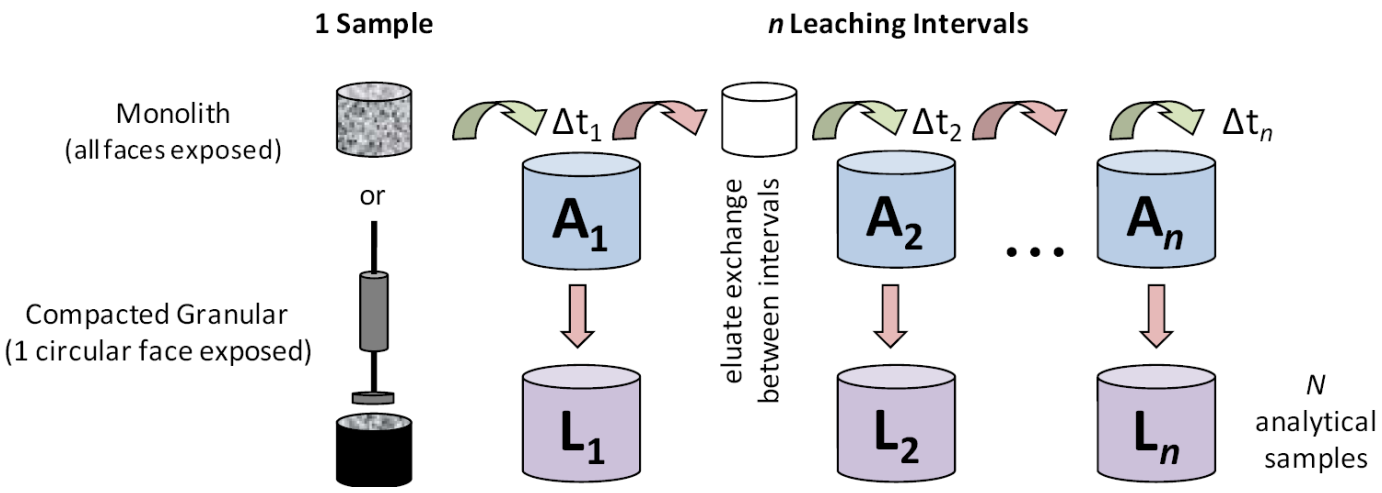
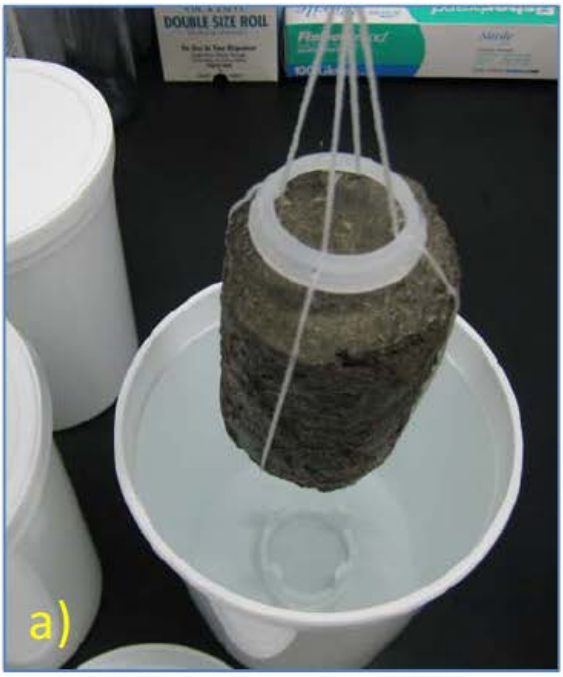


Figure obtained and modified from Ref. 1.

FIGURE 6

EXAMPLE LEACHING PROCEDURE STEPS



Start of Leaching Interval



Sample Centered in Eluant (top view)



Removing Sample for Exchange



Mass of Sample and Holder

FIGURE 7

EXAMPLE DATA REPORTING FORMAT

EPA METHOD 1315
Report of Analysis

ABC Laboratories
123 Main Street
Anytown, USA
Contact: John Smith
(555) 111-1111

Client Contact: Susan Jones
(555) 222-2222

Material Code:	XYZ	Particle Size:	88% passing 2-mm sieve
Material Type:	Coal Combustion Fly Ash	Mass used in Column:	860 g
Date Received:	10/1/20xx	Moisture Content:	0.002 g_{H_2O}/g
Test Start Date:	11/1/20xx	Sample Geometry:	Cylinder
Report Date:	12/1/20xx	Sample Diameter	10.0 cm
		Sample Depth:	60.3 cm
Test Type:	Compacted Granular	Mass of Sample & Holder	1020 g
Eluent:	ASTM Type II Water	Lab Temperature:	21 ± 2 °C

Test Position	Replicate	Value	Units	Method	Note
T01	A				
	Eluate Sample ID	**XYZ-1315-T01-A**			
	Exchange Date	11/1/20xx			
	Target Exchange Time	12:00	PM		
	Actual Exchange Time	12:15	PM		
	Mass of Sample & Holder	1026	g		
	Eluate Mass	730.4	g		
	Eluate pH	8.82	-	EPA 9040	
	Eluate Conductivity	5.4	mS/c	EPA 9050	
	Eluate ORP	NA	mv		

Chemical Analysis	Value	Units	QC Flag	Method	Date	Dilution Factor
Al	4.72	mg/L		EPA 6020	11/7/20xx	1000
As	0.12	mg/L		EPA 6020	11/7/20xx	10
Cl	5.42	mg/L		EPA 9056	11/9/20xx	1

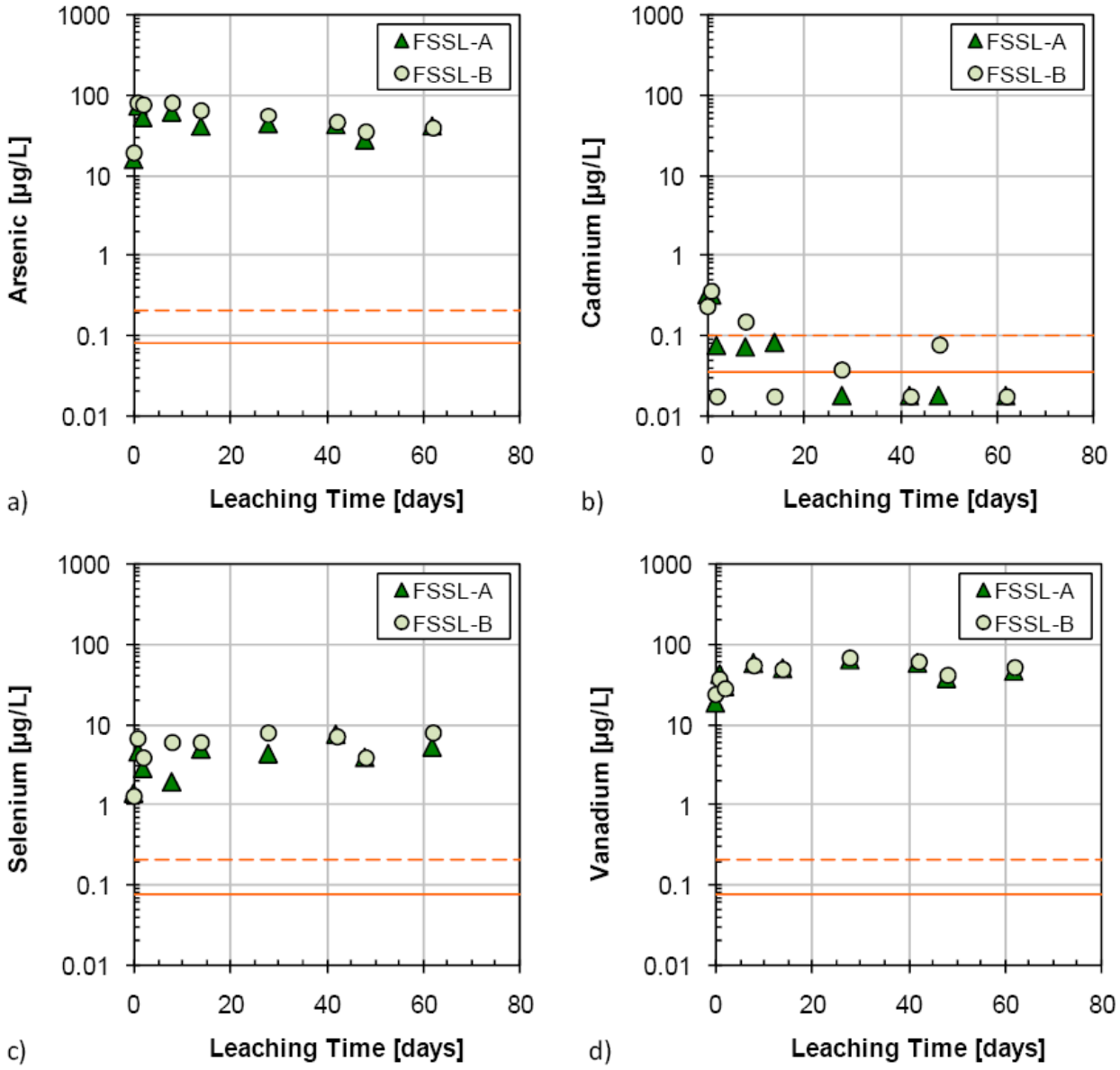
Test Position	Replicate	Value	Units	Method	Note
T02	A				
	Eluate Sample ID	**XYZ-1315-T02-A**			
	Exchange Date	11/1/20xx			
	Target Exchange Time	12:00	PM		
	Actual Exchange Time	12:18	PM		
	Mass of Sample & Holder	1027	g		
	Eluate Mass	725.0	g		
	Eluate pH	9.15	-	EPA 9040	
	Eluate Conductivity	2.8	mS/c	EPA 9050	
	Eluate ORP	NA	mv		

Chemical Analysis	Value	Units	QC Flag	Method	Date	Dilution Factor
Al	2.99	mg/L		EPA 6020	11/7/20xx	1000
As	0.21	mg/L		EPA 6020	11/7/20xx	10
Cl	4.20	mg/L	U	EPA 9056	11/7/20xx	1

QC Flag Key: U Value below lower limit of quantitation as reported (< "LLOQ")

FIGURE 8

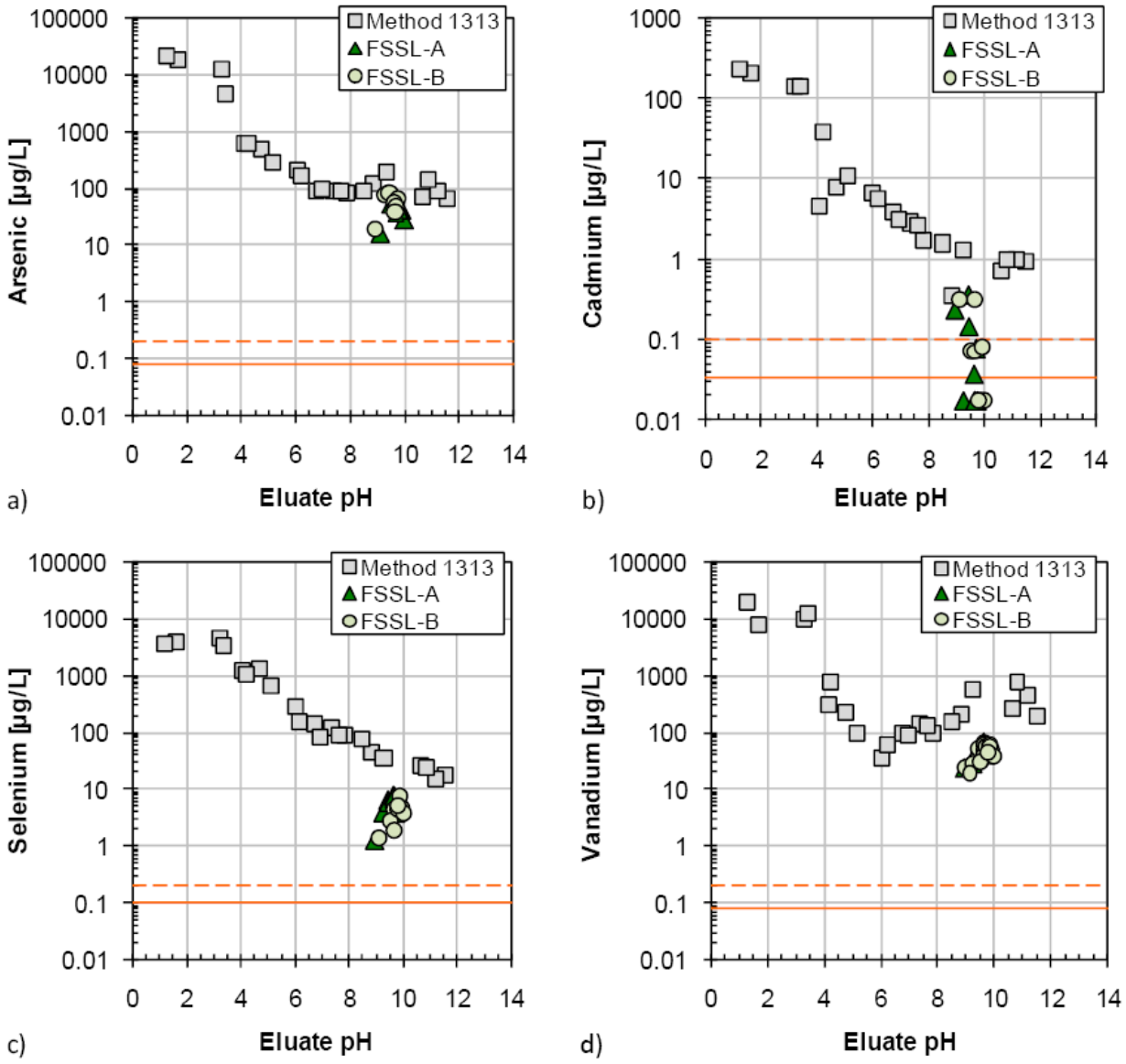
EXAMPLE INTERVAL CONCENTRATION GRAPHS



NOTE: Orange lines represent cumulative release if all eluate extracts were at the quantitation limit (dashed) and detection limit (solid). Chemical analyses below the detection limit are shown at ½ the detection limit value.

FIGURE 9

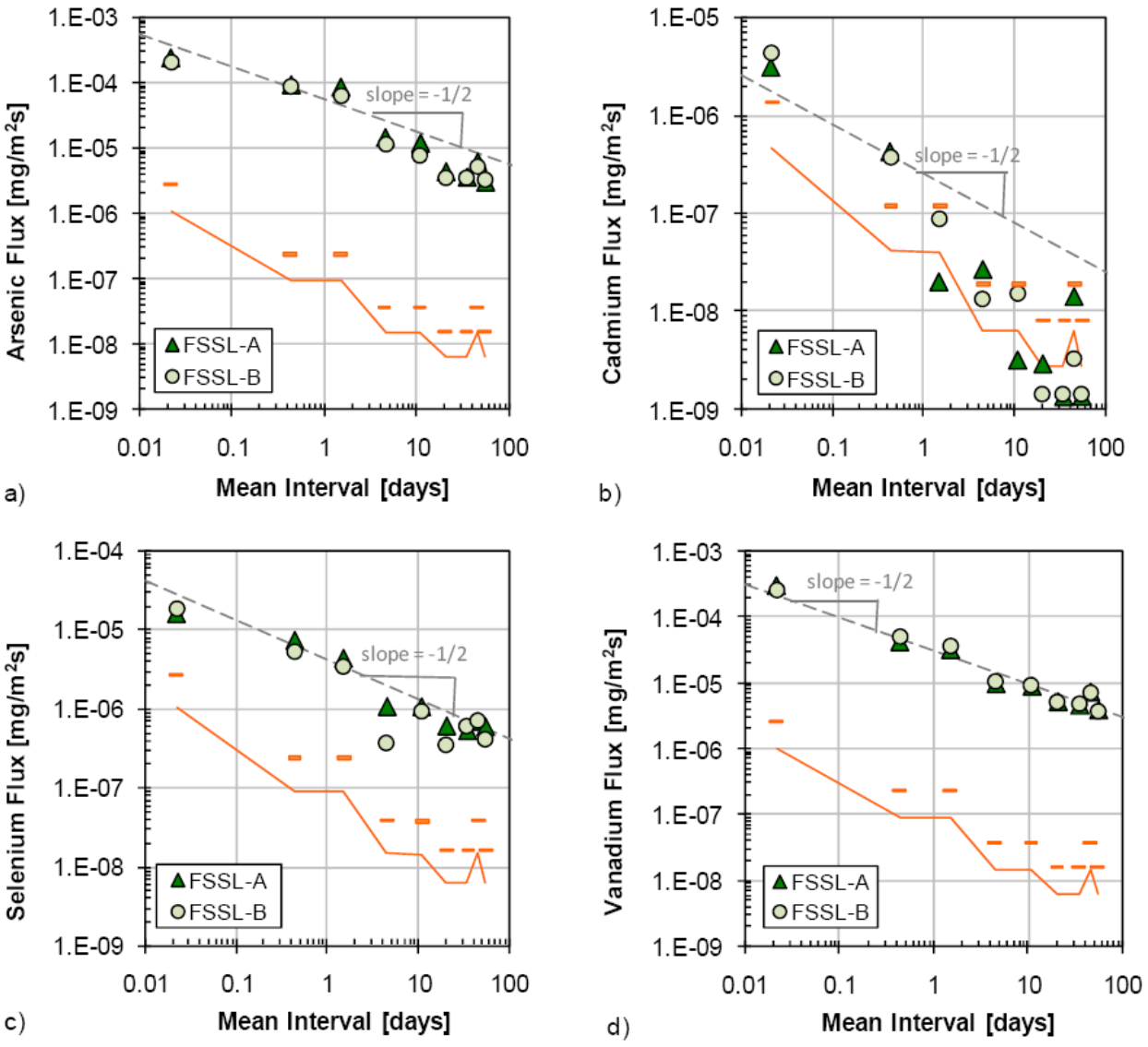
EXAMPLE OF SATURATION CHECK BETWEEN INTERVAL CONCENTRATIONS AND METHOD 1313 DATA



NOTE: Orange lines represent cumulative release if all eluate extracts were at the quantitation limit (dashed) and detection limit (solid). Chemical analyses below the detection limit are shown at ½ the detection limit value.

FIGURE 10

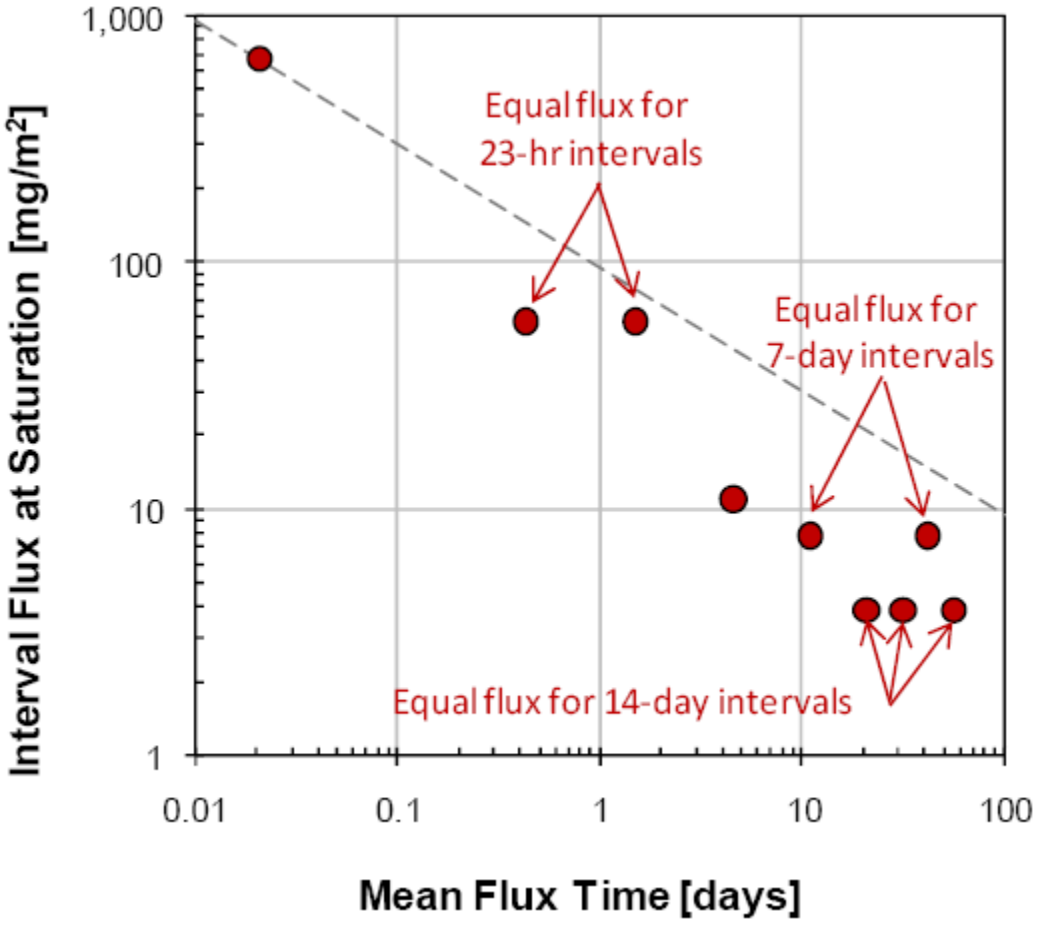
EXAMPLE INTERVAL FLUX GRAPHS



NOTE: Orange data represent cumulative release if all eluate extracts were at the quantitation limit (dashes) and detection limit (solid line).

FIGURE 11

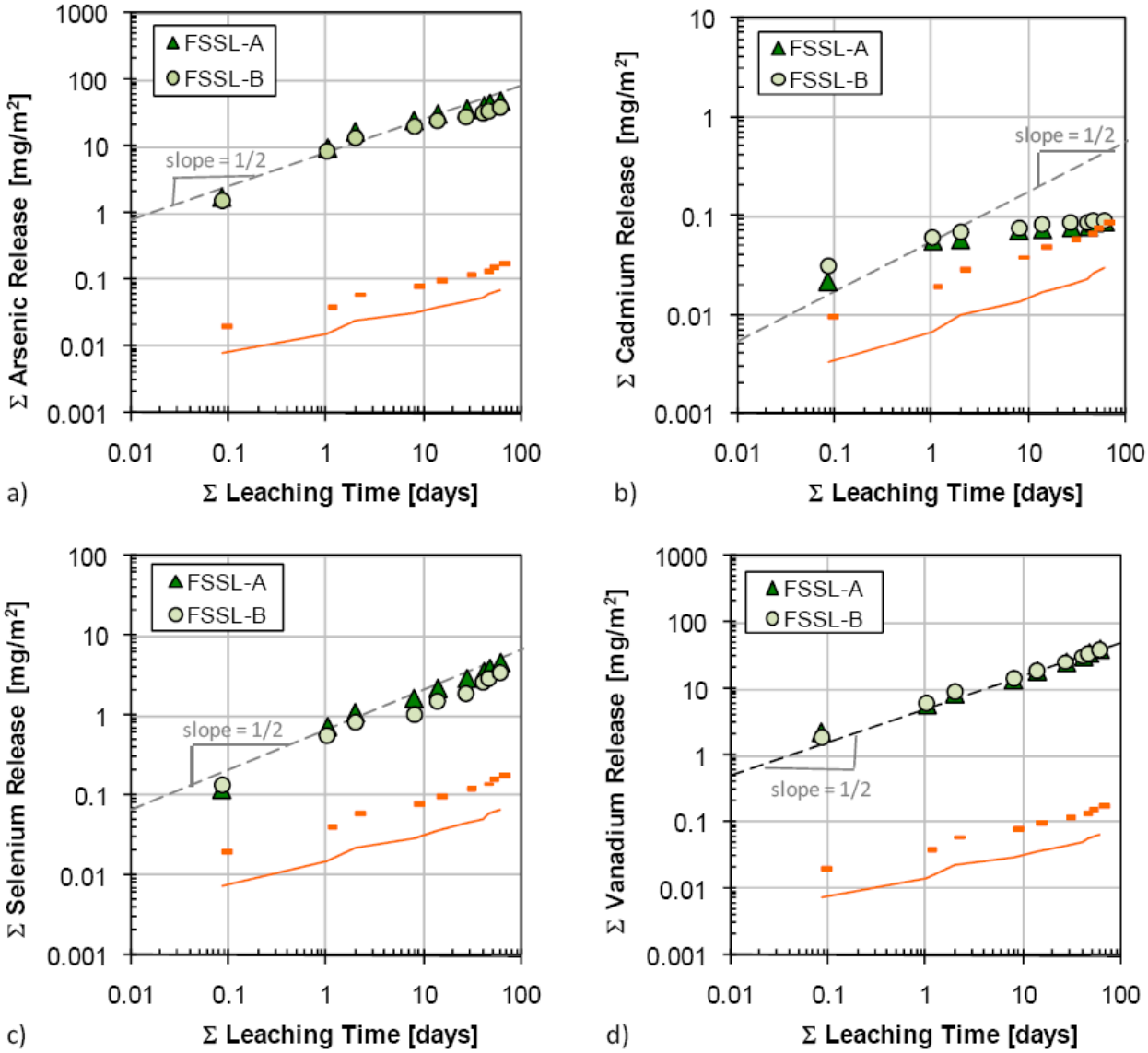
INTERVAL FLUX AT ELUATE SATURATION



NOTE: This figure assumes that the concentration in the eluate approaches saturation during the leaching interval (i.e., the driving force for diffusion approaches zero). When the leaching solution is saturated, the resulting mass release and interval flux is constant for intervals of the same duration.

FIGURE 12

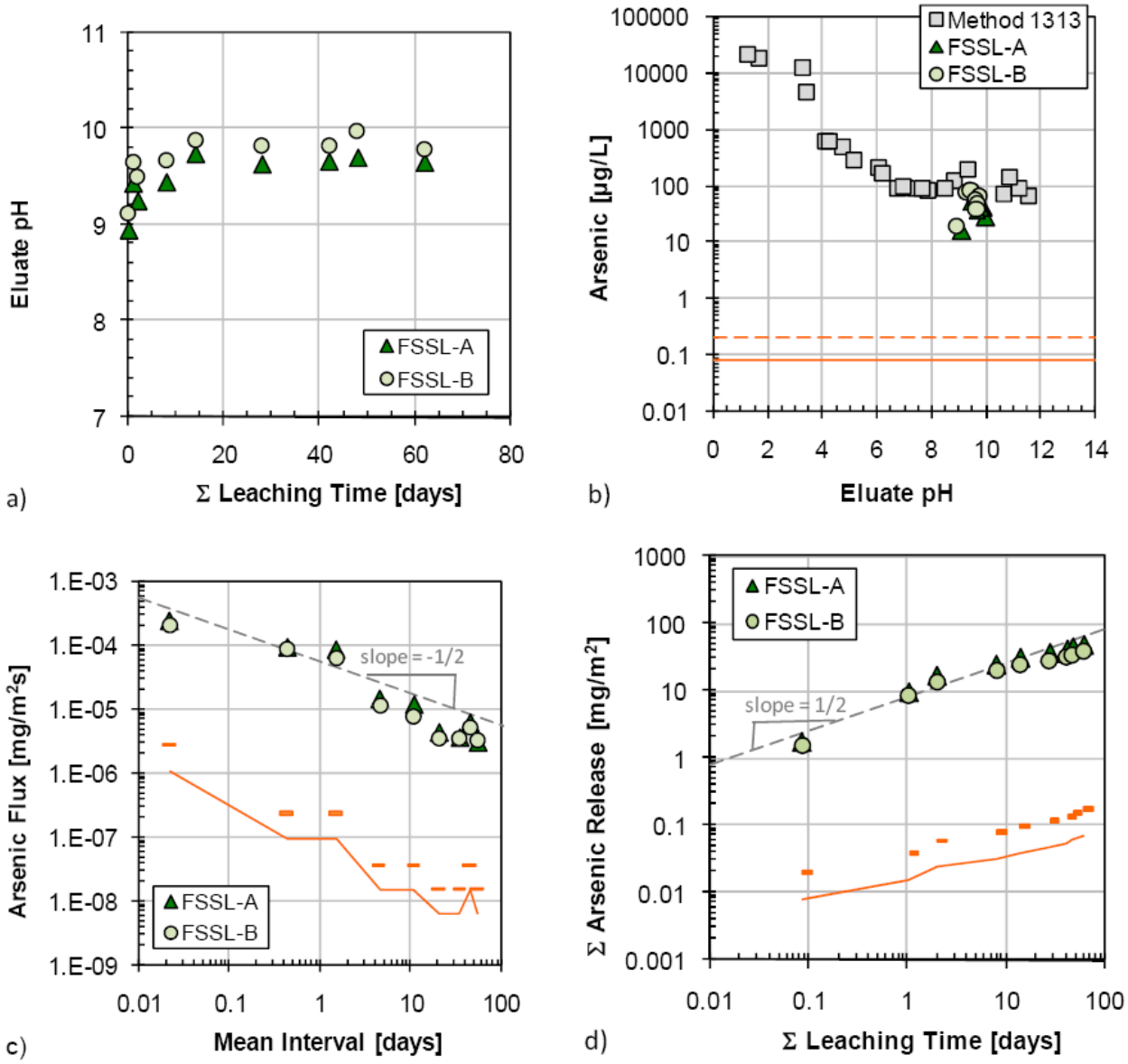
EXAMPLE CUMULATIVE RELEASE GRAPHS



NOTE: Orange data represent cumulative release if all eluate extracts were at the quantitation limit (dashes) and detection limit (solid line).

FIGURE 13

DATA REPRESENTATION BY CONSTITUENT (QUAD FORMAT)



NOTE: Orange data represent cumulative release if all eluate extracts were at the quantitation limit (dashes) and detection limit (solid line).

DOCUMENT 7

METHOD 1316[1]

LIQUID-SOLID PARTITIONING AS A FUNCTION OF LIQUID-TO-SOLID RATIO IN SOLID MATERIALS USING A PARALLEL BATCH PROCEDURE

SW-846 is not intended to be an analytical training manual. Therefore, method procedures are written based on the assumption that they will be performed by analysts who are formally trained in at least the basic principles of chemical analysis and in the use of the subject technology.

In addition, SW-846 methods, with the exception of required methods used for the analysis of method-defined parameters, are intended to be guidance methods that contain general information on how to perform an analytical procedure or technique, which a laboratory can use as a basic starting point for generating its own detailed standard operating procedure (SOP), either for its own general use or for a specific project application. Performance data included in this method are for guidance purposes only and must not be used as absolute quality control (QC) acceptance criteria for purposes of laboratory QC or accreditation.

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[1] This method has been derived from the SR003 procedure (Ref. 4) using Environmental Protection Agency-reviewed and accepted methodologies (see Ref. 3, Ref. 6, and Ref. 7). The method is analogous to batch L/S-dependence method EN12457 (Ref. 5) developed for the Comité Européen de Normalisation (CEN).

1.0 SCOPE AND APPLICATION

1.1 This method is designed to provide the liquid-solid partitioning (LSP) of inorganic constituents (e.g., metals, radionuclides) and non-volatile organic constituents (e.g., polycyclic aromatic hydrocarbons (PAHs)), dissolved organic carbon) at the natural pH of the solid material as a function of liquid-to-solid ratio (L/S) under conditions that approach liquid-solid chemical equilibrium. Table 1 shows the range of target L/S values tested under this method.

1.2 The eluate concentrations at a low L/S provide insight into pore solution composition either in a granular bed (e.g., soil column) or in the pore space of low-permeability material (e.g., solidified monolithic or compacted granular fill). In addition, analysis of eluates for dissolved organic carbon and of the solid phase for total organic carbon allow for evaluation of the impact of organic carbon release and the influence of dissolved organic carbon on the LSP of inorganic constituents.

1.3 This method is intended to be used as part of environmental leaching assessment for the evaluation of disposal, beneficial use, treatment effectiveness and site remediation. The method is not required by federal regulations to determine whether waste passes or fails the toxicity characteristic as defined at 40 CFR 261.24.

1.4 This method is suitable for assessing the leaching potential of a wide range of solid materials. Examples of solid materials include: industrial wastes, soils, sludges, combustion residues, sediments, stabilized materials, construction materials, and mining wastes.

1.5 This method is a leaching characterization method used to provide intrinsic material parameters that control leaching of inorganic species under equilibrium conditions. This test method is intended as a means for obtaining an extract (i.e., the eluate) of a solid material which may be used to estimate the solubility and release of inorganic constituents under the laboratory conditions described in this method. Extract concentrations may be used in conjunction with information regarding environmental management scenarios to estimate anticipated leaching concentrations, and release rate and extent for individual material constituents in the management scenarios evaluated. Extract concentrations may also be used along with geochemical speciation modeling to infer the mineral phases that control the LSP in the pore structure of the solid material.

1.6 This method is not applicable to characterize the release of volatile organic analytes (e.g., benzene, toluene and xylenes).

1.7 This method provides solutions that are considered to be indicative of leachate under field conditions only where the field leaching pH and L/S ranges are encompassed by the laboratory extract final conditions and the LSP is controlled by aqueous-phase saturation of the constituent of interest. When LSP is controlled by the amount of the constituent present in the solid that may dissolve (i.e., for highly soluble species), the mass released (mg/kg), rather than the concentration, is indicative of field conditions.

1.8 The solvent used in this method is reagent water.

1.9 Analysts are advised to take reasonable measures to ensure that the sample is homogenized to the extent practical prior to employment of this method. Particle size reduction may

provide additional assurance of sample homogenization. Table 2 designates a minimum dry equivalent mass of sample to be added to each extraction vessel and the associated extraction contact time as a function maximum particle diameter. If the heterogeneity of the sample is suspected as the cause of unacceptable levels of precision in replicate test results or is considered significant based on professional judgment, the sample mass used in the test procedure may be increased to a greater minimum dry equivalent mass than shown in Table 1 with the amount of extractant increased proportionately to maintain the designated L/S.

1.10 In the preparation of solid materials for use in this method, particle size reduction of samples with large grain size is used to enhance the approach towards liquid-solid equilibrium under the designated contact time interval of the extract process. The extract contact time for samples reduced to a finer maximum particle size will be shorter.

1.11 Prior to employing this method, analysts are advised to consult the base method for each type of procedure that may be employed in the overall analysis (e.g., Methods 9040, 9045, and 9050) for additional information on QC procedures, development of QC acceptance criteria, calculations, and general guidance. Analysts also should consult the disclaimer statement at the front of the manual and the information in Chapter Two for: 1) guidance on the intended flexibility in the choice of methods, apparatus, materials, reagents, and supplies, and 2) the responsibilities of the analyst for demonstrating that the techniques employed are appropriate for the analytes of interest, in the matrix of interest, and at the levels of concern.

In addition, analysts and data users are advised that, except where explicitly specified in a regulation, the use of SW-846 methods is not mandatory in response to federal testing requirements. The information contained in this method is provided by the Environmental Protection Agency (EPA or the Agency) as guidance to be used by the analyst and the regulated community in making judgments necessary to generate results that meet the data quality objectives (DQOs) for the intended application.

1.12 This method is restricted to use by, or under supervision of, properly experienced and trained personnel. Each analyst must demonstrate the ability to generate acceptable results with this method.

2.0 SUMMARY OF METHOD

This method consists of five parallel extractions of a particle size-reduced solid material in reagent water over a range of L/S values from 0.5 to 10 mL eluent/g dry material (see Table 1). In addition to the five test extractions, a method blank without solid sample is carried through the procedure in order to verify that analyte interferences are not introduced as a consequence of reagent impurities or equipment contamination. If multiple materials or replicate tests are carried out in parallel, only one set of method blanks is necessary. In total, six bottles (i.e., five test positions and one method blank) are tumbled in an end-over-end fashion for a specified contact time based on the maximum particle size of the solid (see Table 2). At the end of the contact interval, the liquid and solid phases are roughly separated via settling or centrifugation. Extract pH and specific conductance measurements are then taken on an aliquot of the liquid phase. The bulk of the eluate is clarified by pressure or vacuum filtration in preparation for constituent analysis. Analytical aliquots of the extracts are collected and preserved accordingly based on the determinative methods to be performed. The eluate constituent concentrations are plotted as a function of L/S and compared to QC and assessment limits.

3.0 DEFINITIONS

3.1 Constituent of potential concern (COPC) – A chemical species of interest, which may or may not be regulated, but may be characteristic of release-controlling properties of the sample geochemistry.

3.2 Release – The dissolution or partitioning of a COPC from the solid phase to the aqueous phase during laboratory testing (or under field conditions). In this method, mass release is expressed in units of mg COPC/kg dry solid material.

3.3 Liquid-solid partitioning (LSP) – The distribution of COPCs between the solid and liquid phases at the conclusion of the extraction.

3.4 Liquid-to-solid ratio (L/S) – The fraction of the total liquid volume (including the moisture contained in the "as used" solid sample) to the dry mass equivalent of the solid material. L/S is typically expressed in volume units of liquid per dry mass of solid material (mL/g-dry).

3.5 "As-tested" sample – The solid sample at the conditions (e.g., moisture content and particle-size distribution) present at the time of the start of the test procedure. The "as-tested" conditions will differ from the "as-received" sample conditions if particle-size reduction and drying were necessarily performed.

3.6 Dry-mass equivalent – The mass of "as-tested" (i.e., "wet") sample that equates to the mass of dry solids plus associated moisture, based on the moisture content of the "as-tested" material. The dry-mass equivalent is typically expressed in mass units of the "as-tested" sample (g).

3.7 Eluent – The solution used to contact the solid material in a leaching test. The eluent is usually free of COPCs but may contain other species used to control the test conditions of the extraction.

3.8 Eluate – The solution collected as an extract from a leaching test that contains the eluent plus constituents leached from the solid phase.[2]

3.9 Refer to Chapter One, Chapter Three, and the manufacturers' instructions for definitions that may be relevant to this procedure.

4.0 INTERFERENCES

Solvents, reagents, glassware, and other sample processing hardware may yield artifacts and/or interferences to sample analysis. All of these materials must be demonstrated to be free from interferences under the conditions of the analysis by analyzing method blanks. Specific selection of reagents may be necessary. Refer to each method to be used for specific guidance on QC procedures

[2] The definition of "eluate" is used in this method to differentiate the output solution of a leaching test from the "leachate" solution collected from, or measured in, the field. The distinction between terms is made to minimize confusion when comparing laboratory results to field data (Ref. 5).

and to Chapters Three and Four for general guidance on glassware cleaning. Also refer to Methods 9040, 9045, and 9050 for a discussion of interferences.

5.0 SAFETY

This method does not address all safety issues associated with its use. The laboratory is responsible for maintaining a safe work environment and a current awareness file of Occupational Safety and Health Administration (OSHA) regulations regarding the safe handling of the chemicals specified in this method. A reference file of material safety data sheets (MSDSs) should be available to all personnel involved in these analyses.

6.0 EQUIPMENT AND SUPPLIES

The mention of trade names or commercial products in this manual is for illustrative purposes only, and does not constitute an EPA endorsement or exclusive recommendation for use. The products and instrument settings cited in SW-846 methods represent those products and settings used during the method development or subsequently evaluated by the Agency. Glassware, reagents, supplies, equipment, and settings other than those listed in this manual may be employed provided that method performance appropriate for the intended application has been demonstrated and documented.

This section does not list all common laboratory glassware (e.g., beakers and flasks) that might be used.

6.1 Extraction vessels

6.1.1 Six wide-mouth bottles (i.e., five for test positions plus one for a method blank) constructed of inert material, resistant to high and low pH conditions and interaction with the constituents of interest, as described in the following sections.

6.1.1.1 For the evaluation of inorganic COPCs, bottles made of high density polyethylene (HDPE) (e.g., Nalgene #3140-0250 or equivalent), polypropylene (PP), or polyvinyl chloride (PVC) are recommended.

6.1.1.2 For the evaluation of non-volatile organic and mixed organic/inorganic COPCs, bottles made of glass or Type-316 stainless steel are recommended. Polytetrafluoroethene (PTFE) is not recommended for non-volatile organics, due to the sorption of species with high hydrophobicity (e.g., PAHs). Borosilicate glass is recommended over other types of glass, especially when inorganic analytes are of concern.

6.1.2. The extraction vessels must be of sufficient volume to accommodate both the solid sample and an extractant volume based on the schedule of L/S values shown in Table 1. For example, a 500-mL bottle is recommended when 100 g dry equivalent mass is contacted with 200 mL of eluent (see T03 in Table 1).

6.1.3 The vessels must have a leak-proof seal that can sustain end-over-end tumbling for the duration of the designated contact time.

6.1.4 If centrifugation is anticipated to be beneficial for initial phase separation, the extraction vessels should be capable of withstanding centrifugation at 4000 ± 100 rpm for a minimum of 10 ± 2 min. Alternately, samples may be extracted in bottles that do not meet this centrifugation specification (e.g., Nalgene I-Chem #311-0250 or equivalent) and the solid-liquid slurries transferred into appropriate centrifugation vessels for phase separation as needed.

6.2 Balance – Capable of 0.01 g resolution for masses less than 500 g

6.3 Rotary tumbler – Capable of rotating the extraction vessels end-over-end at a constant speed of 28 ± 2 rpm (e.g., Environmental Express, Charleston, SC or equivalent)

NOTE: The holding capacity of tumblers may vary and modifications (e.g., packing or bottle-holding inserts) may be necessary to accommodate the extraction vessels.

6.4 Filtration apparatus – Pressure or vacuum filtration apparatus composed of appropriate materials to maximize collection of extracts and minimize loss of COPCs (e.g., Nalgene #300-4000 or equivalent) (see Sec. 6.1)

6.5 Filtration membranes – Composed of polypropylene or equivalent material with an effective pore size of 0.45 µm (e.g., Gelman Sciences GH Polypro #66548 from Fisher Scientific or equivalent)

6.6 pH meter – Laboratory model capable of temperature compensation (e.g., Accumet 20, Fisher Scientific or equivalent) with a minimum resolution of 0.1 pH units

6.7 pH combination electrode – Composed of chemically resistant materials

6.8 Conductivity meter – Laboratory model (e.g., Accumet 20, Fisher Scientific or equivalent), with a minimum resolution of 5% of the measured value

6.9 Conductivity electrodes – Composed of chemically resistant materials

6.10 Adjustable-volume pipettor – Oxford Benchmate series or equivalent.

The necessary delivery range will depend on the buffering capacity of the solid material and acid/base strength used in the test.

6.11 Disposable pipettor tips

6.12 Centrifuge (recommended) – Capable of centrifuging the extraction vessels at a rate of 4000 ± 100 rpm for 10 ± 2 min

7.0 REAGENTS AND STANDARDS

7.1 Reagent-grade chemicals, at a minimum, should be used in all tests. Unless otherwise indicated, all reagents should conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society (ACS), where such specifications are available. Other grades may be used, provided the reagents are of sufficiently high purity to permit use without lessening the accuracy of the determination. Inorganic reagents and extracts should be stored in plastic to prevent interaction

of constituents from glass containers. Organic reagents should be stored in glass to prevent leaching of contaminants from plastic containers.

7.2 Reagent water must be interference free. All references to water in this method refer to reagent water unless otherwise specified.

7.3 Consult Methods 9040 and 9050 for additional information regarding the preparation of reagents required for pH and specific conductance measurements.

8.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE

8.1 See Chapter Three, "Inorganic Analytes," and Chapter Four, "Organic Analytes," for sample collection and preservation information.

8.2 All solid samples should be collected using an appropriate sampling plan.

8.3 All containers should be composed of materials that minimize interaction with solution COPCs. For further information, see Chapters Three and Four.

8.4 Preservatives should not be added to samples before extraction.

8.5 Samples can be refrigerated, unless refrigeration results in an irreversible physical change to the sample.

8.6 Analytical extracts or leachates should be preserved according to the guidance given in the individual determinative methods for the COPCs.

8.7 Extract holding times should be consistent with the holding times specified in the individual determinative methods for the COPCs.

9.0 QUALITY CONTROL

9.1 Refer to Chapter One for guidance on quality assurance (QA) and quality control (QC) protocols. When inconsistencies exist between QC guidelines, method-specific QC criteria take precedence over both technique-specific criteria and Chapter One criteria, and technique-specific QC criteria take precedence over Chapter One criteria. Any effort involving the collection of analytical data should include development of a structured and systematic planning document, such as a quality assurance project plan (QAPP) or a sampling and analysis plan (SAP), which translates project objectives and specifications into directions for those who will implement the project and assess the results.

Each laboratory should maintain a formal QA program. The laboratory should also maintain records to document the quality of the data generated. Development of in-house QC limits for each method is encouraged. Use of instrument-specific QC limits is encouraged, provided such limits will generate data appropriate for use in the intended application. All data sheets and QC data should be maintained for reference or inspection.

9.2 In order to demonstrate the purity of reagents and sample contact surfaces, a method blank (e.g., a bottle without solid material but with eluent carried through the extraction, filtration and analytical sample preparation process) should be tested.

9.3 The analysis of extracts should follow appropriate QC procedures, as specified in the determinative methods for the COPCs. Refer to Chapter One for specific QC procedures.

9.4 Solid materials should be tested within one month of receipt unless the project requires that the "as-received" samples are tested sooner (e.g., the material is part of a time-dependent study or the material may change during storage due to oxidation or carbonation).

9.5 Initial demonstration of proficiency (IDP)

Leachate methods are not amenable to typical IDPs when reference materials with known values are not available. However, prior to using this method an analyst should have documented proficiency in the skills required for successful implementation of the method. For example, skill should be demonstrated in the use of an analytical balance, the determination of pH using methods 9040 and 9045 and the determination of conductance using method 9050.

10.0 CALIBRATION AND STANDARDIZATION

10.1 The balance should be calibrated and certified, at a minimum, annually or in accordance with laboratory policy.

10.2 Prior to measurement of eluate pH, the pH meter should be calibrated using a minimum of two standards that bracket the range of pH measurements. Refer to Methods 9040 and 9045 for additional guidance.

10.3 Prior to measurement of eluate conductivity, the meter should be calibrated using at least one standard at a value greater than the range of conductivity measurements. Refer to Method 9050 for additional guidance.

11.0 PROCEDURE

A flowchart of the method is presented in Figure 1. Microsoft Excel® data templates are available to aid in collecting and archiving of laboratory and analytical data.[3]

11.1 Particle size reduction (if required)

11.1.1 In this method, particle size reduction is used to prepare large-grained samples for extraction so that the approach toward liquid-solid equilibrium is enhanced and mass transport through large particles is minimized. A longer extract contact time is required for larger maximum particle size designations. This method designates three maximum particle sizes and associated contact times (see Table 2). The selection of an appropriate maximum

[3] These Excel® templates form the basis for uploading method data into the data management program, LeachXS Lite™. Both the data templates and LeachXS Lite™ are available at http://vanderbilt.edu/leaching.

particle size from this table should be based on professional judgment regarding the practical effort required to size reduce the solid material.

11.1.2 Particle size reduction of "as received" sample may be achieved through crushing, milling, or grinding with equipment made from chemically inert materials. During the reduction process, care should be taken to minimize loss of sample and potentially volatile constituents in the sample.

11.1.3 If the moisture content of the "as-received" material is greater than 15% (wet basis), air drying or desiccation may be necessary. Oven drying is not recommended for preparation of test samples due to the potential for mineral alteration. In all cases, the moisture content of the "as received" material should be recorded.

NOTE: If the solid material is susceptible to interaction with the atmosphere (e.g., carbonation, oxidation), drying should be conducted in an inert environment.

11.1.4 When the material seems to be of a relatively uniform particle size, calculate the percentage less than the sieve size as follows:

$$\%\ \text{Passing} = \frac{M_{sieved}}{M_{total}} \times 100\%$$

Where: M_{sieved} = mass of sample passing the sieve (g)
M_{total} = mass of total sample (g) (e.g., M_{sieved} + mass not passing sieve)

11.1.5 The fraction retained by the sieve should be recycled for further particle size reduction until at least 85% of the initial mass has been reduced below the designated maximum particle size. Calculate and record the final percentage passing the sieve and the designated maximum particle size. For the uncrushable fraction of the "as received" material, record the fraction mass and nature (e.g., rock, metal or glass shards, etc).

11.1.6 Store the size-reduced material in an airtight container in order to prevent contamination via gas exchange with the atmosphere. Store the container in a cool, dark and dry place prior to use.

11.2 Determination of solids and moisture content

11.2.1 In order to provide the dry mass equivalent of the "as-tested" material, the solids content of the subject material should be determined. Often, the moisture content of the solid sample is recorded. In this method, the moisture content is determined and recorded on the basis of the "wet" or "as-tested" sample.

WARNING: The drying oven should be contained in a hood or otherwise properly ventilated. Significant laboratory contamination or inhalation hazards may result when drying heavily contaminated samples. Consult the laboratory safety officer for proper handling procedures prior to drying samples that may contain volatile, hazardous, flammable or explosive materials.

11.2.2 Place a 5 to 10-g sample of solid material into a tared dish or crucible. Dry the sample to a constant mass at 105 ± 2 °C. Check for constant mass by returning the dish to the drying oven for 24 hours, cooling to room temperature in a desiccator and re-weighing. The two mass readings should agree within the larger of 0.2% or 0.02 g.

NOTE: The oven-dried sample is not used for the extraction and should be properly disposed of once the dry mass is determined.

11.2.3 Calculate and report the solids content as follows:

$$SC = \frac{M_{dry}}{M_{test}}$$

Where: SC = solids content of "as-tested" material (g-dry/g)
M_{dry} = mass of dry material specified in the method (g-dry)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)

11.2.4 Calculate and report the moisture content (wet basis) as follows:

$$MC_{wet} = \frac{M_{test} - M_{dry}}{M_{test}}$$

Where: $MC_{(wet)}$ = moisture content on a wet basis (g_{H_2O}/g)
M_{dry} = mass of dry material specified in the method (g-dry)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)

11.3 Extraction setup schedule (Microsoft Excel® spreadsheet template available at http://www.vanderbilt.edu/leaching/downloads/test-methods/).

An Excel® template accompanies this method and may be used to set up the extraction schedule. If using the provided template, disregard Sec. 11.3 and proceed to the extraction procedure Sec. 11.4.

11.3.1 Using the schedule shown in Table 1 as a guide, set up five test extractions and one method blank. The mass of solids in an extraction may be scaled to minimize headspace in each extraction vessel. However, the volume of eluent should always be based on the target L/S in Column B of Table 1.

11.3.2 Calculate and record the amount of "as-tested" material equivalent to the dry mass in Column D of Table 1 as follows:

$$M_{test} = \frac{M_{dry}}{SC}$$

Where: M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)
M_{dry} = mass of dry material specified in the method (g-dry)
SC = solids content of "as-tested" material (g-dry/g)

11.3.3 Calculate and record the volume of moisture contained in the "as-tested" sample in Column E of Table 1 as follows:

$$V_{W,sample} = \frac{M_{test} \times (1 - SC)}{\rho_w}$$

Where: $V_{W,sample}$ = volume of water in the “as tested” sample (mL)
M_{test} = mass of "as-tested" solid equivalent to the dry-material mass (g)
SC = solids content of the "as tested" sample (g-dry/g)
ρ_w = density of water (1.0 g/mL at room temperature)

11.3.4 Calculate and record the volume of reagent water required to bring each extraction to the target L/S in Column F of Table 1 as follows:

$$V_{RW} = M_{dry} \times LS - V_{W,sample}$$

Where: V_{RW} = volume of reagent water required to complete L/S (mL)
M_{dry} = mass of dry material specified in the method (g-dry)
LS = liquid-to-dry-solid ratio (10 mL/g)
$V_{W,sample}$ = volume of water in "as tested" sample (mL)

The size of the extraction bottle should be sufficient to contain the combined volume of solid material and eluent, ideally with a minimum amount of headspace.

11.4 Extraction procedure

11.4.1 Label five bottles with test position numbers and an additional bottle as a method blank according to Column A in Table 1.

11.4.2 Place the dry-mass equivalent (± 0.1 g) of "as-tested" sample as shown in Column D in Table 1 into each of the five test position extraction vessels.

NOTE: Do not put solid material in the method blank extraction vessel.

11.4.3 Add the appropriate volume (± 0.5 mL) of reagent water to both the test position and method blank extraction vessels as specified in Column F of Table 1.

11.4.4 Tighten the leak-proof lid on each bottle and tumble all extractions (i.e., test positions and method blanks) in an end-over-end fashion at a speed of 28 ± 2 rpm at room temperature (20 ± 2 °C). The contact time for this method will vary depending on the maximum particle size as shown in Table 2.

NOTE: The length of the contact time is designed to enhance the approach toward liquid-solid equilibrium. Longer contact times are required for larger particles to compensate for the effects of intra-particle diffusion. See Table 2 for required contact times based on the maximum particle size.

11.4.5 Remove the extraction vessels from the rotary tumbler and clarify the extracts by allowing the bottles to stand for 15 ± 5 min. Alternately, centrifuge the extraction vessels at 4000 ± 100 rpm for 10 ± 2 min.

NOTE: If clarification is significantly incomplete after settling or centrifugation, eluate measurements for pH, conductivity, and oxidization-reduction potential (ORP) may be

taken on filtered samples. In this case, perform the filtration in Sec. 11.4.8 prior to eluate measurement in Sec. 11.4.6 and note the deviation from the written procedure.

CAUTION: Following separation from the solid phase, eluate samples lack the buffering provided by the solid phase and therefore may be susceptible to pH change resulting from interaction with air.

11.4.6 For each extraction vessel, decant a minimum volume (approximately 5 mL) of clear, unpreserved supernatant into a clean container.

11.4.7 Measure and record the pH, specific conductivity, and ORP of the extracts (see Methods 9040, 9045, and 9050).

NOTE: Measurement of pH, conductivity, and ORP should be taken within 15 minutes of eluate processing (Sec. 11.4.8) to avoid neutralization of the solution due to exposure to carbon dioxide, especially when alkaline materials are tested.

NOTE: The measurement of ORP is optional, but strongly recommended, especially when testing materials where oxidation is likely to change the LSP of COPCs.

11.4.8 Separate the solid from the remaining liquid in each extraction vessel by pressure or vacuum filtration through a clean 0.45-µm pore size membrane (Sec. 6.5). The filtration apparatus may be exchanged for a clean apparatus as often as necessary until all liquid has been filtered.

11.4.9 Immediately, preserve and store the volume(s) of eluate required for chemical analysis. Preserve all analytical samples in a manner that is consistent with the determinative chemical analyses to be performed.

12.0 DATA ANALYSIS AND CALCULATIONS (EXCEL® TEMPLATE PROVIDED)

12.1 Data reporting

12.1.1 Figure 2 shows an example of a data sheet that may be used to report the concentration results of this method. This example is included in the Excel® template. At a minimum, the basic test report should include:

a) Name of the laboratory
b) Laboratory technical contact information
c) Date and time at the start of the test
d) Name or code of the solid material
e) Particle size (85 wt% less than designated particle size)
f) Ambient temperature during extraction (°C)
g) Extraction contact time (h)
h) Eluate-specific information (see Sec. 12.1.2 below)

12.1.2 The minimum set of data that should be reported for each eluate includes:

a) Eluate sample ID
b) Target L/S (mL/g-dry)
c) Mass of "as tested" solid material used (g)
d) Moisture content of material used (g_{H_2O}/g)
e) Volume of eluent used (mL)
f) Measured final eluate pH
g) Measured eluate conductivity (mS/cm)
h) Measured ORP (mV) (optional)
i) Concentrations of all COPCs
j) Analytical QC qualifiers as appropriate

12.2 Data interpretation and presentation (optional)

12.2.1 LSP curve

12.2.1.1 A constituent LSP curve can be generated for each COPC after chemical analysis of all extracts by plotting the constituent concentration in the liquid phase as a function of L/S used for each extraction. The curve indicates the equilibrium concentration of the COPC as a function of L/S at the natural pH.

12.2.1.2 The lower limit of quantitation (LLOQ) for the analytical technique for each COPC may be shown as a horizontal line. COPC concentrations below this line indicate negligible or non-quantitative concentrations.

NOTE: The LLOQ is highly matrix-dependent and should be determined as part of a QA/QC plan.

12.2.1.3 Figure 3 provides example LSP curves as a function of L/S for a coal combustion fly ash and a coal combustion flue gas desulfurization filter cake.

13.0 METHOD PERFORMANCE

13.1 Performance data and related information are provided in SW-846 methods only as examples and guidance. The data do not represent required performance criteria for users of the methods. Instead, performance criteria should be developed on a project-specific basis, and the laboratory should establish in-house QC performance criteria for the application of this method. Performance data must not be used as absolute QC acceptance criteria for purposes of laboratory QC or accreditation.

13.2 Interlaboratory validation of this method was conducted using a coal combustion fly ash (material code EaFA), a contaminated smelter site soil (material code CFS) and a solidified waste analog (material code SWA). The median values and inner quartile ranges (IQRs) for repeatability and reproducibility were determined for eluate concentration results across all study materials and pH target values (see Table 3). More details on the interlaboratory validation may be found in Ref. 2.

13.3 Ref. 1 and Ref. 4 may provide additional guidance and insight on the use, performance and application of this method.

14.0 POLLUTION PREVENTION

14.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity and/or toxicity of waste at the point of generation. Numerous opportunities for pollution prevention exist in laboratory operations. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to address their waste generation. When wastes cannot be feasibly reduced at the source, the Agency recommends recycling as the next best option.

14.2 For information about pollution prevention that may be applicable to laboratories and research institutions consult *Less is Better: Laboratory Chemical Management for Waste Reduction,* a free publication available from the ACS, Committee on Chemical Safety, http://portal.acs.org/portal/fileFetch/C/WPCP_012290/pdf/WPCP_012290.pdf.

15.0 WASTE MANAGEMENT

The EPA requires that laboratory waste management practices be conducted consistent with all applicable rules and regulations. Laboratories are urged to protect the air, water, and land by minimizing and controlling all releases from hoods and bench operations, complying with the letter and spirit of any sewer discharge permits and regulations, and by complying with all solid and hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions. For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel* available from ACS at the web address listed in Sec. 14.2.

16.0 REFERENCES

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5. EN12457, "Characterization of Waste – Leaching – Compliance Test for Leaching of Granular Waste Materials and Sludges," *Comité Européen de Normalisation*, Brussels, Belgium, 2001.

6. F. Sanchez, R. Keeney, D.S. Kosson, and R. DeLapp, "Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control," EPA-600/R-06/008, *U.S. Environmental Protection Agency*, Washington DC, 2006.

7. F. Sanchez, D.S. Kosson, R. Keeney, R. DeLapp, L. Turner, and P. Kariher, "Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control," EPA-600/R-08/077, *U.S. Environmental Protection Agency*, Washington DC, 2008.

17.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA

The following pages contain the tables and figures referenced by this method.

TABLE 1

EXAMPLE SCHEDULE FOR EXTRACTION SETUP

A	B	C	D	E	F	G
Test Position	Target LS	Minimum Dry Mass (g-dry)	Mass of "As-Tested" Sample (g)	Moisture in "As-Tested" Sample (mL)	Volume of Reagent Water (mL)	Recommended Bottle Size (mL)
T01	10.0	20	22.2	2.2	198	250
T02	5.0	40	44.4	4.4	196	250
T03	2.0	100	111.1	11.1	189	500
T04	1.0	200	222.2	22.2	178	500
T05	0.5	400	444.4	44.4	156	1000
B03	QC	–	–	–	200	250
Total	–	–	844.4	–	1120	–

NOTE: 1) This schedule assumes a target liquid volume of 200 mL.
2) This schedule is based on "as tested" solids content of 0.90 g-dry/g.
3) Test position marked B01 is a method blank of reagent water.

Table data modified from Ref. 4.

TABLE 2

EXTRACTION PARAMETERS AS FUNCTION OF MAXIMUM PARTICLE SIZE

Particle Size (85% less than) (mm)	US Sieve Size	Minimum Dry Mass (g-dry)	Contact Time (h)	Recommended Vessel size (mL)
0.3	50	20 ± 0.05	24 ± 2	250
2.0	10	40 ± 0.1	48 ± 2	500
5.0	4	80 ± 0.1	72 ± 2	1000

R000195

TABLE 3

MEDIAN METHOD PRECISION ACROSS STUDY MATERIALS

Analyte	Symbol	Repeatability - Median $\%RSD_r$	Repeatability - IQR $\%RSD_r$	Reproducibility - Median $\%RSD_R$	Reproducibility - IQR $\%\ RSD_R$
Antimony	Sb	12%	8-13%	21%	17-27%
Arsenic	As	15%	12-28%	31%	23-34%
Barium	Ba	7%	5-9%	16%	13-30%
Boron	B	7%	5-10%	13%	9-34%
Calcium	Ca	6%	3-7%	8%	7-19%
Molybdenum	Mo	7%	6-9%	18%	11-31%
Selenium	Se	8%	4-9%	20%	13-24%
Vanadium	V	6%	4-12%	16%	13-26%
Median of Medians	–	7%	3-28%	17%	7-34%

Data taken from Ref. 2.

FIGURE 1

METHOD FLOWCHART

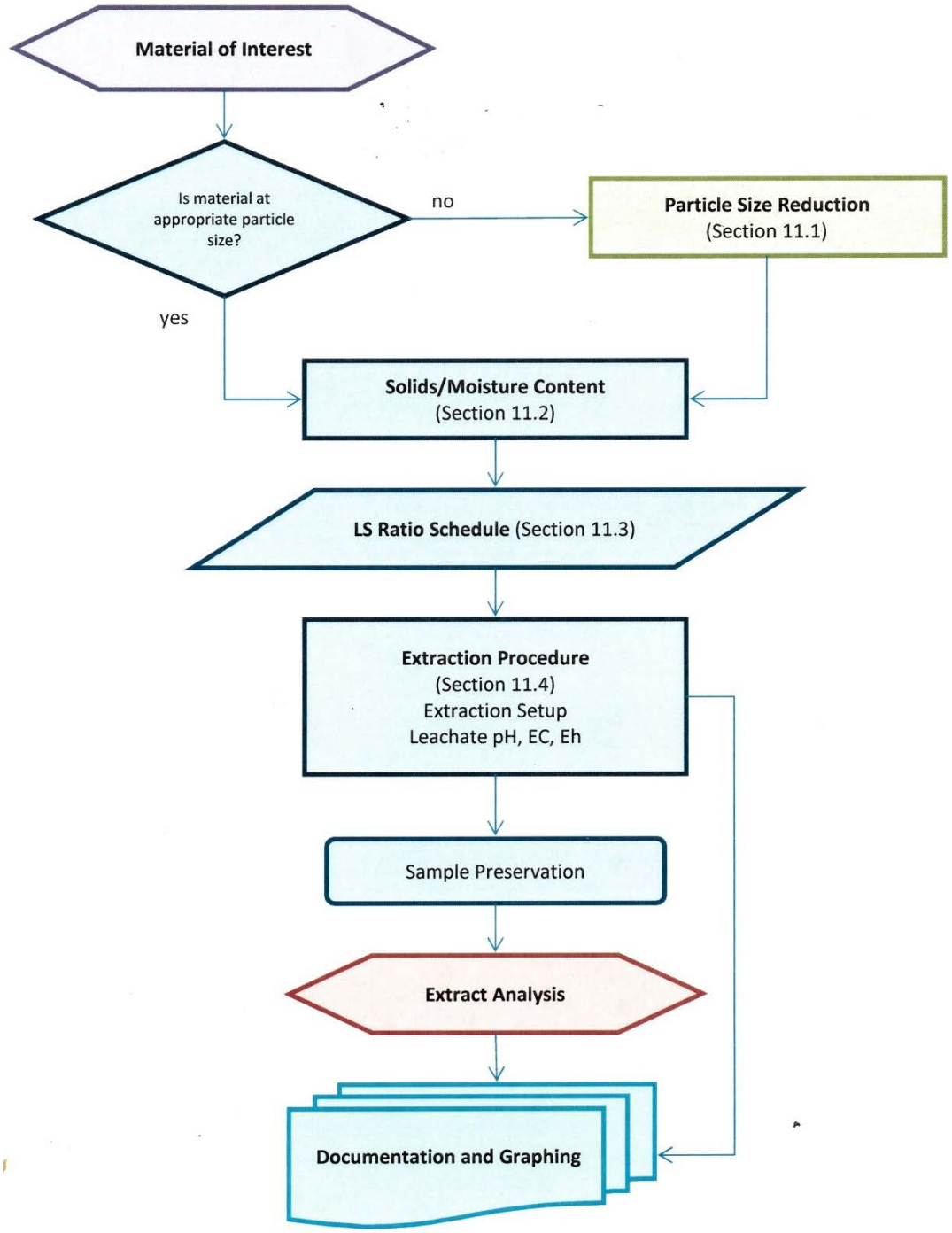


FIGURE 2

EXAMPLE DATA REPORTING FORMAT

EPA METHOD 1316
Report of Analysis

ABC Laboratories
123 Main Street
Anytown, USA
Contact: John Smith
(555) 111-1111

Client Contact: Susan Jones
(555) 222-2222

Material Code:	**FAX**	Particle Size:	88% passing 2-mm sieve
Material Type:	Coal Combustion Fly Ash	Contact Time:	860 g
Date Received:	10/1/20xx	Lab Temperature:	21 ± 2 °C
Test Start Date:	11/1/20xx	Eluent Used:	ASTM Type II Water
Report Date:	12/1/20xx		

Test Position	Replicate	Value	Units	Method	Note
T01	**A**				
	Eluate Sample ID	**XYZ-1316-T01-A**			
	Solid Material	40.0	g		
	Moisture Content	0.01	g_{H_2O}/g		
	Water Added	386.0	mL		
	Target L/S	10.0	mL/g-dry		
	Eluate pH	1.89	–	EPA 9040	
	Eluate Conductivity	12.6	mS/cm	EPA 9050	
	Eluate ORP	203	mv		

Chemical Analysis	Value	Units	QC Flag	Method	Date	Dilution Factor
Al	216.0	mg/L		EPA 6020	11/7/20xx	1000
As	7.64	mg/L		EPA 6020	11/7/20xx	10
Cl	< 4.13	mg/L	U	EPA 9056	11/9/20xx	1

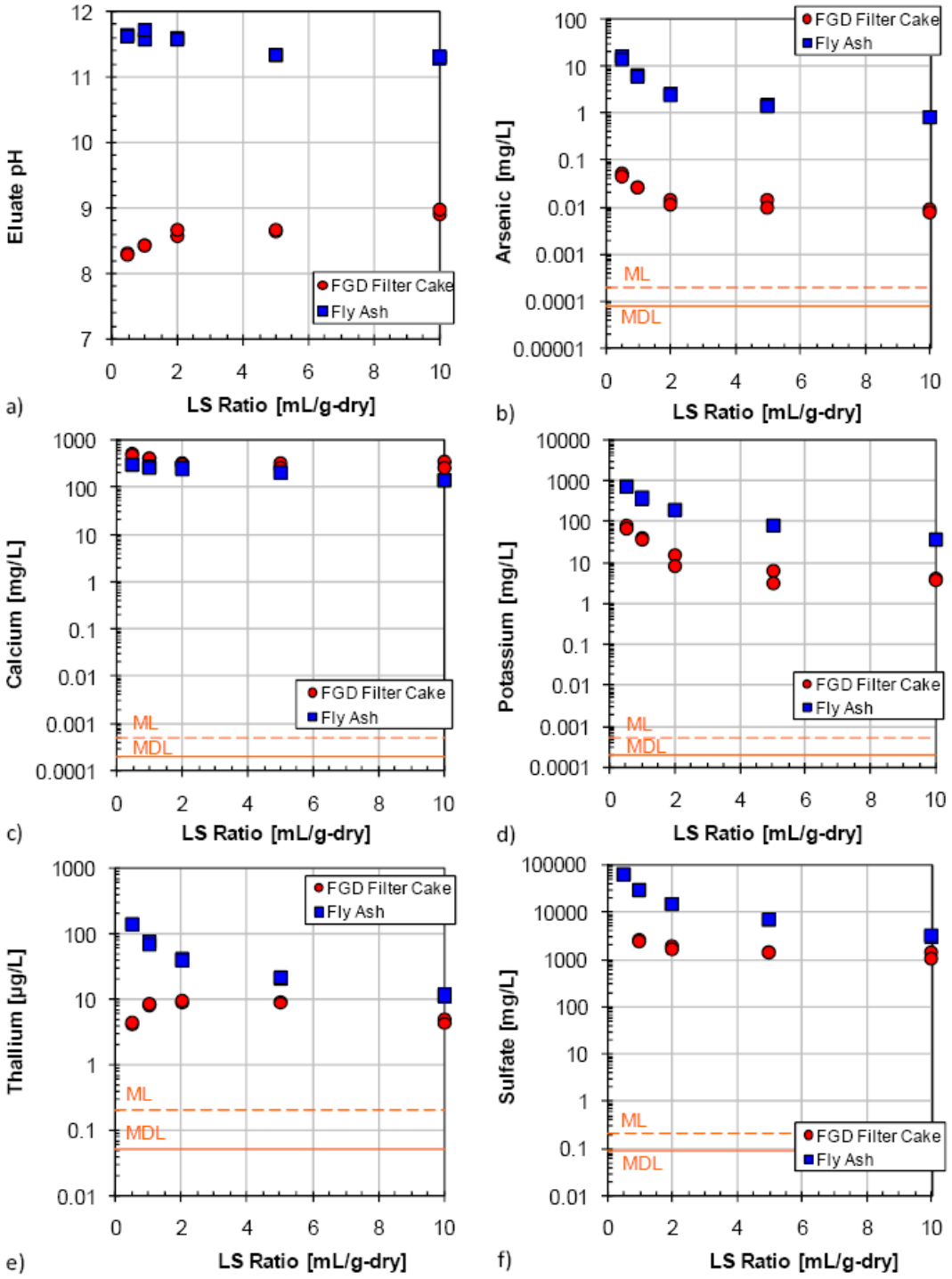
Test Position	Replicate	Value	Units	Method	Note
T02	**A**				
	Eluate Sample ID	**XYZ-1316-T02-A**			
	Solid Material	20.0	g		
	Moisture Content	0.01	g_{H_2O}/g		
	Water Added	400.0	mL		
	Target L/S	5.0	mL/g-		
	Eluate pH	3.86	–	EPA 9040	
	Eluate Conductivity	0.99	mS/cm	EPA 9050	
	Eluate ORP	180	mv		

Chemical Analysis	Value	Units	QC Flag	Method	Date	Dilution Factor
Al	449.0	mg/L		EPA 6020	11/7/20xx	1000
As	97.9	mg/L		EPA 6020	11/7/20xx	10
Cl	< 4.13	mg/L	U	EPA 9056	11/7/20xx	1

QC Flag Key: U Value below lower limit of quantitation as reported (<"LLOQ")

FIGURE 3

EXAMPLE CONCENTRATON RESULTS FROM A COAL COMBUSTION FLY ASH AND FLUE-GAS DESULFURIZATION FILTER CAKE



DOCUMENT 8

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION I

LOW STRESS (low flow) PURGING AND SAMPLING PROCEDURE FOR THE COLLECTION OF GROUNDWATER SAMPLES FROM MONITORING WELLS

Quality Assurance Unit
U.S. Environmental Protection Agency – Region 1
11 Technology Drive
North Chelmsford, MA 01863

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Prepared by: ROBERT REINHART Digitally signed by ROBERT REINHART Date: 2017.09.19 16:15:38 -04'00'
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Approved by: JOHN SMALDONE Digitally signed by JOHN SMALDONE Date: 2017.09.20 15:11:00 -04'00'
(John Smaldone, Quality Assurance Unit) Date

Revision Page

Date	Rev #	Summary of changes	Sections
7/30/96	1	Finalized	
01/19/10	2	Updated	All sections
3/23/17	3	Updated	All sections
9/20/17	4	Updated	Section 7.0

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1.0 USE OF TERMS

Equipment blank: The equipment blank shall include the pump and the pump's tubing. If tubing is dedicated to the well, the equipment blank needs only to include the pump in subsequent sampling rounds. If the pump and tubing are dedicated to the well, the equipment blank is collected prior to its placement in the well. If the pump and tubing will be used to sample multiple wells, the equipment blank is normally collected after sampling from contaminated wells and not after background wells.

Field duplicates: Field duplicates are collected to determine precision of the sampling procedure. For this procedure, collect duplicate for each analyte group in consecutive order (VOC original, VOC duplicate, SVOC original, SVOC duplicate, etc.).

Indicator field parameters: This SOP uses field measurements of turbidity, dissolved oxygen, specific conductance, temperature, pH, and oxidation/reduction potential (ORP) as indicators of when purging operations are sufficient and sample collection may begin.

Matrix Spike/Matrix Spike Duplicates: Used by the laboratory in its quality assurance program. Consult the laboratory for the sample volume to be collected.

Potentiometric Surface: The level to which water rises in a tightly cased well constructed in a confined aquifer. In an unconfined aquifer, the potentiometric surface is the water table.

QAPP: Quality Assurance Project Plan

SAP: Sampling and Analysis Plan

SOP: Standard operating procedure

Stabilization: A condition that is achieved when all indicator field parameter measurements are sufficiently stable (as described in the "Monitoring Indicator Field Parameters" section) to allow sample collection to begin.

Temperature blank: A temperature blank is added to each sample cooler. The blank is measured upon receipt at the laboratory to assess whether the samples were properly cooled during transit.

Trip blank (VOCs): Trip blank is a sample of analyte-free water taken to the sampling site and returned to the laboratory. The trip blanks (one pair) are added to each sample cooler that contains VOC samples.

2.0 SCOPE & APPLICATION

The goal of this groundwater sampling procedure is to collect water samples that reflect the total mobile organic and inorganic loads (dissolved and colloidal sized fractions) transported through the subsurface under ambient flow conditions, with minimal physical and chemical alterations from sampling operations. This standard operating procedure (SOP) for collecting groundwater samples will help ensure that the project's data quality objectives (DQOs) are met under certain low-flow conditions.

The SOP emphasizes the need to minimize hydraulic stress at the well-aquifer interface by maintaining low water-level drawdowns, and by using low pumping rates during purging and sampling operations. Indicator field parameters (e.g., dissolved oxygen, pH, etc.) are monitored during purging in order to determine when sample collection may begin. Samples properly collected using this SOP are suitable for analysis of groundwater contaminants (volatile and semi-volatile organic analytes, dissolved gases, pesticides, PCBs, metals and other inorganics), or naturally occurring analytes. This SOP is based on Puls, and Barcelona (1996).

This procedure is designed for monitoring wells with an inside diameter (1.5-inches or greater) that can accommodate a positive lift pump with a screen length or open interval ten feet or less and with a water level above the top of the screen or open interval (Hereafter, the "screen or open interval" will be referred to only as "screen interval"). This SOP is not applicable to other well-sampling conditions.

While the use of dedicated sampling equipment is not mandatory, dedicated pumps and tubing can reduce sampling costs significantly by streamlining sampling activities and thereby reducing the overall field costs.

The goal of this procedure is to emphasize the need for consistency in deploying and operating equipment while purging and sampling monitoring wells during each sampling event. This will help to minimize sampling variability.

This procedure describes a general framework for groundwater sampling. Other site specific information (hydrogeological context, conceptual site model (CSM), DQOs, etc.) coupled with systematic planning must be added to the procedure in order to develop an appropriate site specific SAP/QAPP. In addition, the site specific SAP/QAPP must identify the specific equipment that will be used to collect the groundwater samples.

This procedure does not address the collection of water or free product samples from wells containing free phase LNAPLs and/or DNAPLs (light or dense non-aqueous phase

liquids). For this type of situation, the reader may wish to check: Cohen, and Mercer (1993) or other pertinent documents.

This SOP is to be used when collecting groundwater samples from monitoring wells at all Superfund, Federal Facility and RCRA sites in Region 1 under the conditions described herein. Request for modification of this SOP, in order to better address specific situations at individual wells, must include adequate technical justification for proposed changes. All changes and modifications must be approved and included in a revised SAP/QAPP before implementation in field.

3.0 BACKGROUND FOR IMPLEMENTATION

It is expected that the monitoring well screen has been properly located (both laterally and vertically) to intercept existing contaminant plume(s) or along flow paths of potential contaminant migration. Problems with inappropriate monitoring well placement or faulty/improper well installation cannot be overcome by even the best water sampling procedures. This SOP presumes that the analytes of interest are moving (or will potentially move) primarily through the more permeable zones intercepted by the screen interval.

Proper well construction, development, and operation and maintenance cannot be overemphasized. The use of installation techniques that are appropriate to the hydrogeologic setting of the site often prevent "problem well" situations from occurring. During well development, or redevelopment, tests should be conducted to determine the hydraulic characteristics of the monitoring well. The data can then be used to set the purging/sampling rate, and provide a baseline for evaluating changes in well performance and the potential need for well rehabilitation. Note: if this installation data or well history (construction and sampling) is not available or discoverable, for all wells to be sampled, efforts to build a sampling history should commence with the next sampling event.

The pump intake should be located within the screen interval and at a depth that will remain under water at all times. It is recommended that the intake depth and pumping rate remain the same for all sampling events. The mid-point or the lowest historical midpoint of the saturated screen length is often used as the location of the pump intake. For new wells, or for wells without pump intake depth information, the site's SAP/QAPP must provide clear reasons and instructions on how the pump intake depth(s) will be selected, and reason(s) for the depth(s) selected. If the depths to top and bottom of the well screen are not known, the SAP/QAPP will need to describe how the sampling depth will be determined and how the data can be used.

Stabilization of indicator field parameters is used to indicate that conditions are suitable for sampling to begin. Achievement of turbidity levels of less than 5 NTU, and stable drawdowns of less than 0.3 feet, while desirable, are not mandatory. Sample collection

may still take place provided the indicator field parameter criteria in this procedure are met. If after 2 hours of purging indicator field parameters have not stabilized, one of three optional courses of action may be taken: a) continue purging until stabilization is achieved, b) discontinue purging, do not collect any samples, and record in log book that stabilization could not be achieved (documentation must describe attempts to achieve stabilization), c) discontinue purging, collect samples and provide full explanation of attempts to achieve stabilization (note: there is a risk that the analytical data obtained, especially metals and strongly hydrophobic organic analytes, may reflect a sampling bias and therefore, the data may not meet the data quality objectives of the sampling event).

It is recommended that low-flow sampling be conducted when the air temperature is above 32°F (0°C). If the procedure is used below 32°F, special precautions will need to be taken to prevent the groundwater from freezing in the equipment. Because sampling during freezing temperatures may adversely impact the data quality objectives, the need for water sample collection during months when these conditions are likely to occur should be evaluated during site planning and special sampling measures may need to be developed. Ice formation in the flow-through-cell will cause the monitoring probes to act erratically. A transparent flow-through-cell needs to be used to observe if ice is forming in the cell. If ice starts to form on the other pieces of the sampling equipment, additional problems may occur.

4.0 HEALTH & SAFETY

When working on-site, comply with all applicable OSHA requirements and the site's health/safety procedures. All proper personal protection clothing and equipment are to be worn. Some samples may contain biological and chemical hazards. These samples should be handled with suitable protection to skin, eyes, etc.

5.0 CAUTIONS

The following cautions need to be considered when planning to collect groundwater samples when the below conditions occur.

If the groundwater degasses during purging of the monitoring well, dissolved gases and VOCs will be lost. When this happens, the groundwater data for dissolved gases (e.g., methane, ethene, ethane, dissolved oxygen, etc.) and VOCs will need to be qualified. Some conditions that can promote degassing are the use of a vacuum pump (e.g., peristaltic pumps), changes in aperture along the sampling tubing, and squeezing/pinching the pump's tubing which results in a pressure change.

When collecting the samples for dissolved gases and VOCs analyses, avoid aerating the groundwater in the pump's tubing. This can cause loss of the dissolved gases and VOCs in

the groundwater. Having the pump's tubing completely filled prior to sampling will avoid this problem when using a centrifugal pump or peristaltic pump.

Direct sun light and hot ambient air temperatures may cause the groundwater in the tubing and flow-through-cell to heat up. This may cause the groundwater to degas which will result in loss of VOCs and dissolved gases. When sampling under these conditions, the sampler will need to shade the equipment from the sunlight (e.g., umbrella, tent, etc.). If possible, sampling on hot days, or during the hottest time of the day, should be avoided. The tubing exiting the monitoring well should be kept as short as possible to avoid the sun light or ambient air from heating up the groundwater.

Thermal currents in the monitoring well may cause vertical mixing of water in the well bore. When the air temperature is colder than the groundwater temperature, it can cool the top of the water column. Colder water which is denser than warm water sinks to the bottom of the well and the warmer water at the bottom of the well rises, setting up a convection cell. "During low-flow sampling, the pumped water may be a mixture of convecting water from within the well casing and aquifer water moving inward through the screen. This mixing of water during low-flow sampling can substantially increase equilibration times, can cause false stabilization of indicator parameters, can give false indication of redox state, and can provide biological data that are not representative of the aquifer conditions" (Vroblesky 2007).

Failure to calibrate or perform proper maintenance on the sampling equipment and measurement instruments (e.g., dissolved oxygen meter, etc.) can result in faulty data being collected.

Interferences may result from using contaminated equipment, cleaning materials, sample containers, or uncontrolled ambient/surrounding air conditions (e.g., truck/vehicle exhaust nearby).

Cross contamination problems can be eliminated or minimized through the use of dedicated sampling equipment and/or proper planning to avoid ambient air interferences. Note that the use of dedicated sampling equipment can also significantly reduce the time needed to complete each sampling event, will promote consistency in the sampling, and may reduce sampling bias by having the pump's intake at a constant depth.

Clean and decontaminate all sampling equipment prior to use. All sampling equipment needs to be routinely checked to be free from contaminants and equipment blanks collected to ensure that the equipment is free of contaminants. Check the previous equipment blank data for the site (if they exist) to determine if the previous cleaning procedure removed the contaminants. If contaminants were detected and they are a concern, then a more vigorous cleaning procedure will be needed.

6.0 PERSONNEL QUALIFICATIONS

All field samplers working at sites containing hazardous waste must meet the requirements of the OSHA regulations. OSHA regulations may require the sampler to take the 40 hour OSHA health and safety training course and a refresher course prior to engaging in any field activities, depending upon the site and field conditions.

The field samplers must be trained prior to the use of the sampling equipment, field instruments, and procedures. Training is to be conducted by an experienced sampler before initiating any sampling procedure.

The entire sampling team needs to read, and be familiar with, the site Health and Safety Plan, all relevant SOPs, and SAP/QAPP (and the most recent amendments) before going onsite for the sampling event. It is recommended that the field sampling leader attest to the understanding of these site documents and that it is recorded.

7.0 EQUIPMENT AND SUPPLIES

A. Informational materials for sampling event

A copy of the current Health and Safety Plan, SAP/QAPP, monitoring well construction data, location map(s), field data from last sampling event, manuals for sampling, and the monitoring instruments' operation, maintenance, and calibration manuals should be brought to the site.

B. Well keys.

C. Extraction device

Adjustable rate, submersible pumps (e.g., centrifugal, bladder, etc.) which are constructed of stainless steel or polytetrafluoroethylene (PTFE, i.e. Teflon®) are preferred. PTFE, however, should not be used when sampling for per- and polyfluoroalkyl substances (PFAS) as it is likely to contain these substances.

Note: If extraction devices constructed of other materials are to be used, adequate information must be provided to show that the substituted materials do not leach contaminants nor cause interferences to the analytical procedures to be used. Acceptance of these materials must be obtained before the sampling event.

If bladder pumps are selected for the collection of VOCs and dissolved gases, the pump setting should be set so that one pulse will deliver a water volume that is sufficient to fill a 40 mL VOC vial. This is not mandatory, but is considered a "best practice". For the proper operation, the bladder pump will need a minimum amount of water above the pump; consult the manufacturer for the recommended submergence. The pump's recommended submergence value should be determined during the planning stage, since it may influence well construction and placement of dedicated pumps where water-level fluctuations are significant.

Adjustable rate, peristaltic pumps (suction) are to be used with caution when collecting samples for VOCs and dissolved gases (e.g., methane, carbon dioxide, etc.) analyses. Additional information on the use of peristaltic pumps can be found in Appendix A. If peristaltic pumps are used, the inside diameter of the rotor head tubing needs to match the inside diameter of the tubing installed in the monitoring well.

Inertial pumping devices (motor driven or manual) are not recommended. These devices frequently cause greater disturbance during purging and sampling, and are less easily controlled than submersible pumps (potentially increasing turbidity and sampling variability, etc.). This can lead to sampling results that are adversely affected by purging and sampling operations, and a higher degree of data variability.

D. Tubing

PTFE (Teflon®) or PTFE-lined polyethylene tubing are preferred when sampling is to include VOCs, SVOCs, pesticides, PCBs and inorganics. As discussed in the previous section, PTFE tubing should not be used when sampling for PFAS. In this case, a suitable alternative such as high-density polyethylene tubing should be used.

PVC, polypropylene or polyethylene tubing may be used when collecting samples for metal and other inorganics analyses.

Note: If tubing constructed of other materials is to be used, adequate information must be provided to show that the substituted materials do not leach contaminants nor cause interferences to the analytical procedures to be used. Acceptance of these materials must be obtained before the sampling event.

The use of 1/4 inch or 3/8 inch (inside diameter) tubing is recommended. This will help ensure that the tubing remains liquid filled when operating at very low pumping rates when using centrifugal and peristaltic pumps.

Silastic tubing should be used for the section around the rotor head of a peristaltic pump. It should be less than a foot in length. The inside diameter of the tubing used at the pump rotor head must be the same as the inside diameter of tubing placed in the well. A tubing connector is used to connect the pump rotor head tubing to the well tubing. Alternatively, the two pieces of tubing can be connected to each other by placing the one end of the tubing inside the end of the other tubing. The tubing must not be reused.

E. The water level measuring device

Electronic ”tape”, pressure transducer, water level sounder/level indicator, etc. should be capable of measuring to 0.01 foot accuracy. Recording pressure transducers, mounted above the pump, are especially helpful in tracking water levels during pumping operations, but their use must include check measurements with a water level “tape” at the start and end of each sampling event.

F. Flow measurement supplies

Graduated cylinder (size according to flow rate) and stopwatch usually will suffice.

Large graduated bucket used to record total water purged from the well.

G. Interface probe

To be used to check on the presence of free phase liquids (LNAPL, or DNAPL) before purging begins (as needed).

H. Power source (generator, nitrogen tank, battery, etc.)

When a gasoline generator is used, locate it downwind and at least 30 feet from the well so that the exhaust fumes do not contaminate samples.

I. Indicator field parameter monitoring instruments

Use of a multi-parameter instrument capable of measuring pH, oxidation/reduction potential (ORP), dissolved oxygen (DO), specific conductance, temperature, and coupled with a flow-through-cell is required when measuring all indicator field parameters, except turbidity. Turbidity is collected using a separate instrument. Record equipment/instrument identification (manufacturer, and model number).

Transparent, small volume flow-through-cells (e.g., 250 mLs or less) are preferred. This allows observation of air bubbles and sediment buildup in the cell, which can interfere with the operation of the monitoring instrument probes, to be easily detected. A small volume

cell facilitates rapid turnover of water in the cell between measurements of the indicator field parameters.

It is recommended to use a flow-through-cell and monitoring probes from the same manufacturer and model to avoid incompatibility between the probes and flow-through-cell.

Turbidity samples are collected before the flow-through-cell. A "T" connector coupled with a valve is connected between the pump's tubing and flow-through-cell. When a turbidity measurement is required, the valve is opened to allow the groundwater to flow into a container. The valve is closed and the container sample is then placed in the turbidimeter.

Standards are necessary to perform field calibration of instruments. A minimum of two standards are needed to bracket the instrument measurement range for all parameters except ORP which use a Zobell solution as a standard. For dissolved oxygen, a wet sponge used for the 100% saturation and a zero dissolved oxygen solution are used for the calibration.

Barometer (used in the calibration of the Dissolved Oxygen probe) and the conversion formula to convert the barometric pressure into the units of measure used by the Dissolved Oxygen meter are needed.

J. Decontamination supplies

Includes (for example) non-phosphate detergent, distilled/deionized water, isopropyl alcohol, etc.

K. Record keeping supplies

Logbook(s), well purging forms, chain-of-custody forms, field instrument calibration forms, etc.

L. Sample bottles

M. Sample preservation supplies (as required by the analytical methods)

N. Sample tags or labels

O. PID or FID instrument

If appropriate, to detect VOCs for health and safety purposes, and provide qualitative field evaluations.

P. Miscellaneous Equipment

Equipment to keep the sampling apparatus shaded in the summer (e.g., umbrella) and from freezing in the winter. If the pump's tubing is allowed to heat up in the warm weather, the cold groundwater may degas as it is warmed in the tubing.

8.0 EQUIPMENT/INSTRUMENT CALIBRATION

Prior to the sampling event, perform maintenance checks on the equipment and instruments according to the manufacturer's manual and/or applicable SOP. This will ensure that the equipment/instruments are working properly before they are used in the field.

Prior to sampling, the monitoring instruments must be calibrated and the calibration documented. The instruments are calibrated using U.S Environmental Protection Agency Region 1 *Calibration of Field Instruments (temperature, pH, dissolved oxygen, conductivity/specific conductance, oxidation/reduction [ORP], and turbidity),* March 23, 2017, or latest version or from one of the methods listed in 40CFR136, 40CFR141 and SW-846.

The instruments shall be calibrated at the beginning of each day. If the field measurement falls outside the calibration range, the instrument must be re-calibrated so that all measurements fall within the calibration range. At the end of each day, a calibration check is performed to verify that instruments remained in calibration throughout the day. This check is performed while the instrument is in measurement mode, not calibration mode. If the field instruments are being used to monitor the natural attenuation parameters, then a calibration check at mid-day is highly recommended to ensure that the instruments did not drift out of calibration. Note: during the day if the instrument reads zero or a negative number for dissolved oxygen, pH, specific conductance, or turbidity (negative value only), this indicates that the instrument drifted out of calibration or the instrument is malfunctioning. If this situation occurs the data from this instrument will need to be qualified or rejected.

9.0 PRELIMINARY SITE ACTIVITIES (as applicable)

Check the well for security (damage, evidence of tampering, missing lock, etc.) and record pertinent observations (include photograph as warranted).

If needed, lay out a sheet of clean polyethylene for monitoring and sampling equipment, unless equipment is elevated above the ground (e.g., on a table, etc.).

Remove well cap and if appropriate measure VOCs at the rim of the well with a PID or FID instrument and record reading in field logbook or on the well purge form.

If the well casing does not have an established reference point (usually a V-cut or indelible mark in the well casing), make one. Describe its location and record the date of the mark in the logbook (consider a photographic record as well). All water level measurements must be recorded relative to this reference point (and the altitude of this point should be determined using techniques that are appropriate to site's DQOs.

If water-table or potentiometric surface map(s) are to be constructed for the sampling event, perform synoptic water level measurement round (in the shortest possible time) before any purging and sampling activities begin. If possible, measure water level depth (to 0.01 ft.) and total well depth (to 0.1 ft.) the day before sampling begins, in order to allow for re-settlement of any particulates in the water column. This is especially important for those wells that have not been recently sampled because sediment buildup in the well may require the well to be redeveloped. If measurement of total well depth is not made the day before, it should be measured after sampling of the well is complete. All measurements must be taken from the established referenced point. Care should be taken to minimize water column disturbance.

Check newly constructed wells for the presence of LNAPLs or DNAPLs before the initial sampling round. If none are encountered, subsequent check measurements with an interface probe may not be necessary unless analytical data or field analysis signal a worsening situation. This SOP cannot be used in the presence of LNAPLs or DNAPLs. If NAPLs are present, the project team must decide upon an alternate sampling method. All project modifications must be approved and documented prior to implementation.

If available check intake depth and drawdown information from previous sampling event(s) for each well. Duplicate, to the extent practicable, the intake depth and extraction rate (use final pump dial setting information) from previous event(s). If changes are made in the intake depth or extraction rate(s) used during previous sampling event(s), for either portable or dedicated extraction devices, record new values, and explain reasons for the changes in the field logbook.

10.0 PURGING AND SAMPLING PROCEDURE

Purging and sampling wells in order of increasing chemical concentrations (known or anticipated) are preferred.

The use of dedicated pumps is recommended to minimize artificial mobilization and entrainment of particulates each time the well is sampled. Note that the use of dedicated sampling equipment can also significantly reduce the time needed to complete each sampling event, will promote consistency in the sampling, and may reduce sampling bias by having the pump's intake at a constant depth.

A. Initial Water Level

Measure the water level in the well before installing the pump if a non-dedicated pump is being used. The initial water level is recorded on the purge form or in the field logbook.

B. Install Pump

Lower pump, safety cable, tubing and electrical lines slowly (to minimize disturbance) into the well to the appropriate depth (may not be the mid-point of the screen/open interval). The Sampling and Analysis Plan/Quality Assurance Project Plan should specify the sampling depth (used previously), or provide criteria for selection of intake depth for each new well. If possible keep the pump intake at least two feet above the bottom of the well, to minimize mobilization of particulates present in the bottom of the well.

Pump tubing lengths, above the top of well casing should be kept as short as possible to minimize heating the groundwater in the tubing by exposure to sun light and ambient air temperatures. Heating may cause the groundwater to degas, which is unacceptable for the collection of samples for VOC and dissolved gases analyses.

C. Measure Water Level

Before starting pump, measure water level. Install recording pressure transducer, if used to track drawdowns, to initialize starting condition.

D. Purge Well

From the time the pump starts purging and until the time the samples are collected, the purged water is discharged into a graduated bucket to determine the total volume of groundwater purged. This information is recorded on the purge form or in the field logbook.

Start the pump at low speed and slowly increase the speed until discharge occurs. Check water level. Check equipment for water leaks and if present fix or replace the affected equipment. Try to match pumping rate used during previous sampling event(s). Otherwise, adjust pump speed until there is little or no water level drawdown. If the

minimal drawdown that can be achieved exceeds 0.3 feet, but remains stable, continue purging.

Monitor and record the water level and pumping rate every five minutes (or as appropriate) during purging. Record any pumping rate adjustments (both time and flow rate). Pumping rates should, as needed, be reduced to the minimum capabilities of the pump to ensure stabilization of the water level. Adjustments are best made in the first fifteen minutes of pumping in order to help minimize purging time. During pump start-up, drawdown may exceed the 0.3 feet target and then "recover" somewhat as pump flow adjustments are made. Purge volume calculations should utilize stabilized drawdown value, not the initial drawdown. If the initial water level is above the top of the screen do not allow the water level to fall into the well screen. The final purge volume must be greater than the stabilized drawdown volume plus the pump's tubing volume. If the drawdown has exceeded 0.3 feet and stabilizes, calculate the volume of water between the initial water level and the stabilized water level. Add the volume of the water which occupies the pump's tubing to this calculation. This combined volume of water needs to be purged from the well after the water level has stabilized before samples are collected.

Avoid the use of constriction devices on the tubing to decrease the flow rate because the constrictor will cause a pressure difference in the water column. This will cause the groundwater to degas and result in a loss of VOCs and dissolved gasses in the groundwater samples.

Note: the flow rate used to achieve a stable pumping level should remain constant while monitoring the indicator parameters for stabilization and while collecting the samples.

Wells with low recharge rates may require the use of special pumps capable of attaining very low pumping rates (e.g., bladder, peristaltic), and/or the use of dedicated equipment. For new monitoring wells, or wells where the following situation has not occurred before, if the recovery rate to the well is less than 50 mL/min., or the well is being essentially dewatered during purging, the well should be sampled as soon as the water level has recovered sufficiently to collect the volume needed for all anticipated samples. The project manager or field team leader will need to make the decision when samples should be collected, how the sample is to be collected, and the reasons recorded on the purge form or in the field logbook. A water level measurement needs to be performed and recorded before samples are collected. If the project manager decides to collect the samples using the pump, it is best during this recovery period that the pump intake tubing not be removed, since this will aggravate any turbidity problems. Samples in this specific situation may be collected without stabilization of indicator field parameters. Note that field conditions and efforts to overcome problematic situations must be recorded in order to support field decisions to deviate from normal procedures described in this SOP. If this type of problematic situation persists in a well, then water sample collection should be

changed to a passive or no-purge method, if consistent with the site's DQOs, or have a new well installed.

E. Monitor Indicator Field Parameters

After the water level has stabilized, connect the "T" connector with a valve and the flow-through-cell to monitor the indicator field parameters. If excessive turbidity is anticipated or encountered with the pump startup, the well may be purged for a while without connecting up the flow-through-cell, in order to minimize particulate buildup in the cell (This is a judgment call made by the sampler). Water level drawdown measurements should be made as usual. If possible, the pump may be installed the day before purging to allow particulates that were disturbed during pump insertion to settle.

During well purging, monitor indicator field parameters (turbidity, temperature, specific conductance, pH, ORP, DO) at a frequency of five minute intervals or greater. The pump's flow rate must be able to "turn over" at least one flow-through-cell volume between measurements (for a 250 mL flow-through-cell with a flow rate of 50 mLs/min., the monitoring frequency would be every five minutes; for a 500 mL flow-through-cell it would be every ten minutes). If the cell volume cannot be replaced in the five minute interval, then the time between measurements must be increased accordingly. Note: during the early phase of purging, emphasis should be put on minimizing and stabilizing pumping stress, and recording those adjustments followed by stabilization of indicator parameters. Purging is considered complete and sampling may begin when all the above indicator field parameters have stabilized. Stabilization is considered to be achieved when three consecutive readings are within the following limits:

Turbidity (10% for values greater than 5 NTU; if three Turbidity values are less than 5 NTU, consider the values as stabilized),
Dissolved Oxygen (10% for values greater than 0.5 mg/L, if three Dissolved Oxygen values are less than 0.5 mg/L, consider the values as stabilized),
Specific Conductance (3%),
Temperature (3%),
pH (± 0.1 unit),
Oxidation/Reduction Potential (±10 millivolts).

All measurements, except turbidity, must be obtained using a flow-through-cell. Samples for turbidity measurements are obtained before water enters the flow-through-cell. Transparent flow-through-cells are preferred, because they allow field personnel to watch for particulate build-up within the cell. This build-up may affect indicator field parameter values measured within the cell. If the cell needs to be cleaned during purging operations, continue pumping and disconnect cell for cleaning, then reconnect after cleaning and

continue monitoring activities. Record start and stop times and give a brief description of cleaning activities.

The flow-through-cell must be designed in a way that prevents gas bubble entrapment in the cell. Placing the flow-through-cell at a 45 degree angle with the port facing upward can help remove bubbles from the flow-through-cell (see Appendix B Low-Flow Setup Diagram). Throughout the measurement process, the flow-through-cell must remain free of any gas bubbles. Otherwise, the monitoring probes may act erratically. When the pump is turned off or cycling on/off (when using a bladder pump), water in the cell must not drain out. Monitoring probes must remain submerged in water at all times.

F. Collect Water Samples

When samples are collected for laboratory analyses, the pump's tubing is disconnected from the "T" connector with a valve and the flow-through-cell. The samples are collected directly from the pump's tubing. Samples must not be collected from the flow-through-cell or from the "T" connector with a valve.

VOC samples are normally collected first and directly into pre-preserved sample containers. However, this may not be the case for all sampling locations; the SAP/QAPP should list the order in which the samples are to be collected based on the project's objective(s). Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

If the pump's flow rate is too high to collect the VOC/dissolved gases samples, collect the other samples first. Lower the pump's flow rate to a reasonable rate and collect the VOC/dissolved gases samples and record the new flow rate.

During purging and sampling, the centrifugal/peristaltic pump tubing must remain filled with water to avoid aeration of the groundwater. It is recommended that 1/4 inch or 3/8 inch (inside diameter) tubing be used to help ensure that the sample tubing remains water filled. If the pump tubing is not completely filled to the sampling point, use the following procedure to collect samples: collect non-VOC/dissolved gases samples first, then increase flow rate slightly until the water completely fills the tubing, collect the VOC/dissolved gases samples, and record new drawdown depth and flow rate.

For bladder pumps that will be used to collect VOC or dissolved gas samples, it is recommended that the pump be set to deliver long pulses of water so that one pulse will fill a 40 mL VOC vial.

Use pre-preserved sample containers or add preservative, as required by analytical methods, to the samples immediately after they are collected. Check the analytical methods

(e.g. EPA SW-846, 40 CFR 136, water supply, etc.) for additional information on preservation.

If determination of filtered metal concentrations is a sampling objective, collect filtered water samples using the same low flow procedures. The use of an in-line filter (transparent housing preferred) is required, and the filter size (0.45 μm is commonly used) should be based on the sampling objective. Pre-rinse the filter with groundwater prior to sample collection. Make sure the filter is free of air bubbles before samples are collected. Preserve the filtered water sample immediately. Note: filtered water samples are not an acceptable substitute for unfiltered samples when the monitoring objective is to obtain chemical concentrations of total mobile contaminants in groundwater for human health or ecological risk calculations.

Label each sample as collected. Samples requiring cooling will be placed into a cooler with ice or refrigerant for delivery to the laboratory. Metal samples after acidification to a pH less than 2 do not need to be cooled.

G. Post Sampling Activities

If a recording pressure transducer is used to track drawdown, re-measure water level with tape.

After collection of samples, the pump tubing may be dedicated to the well for re-sampling (by hanging the tubing inside the well), decontaminated, or properly discarded.

Before securing the well, measure and record the well depth (to 0.1 ft.), if not measured the day before purging began. Note: measurement of total well depth annually is usually sufficient after the initial low stress sampling event. However, a greater frequency may be needed if the well has a “silting” problem or if confirmation of well identity is needed.

Secure the well.

11.0 DECONTAMINATION

Decontaminate sampling equipment prior to use in the first well, and then following sampling of each subsequent well. Pumps should not be removed between purging and sampling operations. The pump, tubing, support cable and electrical wires which were in contact with the well should be decontaminated by one of the procedures listed below.

The use of dedicated pumps and tubing will reduce the amount of time spent on decontamination of the equipment. If dedicated pumps and tubing are used, only the initial sampling event will require decontamination of the pump and tubing.

Note if the previous equipment blank data showed that contaminant(s) were present after using the below procedure or the one described in the SAP/QAPP, a more vigorous procedure may be needed.

Procedure 1

Decontaminating solutions can be pumped from either buckets or short PVC casing sections through the pump and tubing. The pump may be disassembled and flushed with the decontaminating solutions. It is recommended that detergent and alcohol be used sparingly in the decontamination process and water flushing steps be extended to ensure that any sediment trapped in the pump is removed. The pump exterior and electrical wires must be rinsed with the decontaminating solutions, as well. The procedure is as follows:

Flush the equipment/pump with potable water.

Flush with non-phosphate detergent solution. If the solution is recycled, the solution must be changed periodically.

Flush with potable or distilled/deionized water to remove all of the detergent solution. If the water is recycled, the water must be changed periodically.

Optional - flush with isopropyl alcohol (pesticide grade; must be free of ketones {e.g., acetone}) or with methanol. This step may be required if the well is highly contaminated or if the equipment blank data from the previous sampling event show that the level of contaminants is significant.

Flush with distilled/deionized water. This step must remove all traces of alcohol (if used) from the equipment. The final water rinse must not be recycled.

Procedure 2

Steam clean the outside of the submersible pump.

Pump hot potable water from the steam cleaner through the inside of the pump. This can be accomplished by placing the pump inside a three or four inch diameter PVC pipe with end cap. Hot water from the steam cleaner jet will be directed inside the PVC pipe and the pump exterior will be cleaned. The hot water from the steam cleaner will then be pumped from the PVC pipe through the pump and collected into another container. Note: additives or solutions should not be added to the steam cleaner.

Pump non-phosphate detergent solution through the inside of the pump. If the solution is recycled, the solution must be changed periodically.

Pump potable water through the inside of the pump to remove all of the detergent solution. If the solution is recycled, the solution must be changed periodically.

Pump distilled/deionized water through the pump. The final water rinse must not be recycled.

12.0 FIELD QUALITY CONTROL

Quality control samples are required to verify that the sample collection and handling process has not compromised the quality of the groundwater samples. All field quality control samples must be prepared the same as regular investigation samples with regard to sample volume, containers, and preservation. Quality control samples include field duplicates, equipment blanks, matrix spike/matrix spike duplicates, trip blanks (VOCs), and temperature blanks.

13.0 FIELD LOGBOOK

A field log shall be kept to document all groundwater field monitoring activities (see Appendix C, example table), and record the following for each well:

Site name, municipality, state.

Well identifier, latitude-longitude or state grid coordinates.

Measuring point description (e.g., north side of PVC pipe).

Well depth, and measurement technique.

Well screen length.

Pump depth.

Static water level depth, date, time and measurement technique.

Presence and thickness of immiscible liquid (NAPL) layers and detection method.

Pumping rate, drawdown, indicator parameters values, calculated or measured total volume pumped, and clock time of each set of measurements.

Type of tubing used and its length.

Type of pump used.

Clock time of start and end of purging and sampling activity.

Types of sample bottles used and sample identification numbers.

Preservatives used.

Parameters requested for analyses.

Field observations during sampling event.

Name of sample collector(s).

Weather conditions, including approximate ambient air temperature.

QA/QC data for field instruments.

Any problems encountered should be highlighted.

Description of all sampling/monitoring equipment used, including trade names, model number, instrument identification number, diameters, material composition, etc.

14.0 DATA REPORT

Data reports are to include laboratory analytical results, QA/QC information, field indicator parameters measured during purging, field instrument calibration information, and whatever other field logbook information is needed to allow for a full evaluation of data usability.

Note: the use of trade, product, or firm names in this sampling procedure is for descriptive purposes only and does not constitute endorsement by the U.S. EPA.

15.0 REFERENCES

Cohen, R.M. and J.W. Mercer, 1993, *DNAPL Site Evaluation*; C.K. Smoley (CRC Press), Boca Raton, Florida.

Robert W. Puls and Michael J. Barcelona, *Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures*, April 1996 (EPA/540/S-95/504).

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U.S Environmental Protection Agency, EPA SW-846.

U.S Environmental Protection Agency, 40 CFR 136.

U.S Environmental Protection Agency, 40 CFR 141.

Vroblesky, Don A., Clifton C. Casey, and Mark A. Lowery, Summer 2007, Influence of Dissolved Oxygen Convection on Well Sampling, *Ground Water Monitoring & Remediation* 27, no. 3: 49-58.

APPENDIX A

PERISTALTIC PUMPS

Before selecting a peristaltic pump to collect groundwater samples for VOCs and/or dissolved gases, (e.g., methane, carbon dioxide, etc.) consideration should be given to the following:

- The decision of whether or not to use a peristaltic pump is dependent on the intended use of the data.
- If the additional sampling error that may be introduced by this device is NOT of concern for the VOC/dissolved gases data's intended use, then this device may be acceptable.
- If minor differences in the groundwater concentrations could affect the decision, such as to continue or terminate groundwater cleanup or whether the cleanup goals have been reached, then this device should NOT be used for VOC/dissolved gases sampling. In these cases, centrifugal or bladder pumps are a better choice for more accurate results.

EPA and USGS have documented their concerns with the use of the peristaltic pumps to collect water sample in the below documents.

- "Suction Pumps are not recommended because they may cause degassing, pH modification, and loss of volatile compounds" *A Compendium of Superfund Field Operations Methods*, EPA/540/P-87/001, December 1987.
- "The agency does not recommend the use of peristaltic pumps to sample ground water particularly for volatile organic analytes" *RCRA Ground-Water Monitoring Draft Technical Guidance*, EPA Office of Solid Waste, November 1992.
- "The peristaltic pump is limited to shallow applications and can cause degassing resulting in alteration of pH, alkalinity, and volatiles loss", *Low-flow (Minimal drawdown) Ground-Water Sampling Procedures*, by Robert Puls & Michael Barcelona, April 1996, EPA/540/S-95/504.
- "Suction-lift pumps, such as peristaltic pumps, can operate at a very low pumping rate; however, using negative pressure to lift the sample can result in the loss of volatile analytes", USGS Book 9 Techniques of Water-Resources Investigation, Chapter A4. (Version 2.0, 9/2006).

APPENDIX B

SUMMARY OF SAMPLING INSTRUCTIONS

These instructions are for using an adjustable rate, submersible pump or a peristaltic pump with the pump's intake placed at the midpoint of a 10 foot or less well screen or an open interval. The water level in the monitoring well is above the top of the well screen or open interval, the ambient temperature is above 32°F, and the equipment is not dedicated. Field instruments are already calibrated. The equipment is setup according to the diagram at the end of these instructions.

1. Review well installation information. Record well depth, length of screen or open interval, and depth to top of the well screen. Determine the pump's intake depth (e.g., mid-point of screen/open interval).

2. On the day of sampling, check security of the well casing, perform any safety checks needed for the site, lay out a sheet of polyethylene around the well (if necessary), and setup the equipment. If necessary a canopy or an equivalent item can be setup to shade the pump's tubing and flow-through-cell from the sun light to prevent the sun light from heating the groundwater.

3. Check well casing for a reference mark. If missing, make a reference mark. Measure the water level (initial) to 0.01 ft. and record this information.

4. Install the pump's intake to the appropriate depth (e.g., midpoint) of the well screen or open interval. Do not turn-on the pump at this time.

5. Measure water level and record this information.

6. Turn-on the pump and discharge the groundwater into a graduated waste bucket. Slowly increase the flow rate until the water level starts to drop. Reduce the flow rate slightly so the water level stabilizes. Record the pump's settings. Calculate the flow rate using a graduated container and a stop watch. Record the flow rate. Do not let the water level drop below the top of the well screen.

If the groundwater is highly turbid or discolored, continue to discharge the water into the bucket until the water clears (visual observation); this usually takes a few minutes. The turbid or discolored water is usually from the well-being disturbed during the pump installation. If the water does not clear, then you need to make a choice whether to continue purging the well (hoping that it will clear after a reasonable time) or continue to

the next step. Note, it is sometimes helpful to install the pump the day before the sampling event so that the disturbed materials in the well can settle out.

If the water level drops to the top of the well screen during the purging of the well, stop purging the well, and do the following:

> Wait for the well to recharge to a sufficient volume so samples can be collected. This may take a while (pump may be removed from well, if turbidity is not a problem). The project manager will need to make the decision when samples should be collected and the reasons recorded in the site's log book. A water level measurement needs to be performed and recorded before samples are collected. When samples are being collected, the water level must not drop below the top of the screen or open interval. Collect the samples from the pump's tubing. Always collect the VOCs and dissolved gases samples first. Normally, the samples requiring a small volume are collected before the large volume samples are collected just in case there is not sufficient water in the well to fill all the sample containers. All samples must be collected, preserved, and stored according to the analytical method. Remove the pump from the well and decontaminate the sampling equipment.

If the water level has dropped 0.3 feet or less from the initial water level (water level measure before the pump was installed); proceed to Step 7. If the water level has dropped more than 0.3 feet, calculate the volume of water between the initial water level and the stabilized water level. Add the volume of the water which occupies the pump's tubing to this calculation. This combined volume of water needs to be purged from the well after the water level has stabilized before samples are be collected.

7. Attach the pump's tubing to the "T" connector with a valve (or a three-way stop cock). The pump's tubing from the well casing to the "T" connector must be as short as possible to prevent the groundwater in the tubing from heating up from the sun light or from the ambient air. Attach a short piece of tubing to the other end of the end of the "T" connector to serve as a sampling port for the turbidity samples. Attach the remaining end of the "T" connector to a short piece of tubing and connect the tubing to the flow-through-cell bottom port. To the top port, attach a small piece of tubing to direct the water into a calibrated waste bucket. Fill the cell with the groundwater and remove all gas bubbles from the cell. Position the flow-through-cell in such a way that if gas bubbles enter the cell they can easily exit the cell. If the ports are on the same side of the cell and the cell is cylindrical shape, the cell can be placed at a 45-degree angle with the ports facing upwards; this position should keep any gas bubbles entering the cell away from the monitoring probes and allow the gas bubbles to exit the cell easily (see Low-Flow Setup Diagram). Note:

make sure there are no gas bubbles caught in the probes' protective guard; you may need to shake the cell to remove these bubbles.

8. Turn-on the monitoring probes and turbidity meter.

9. Record the temperature, pH, dissolved oxygen, specific conductance, and oxidation/reduction potential measurements. Open the valve on the "T" connector to collect a sample for the turbidity measurement, close the valve, do the measurement, and record this measurement. Calculate the pump's flow rate from the water exiting the flow-through-cell using a graduated container and a stop watch, and record the measurement. Measure and record the water level. Check flow-through-cell for gas bubbles and sediment; if present, remove them.

10. Repeat Step 9 every 5 minutes or as appropriate until monitoring parameters stabilized. Note: at least one flow-through-cell volume must be exchanged between readings. If not, the time interval between readings will need to be increased. Stabilization is achieved when three consecutive measurements are within the following limits:

Turbidity (10% for values greater than 5 NTUs; if three Turbidity values are less than 5 NTUs, consider the values as stabilized),
Dissolved Oxygen (10% for values greater than 0.5 mg/L, if three Dissolved Oxygen values are less than 0.5 mg/L, consider the values as stabilized),
Specific Conductance (3%),
Temperature (3%),
pH (± 0.1 unit),
Oxidation/Reduction Potential (±10 millivolts).

If these stabilization requirements do not stabilize in a reasonable time, the probes may have been coated from the materials in the groundwater, from a buildup of sediment in the flow-through-cell, or a gas bubble is lodged in the probe. The cell and the probes will need to be cleaned. Turn-off the probes (not the pump), disconnect the cell from the "T" connector and continue to purge the well. Disassemble the cell, remove the sediment, and clean the probes according to the manufacturer's instructions. Reassemble the cell and connect the cell to the "T" connector. Remove all gas bubbles from the cell, turn-on the probes, and continue the measurements. Record the time the cell was cleaned.

11. When it is time to collect the groundwater samples, turn-off the monitoring probes, and disconnect the pump's tubing from the "T" connector. If you are using a centrifugal or peristaltic pump check the pump's tubing to determine if the tubing is completely filled with water (no air space).

All samples must be collected and preserved according to the analytical method. VOCs and dissolved gases samples are normally collected first and directly into pre-preserved sample containers. However, this may not be the case for all sampling locations; the SAP/QAPP should list the order in which the samples are to be collected based on the project's objective(s). Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

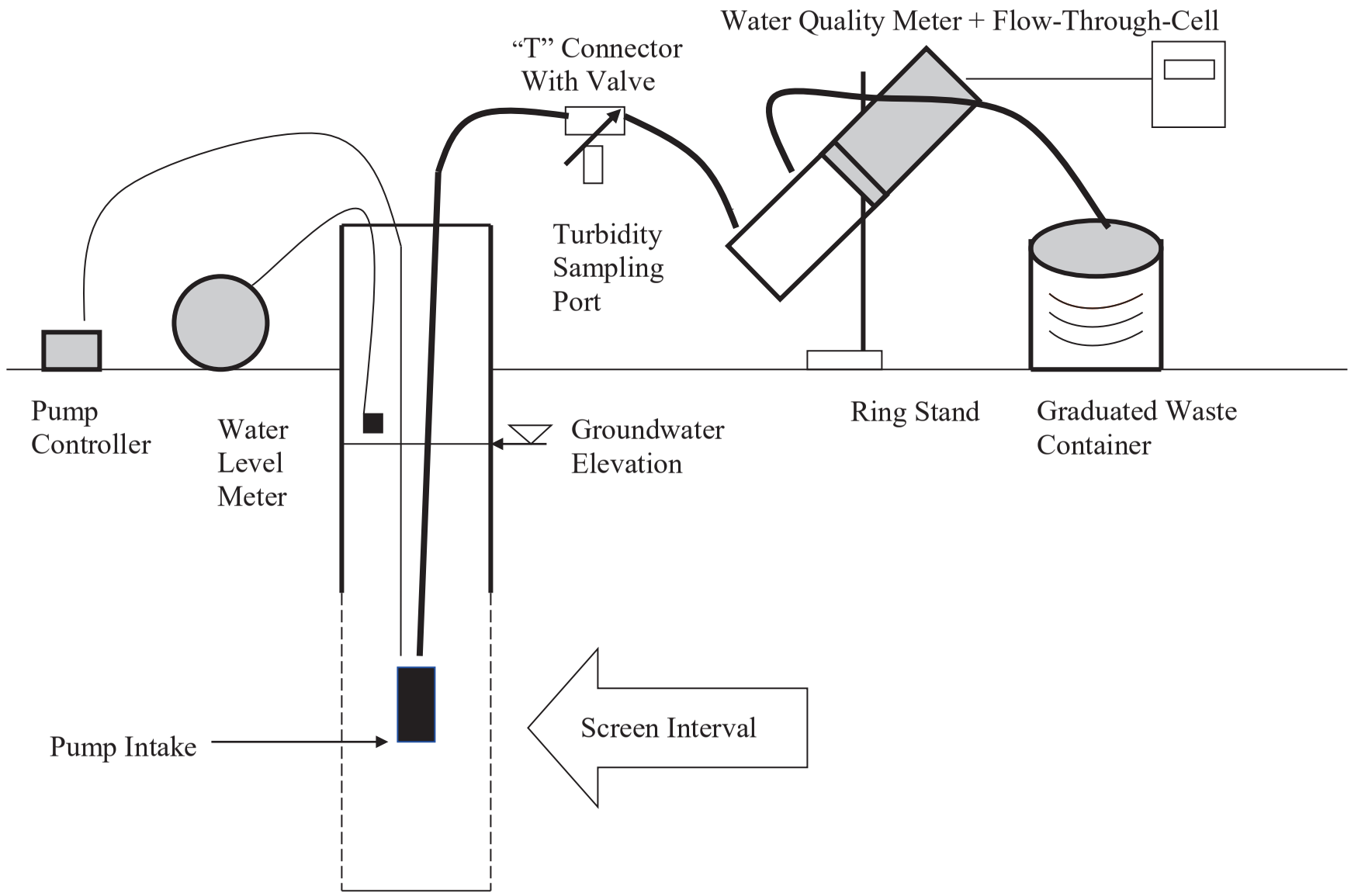
If the pump's tubing is not completely filled with water and the samples are being collected for VOCs and/or dissolved gases analyses using a centrifugal or peristaltic pump, do the following:

> All samples must be collected and preserved according to the analytical method. The VOCs and the dissolved gases (e.g., methane, ethane, ethene, and carbon dioxide) samples are collected last. When it becomes time to collect these samples increase the pump's flow rate until the tubing is completely filled. Collect the samples and record the new flow rate.

12. Store the samples according to the analytical method.

13. Record the total purged volume (graduated waste bucket). Remove the pump from the well and decontaminate the sampling equipment.

Low-Flow Setup Diagram



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APPENDIX C

EXAMPLE (Minimum Requirements)

WELL PURGING-FIELD WATER QUALITY MEASUREMENTS FORM

Location (Site/Facility Name)_____ Depth to _____/_____ of screen
Well Number_____ Date_____ (below MP) top bottom
Field Personnel_____ Pump Intake at (ft. below MP)_____
Sampling Organization_____ Purging Device; (pump type)_____
Identify MP_____ Total Volume Purged _____

Clock Time 24 HR	Water Depth below MP ft	Pump Dial[1]	Purge Rate ml/min	Cum. Volume Purged liters	Temp. "C	Spec. Cond.[2] µS/cm	pH	ORP[3] mv	DO mg/L	Tur-bidity NTU	Comments
Stabilization Criteria					3%	3%	±0.1	±10 mv	10%	10%	

1. Pump dial setting (for example: hertz, cycles/min, etc).
2. µSiemens per cm(same as µmhos/cm)at 25°C.
3. Oxidation reduction potential (ORP)

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DOCUMENT 9

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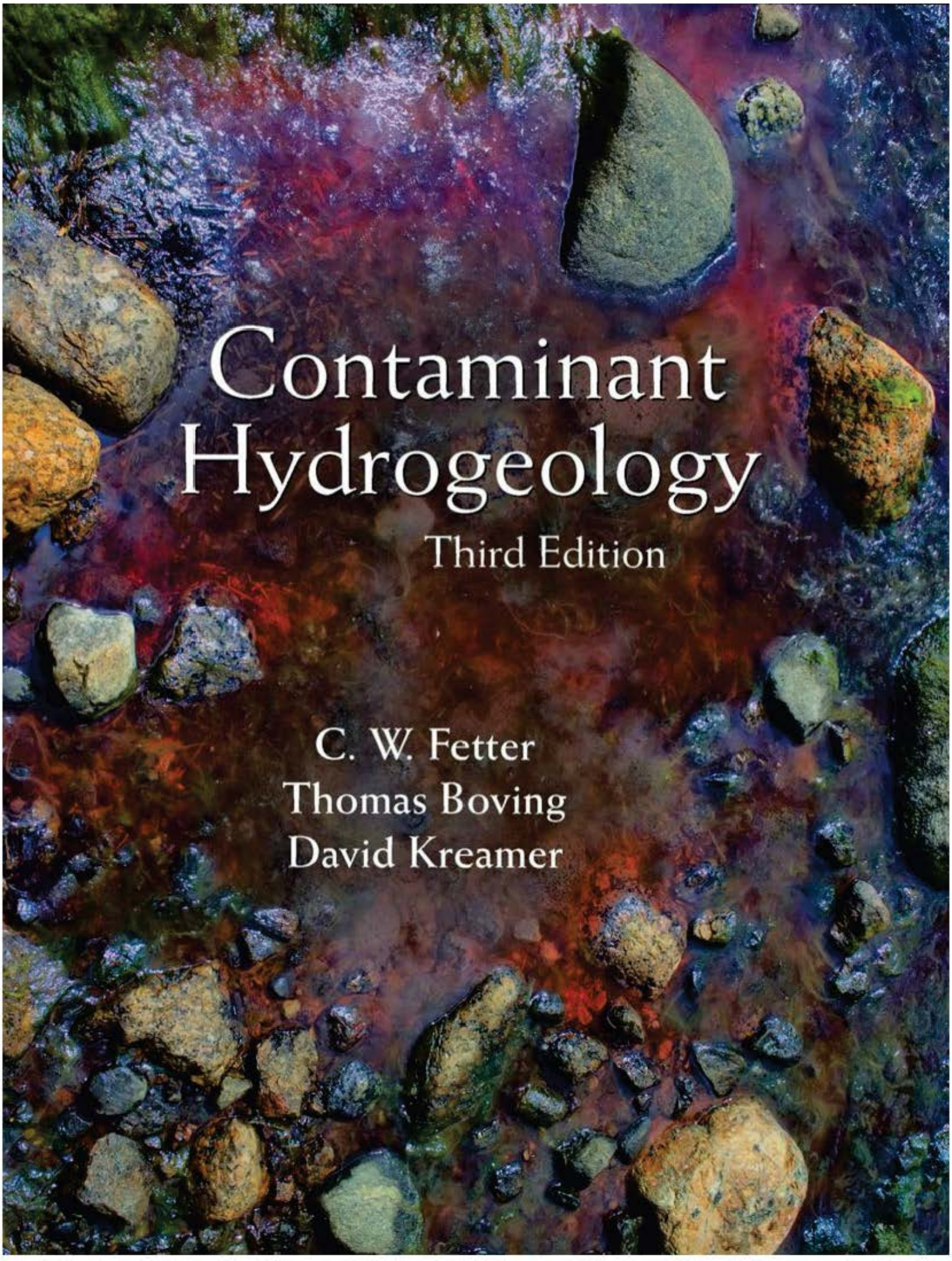
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TABLE 1.3 *Cont'd*

Contaminant	Examples of uses
Other hydrocarbons	
Alkyl sulfonates	Detergents
Cyclohexane	Organic synthesis, solvent, oil extraction
1,3,5,7-Cyclooctatetraene	Organic research
Dicyclopentadiene (DCPD)	Intermediate for insecticides, paints and varnishes, flame retardants
2,3-Dimethylhexane	NA
Fuel oil	Fuel, heating
Gasoline	Fuel
Jet fuels	Fuel
Kerosene	Fuel, heating solvent, insecticides
Lignin	Newsprint, ceramic binder, dyestuffs, drilling fuel additive, plastics
Methylene blue activated substances (MBAS)	Dyestuffs, analytical chemistry
Propane	Fuel, solvent, refrigerants, propellants, organic synthesis
Tannin	Chemical manufacturing, tanning, textiles, electroplating, inks, pharmaceuticals, photography, paper
4,6,8-Trimethyl-1-nonene	NA
Undecane	Petroleum research, organic synthesis
Metals and cations	
Aluminum	Alloys, foundry, paints, protective coatings, electrical industry, packaging, building and construction, machinery and equipment
Antimony	Hardening alloys, solders, sheet and pipe, pyrotechnics
Arsenic	Alloys, dyestuffs, medicine, solders, electronic devices, insecticides, rodenticides, herbicide, preservative
Barium	Alloys, lubricant
Beryllium	Structural material in space technology, inertial guidance systems, additive to rocket fuels, moderator and reflector of neutrons in nuclear reactors
Cadmium	Alloys, coatings, batteries, electrical equipment, fire-protection systems, paints, fungicides, photography
Calcium	Alloys, fertilizers, reducing agent
Chromium	Alloys, protective coatings, paints, nuclear and high-temperature research

(Cont'd)

TABLE 1.3 *Cont'd*

Contaminant	Examples of uses
Cobalt	Alloys, ceramics, drugs, paints, glass, printing, catalyst, electroplating, lamp filaments
Copper	Alloys, paints, electrical wiring, machinery, construction materials, electroplating, piping, insecticides
Iron	Alloys, machinery, magnets
Lead	Alloys, batteries, gasoline additive, sheet and pipe, paints, radiation shielding
Lithium	Alloys, pharmaceuticals, coolant, batteries, solders, propellants
Magnesium	Alloys, batteries, pyrotechnics, precision instruments, optical mirrors
Manganese	Alloys, purifying agent
Mercury	Alloys, electrical apparatus, instruments, fungicides, bactericides, mildew proofing, paper, pharmaceuticals
Molybdenum	Alloys, pigments, lubricant
Nickel	Alloys, ceramics, batteries, electroplating, catalyst
Palladium	Alloys, catalyst, jewelry, protective coatings, electrical equipment
Potassium	Alloys, catalyst
Selenium	Alloys, electronics, ceramics, catalyst
Silver	Alloys, photography, chemical manufacturing, mirrors, electronic equipment, jewelry, equipment, catalyst, pharmaceuticals
Sodium	Chemical manufacturing, catalyst, coolant, nonglare lighting for highways, laboratory reagent
Thallium	Alloys, glass, pesticides, photoelectric applications
Titanium	Alloys, structural materials, abrasives, coatings
Vanadium	Alloys, catalysts, target material for x-rays
Zinc	Alloys, electroplating, electronics, automotive parts, fungicides, roofing, cable wrappings, nutrition
Nonmetals and anions	
Ammonia	Fertilizers, chemical manufacturing, refrigerants, synthetic fibers, fuels, dyestuffs
Boron	Alloys, fibers and filaments, semiconductors, propellants
Chlorides	Chemical manufacturing, water purification, shrink-proofing, flame retardants, food processing

(Cont'd)

TABLE 1.3 *Cont'd*

Contaminant	Examples of uses
Cyanides	Polymer production (heavy duty tires), coatings, metallurgy, pesticides
Fluorides	Toothpastes and other dentrifices, additive to drinking water, aluminum smelting
Nitrates	Fertilizers, food preservatives
Nitrites	Fertilizers, food preservatives
Phosphates	Detergents, fertilizers, food additives
Sulfates	Fertilizers, pesticides
Sulfites	Pulp production and processing, food preservatives
Microorganisms	
Bacteria (coliform)	
Giardia	
Viruses	
Radionuclides	
Cesium 137	Gamma radiation source for certain foods
Chromium 51	Diagnosis of blood volume, blood cell life, cardiac output, etc.
Cobalt 60	Radiation therapy, irradiation, radiographic testing, research
Iodine 131	Medical diagnosis, therapy, leak detection, tracers (e.g., to study efficiency of mixing pulp fibers, chemical reactions, and thermal stability of additives to food products), measuring film thicknesses
Iron 59	Medicine, tracer
Lead 210	NA
Phosphorus 32	Tracer, medical treatment, industrial measurements (e.g., tire-tread wear and thickness of films and ink)
Plutonium 238,243	Energy source, weaponry
Radium 226	Medical treatment, radiography
Radium 228	Naturally occurring
Radon 222	Medicine, leak detection, radiography, flow rate measurement
Ruthenium 106	Catalyst
Scandium 46	Tracer studies, leak detection, semiconductors
Strontium 90	Medicine, industrial applications (e.g., measuring thicknesses, density control)

(Cont'd)

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TABLE 1.3 *Cont'd*

Contaminant	Examples of uses
Thorium 232	Naturally occurring
Tritium	Tracer, luminous instrument dials
Uranium 238	Nuclear reactors, mining operations
Zinc 65	Industrial tracers (e.g., to study wear in alloys, galvanizing, body metabolism, function of oil additives in lubricating oils)
Zirconium 95	NA

[a]NA: No information in Standard sources.

Source: Office of Technology Assessment 1984, with additions.

It should be noted that many compounds can have multiple names, making identification of compounds difficult for the environmental practitioner. In one example from Table 1.3, the compound butoxymethylbenzene can also be known by at least 26 other names or numerical distinctions (Chemspider 2015). Nomenclature can be further confused, as there are other names given for the same compound by different suppliers and vendors. Using the same example of butoxymethylbenzene above, a selective list of vendors in 2015 and their designations for the compound would include at least 14 different additional names or numerical distinctions (Zincdocking 2015). This multiple nomenclature for the same compound can be even more confused with the manufacture and use of mixtures of potential groundwater pollutants, some containing unspecified impurities. There are many types of industrial chemical mixtures in use or being developed, with multiple names and descriptions, including tens of thousands of pesticide products. Also, in recent years there has been increased concern over "emerging" organic contaminants, which were previously not yet industrially developed, not yet discovered in the environment often due to analytical limitations, or alternatively, not yet recognized as potential pollutants. These compounds include pharmaceuticals, personal care products, industrial chemicals, and hormones. Table 1.4 lists some of these compounds and their uses.

The occurrence of the substances found on Tables 1.3 and 1.4 can be detected only if a groundwater sample has been collected and analyzed. In low concentrations most of these substances are colorless, tasteless, and odorless. Specific analytical techniques must be employed to detect the presence and concentration of each substance. Some methods can be employed to analyze a sample for all of the compounds of a particular class. For example, certain organic compounds fall into a class called volatile organic compounds. There are analytical methods that could target all compounds of this class. Likewise, there are methods available to analyze for many of the metals in a single sample. However, other compounds require a specific test. With so many potential contaminants, it is possible that a sample could be collected and tested and a specific contaminant still not be found because no analysis was done for that compound or element.

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compounds are potential groundwater contaminants that can leach from soil used for land applications of wastes and wastewater.

1.5.2 Category II: Sources Designed to Store, Treat and/or Dispose of Substances

Landfills Landfills are, by definition, designed to minimize adverse effects of waste disposal (Miller, 1980). However, many were poorly designed and are leaking liquids, generically termed leachate, which are contaminating groundwater. Landfills can contain nonhazardous municipal waste, nonhazardous industrial waste, or hazardous waste as defined by the Resource Conservation and Recovery Act. Peterson (1983) reported that there were 12,991 landfills in the United States in the 1980s, including 2,395 open dumps. According to the EPA, by 2009 landfills were much larger, but there were only 1,908 solid waste municipal landfills reported. This does not include landfills for construction and demolition wastes, nonhazardous industrial waste landfills, or hazardous waste landfills. There are an unknown number of abandoned landfills.

Materials placed in landfills include such things as municipal garbage and trash, demolition debris, sludge from wastewater-treatment plants, incinerator ash, foundry sand and other foundry wastes, and toxic and hazardous materials. Although no longer permitted in the United States, liquid hazardous waste was disposed in landfills in the past. The U.S. Environmental Protection Agency (2015) estimated that in 2012 over 250 million tons of municipal waste was generated, which is over a three-fold increase in the last half century. The World Bank (2012) has estimated worldwide municipal waste generation at 1.3 billion tons per year with estimates of expected increase to 2.2 billion tons annually in 2025, and over 11 billion by 2100. Total solid waste generation (beyond just municipal waste) is considerably larger at an estimated 11.2 billion tons in 2011 (United Nations Environmental Programme). Interactive waste atlases have also been developed to summarize worldwide waste data (e.g., http://wwwatlas.d-waste.com/).

Leachate is formed from the liquids found in the waste as well as by leaching of the solid waste by rainwater. Table 1.9 contains information on the chemical composition of leachate from municipal landfills. To minimize the amount of leachate generated, modern landfills are built in sections, with a low-permeability cover placed over the waste as soon as possible to limit the infiltration of rainwater. Modern landfills also have low-permeability liner systems and collection pipes to remove the leachate that forms so that it can be taken to a wastewater-treatment plant. A modern landfill that is properly sited with respect to the local geology and that has a properly designed and constructed liner, leachate collection system, and low-permeability cover has limited potential to contaminate groundwater. However, many landfills do not have liners and leachate collection systems. In the past, landfills tended to be placed in any convenient hole or low spot, such as a sand pit, quarry, or marsh. Groundwater contamination from such landfills is highly probable.

Municipal landfills are usually located near urban areas. The trend is toward large landfills that can handle many thousands of tons of waste per year. Hazardous-waste landfills are now regulated under the Resource Conservation and Recovery Act. There is frequently strong local opposition to the siting of either a municipal or a hazardous waste landfill. This is referred to as the NIMBY syndrome: Not In My Back Yard!

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Homeowners may pour waste liquids into ditches or the sanitary sewer; combustibles may be burned in the backyard. These are undesirable practices that can easily result in environmental pollution, including groundwater contamination.

Surface impoundments Pits, ponds, and lagoons are used by industries, farmers, and municipalities for the storage and/or treatment of both liquid nonhazardous and hazardous waste and the discharge of nonhazardous waste. Prior to the passage of the Resource Conservation and Recovery Act, liquid hazardous wastes were also discharged into pits. These pits may be unlined or lined with natural material, such as clay, or artificial materials, such as plastic sheets, rubber membranes, or asphalt.

Impoundments are used to treat wastewater by such processes as settling of solids, biological oxidation, chemical coagulation and precipitation, and pH adjustment. They may also be used to store wastewater prior to treatment. Water from surface impoundments may be discharged to a receiving water course such as a stream or a lake. Unless a discharging impoundment is lined, it will also lose water by seepage into the subsurface. Nondischarging impoundments release water either by evaporation or seepage into the ground or a combination of both. Evaporation ponds are effective only in arid regions, where potential evapotranspiration far exceeds precipitation. Even evaporation ponds that were originally lined may leak and result in groundwater contamination if the liner deteriorates from contact with the pond's contents.

Impoundments are used for wastewater treatment by municipalities and industries such as paper manufacturing, petroleum refining, metals industry, mining, and chemical manufacturing. They are also used for treatment of agricultural waste, such as farm animal waste from feedlots. Power plants use surface impoundments as cooling ponds. Mining operations use surface ponds for the separation of tailings, which is waste rock from the processing of ore that occurs in a slurry mixture of liquid and solid.

Although it is now prohibited, until the 1970s lagoons were used for the disposal of untreated wastewater from manufacturing, ore processing, and other industrial uses into the groundwater. Brine pits were used for many years in the oil patch for the disposal of brines pumped up with the oil. Miller (1980) lists 57 cases of groundwater contamination caused by the leakage of wastewater from surface impoundments. In most of the reported cases water-supply wells had been affected; at the time when use of such impoundments was allowed, groundwater monitoring was not required; usually the only way that leakage was detected was by contamination of a supply well.

In one case in Illinois, up to 500,000 gals per day of mineralized wastewater, containing high total dissolved solids (TDS), which included chloride, sulfate, and calcium, from an ore-processing plant were discharged into waste-disposal ponds excavated in a glacial drift aquifer for a period of about 40 years. Concentrations of chloride, sulfate, TDS, and hardness were elevated in an underlying bedrock aquifer as much as a mile away from the site (U.S. Nuclear Regulatory Commission 1983).

Wastewater from the manufacturing of nerve gas and pesticides at the Rocky Mountain Arsenal at Denver was discharged into unlined evaporation ponds from 1942 until 1956. In 1956 a new pond lined with asphalt was constructed; ultimately that liner failed and the lined pond also leaked. Contamination of nearby farm wells was first detected in 1951 and was especially severe in the drought year of 1954, when irrigated crops died. Groundwater contamination extended at least 8 miles from the ponds and

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was indicated by high chloride content. Ultimately the groundwater under and near the Rocky Mountain Arsenal was found to contain dozens of synthetic organic chemicals, including two that are especially mobile in the subsurface: diisopropylmethylphosphonate (DIMP), a by-product of the manufacture of nerve gas, and dicyclopentadiene (DCPD) a chemical used in the manufacture of pesticides (Konikow and Thompson 1984; Spanggord, Chou, and Mabey 1979). By 2010, after 23 years of active remediation the cleanup of contaminated soil and groundwater at the Rocky Mountain Arsenal, the cost has been $2.1 billion dollars as parcels of the land are taken off the National Priorities list and tracts of land are converted to a National Wildlife Refuge.

There is very little information available on the number of surface impoundments worldwide, nor much up-to-date information from individual countries. Several decades ago the EPA performed a survey of the surface impoundments located in the United States (U.S. EPA 1983). They reported a total of 180,973 impoundments, including 37,185 municipal; 19,437 agricultural; 27,912 industrial; 25,038 mining; 65,688 brine pits for oil and gas; and 5,913 miscellaneous. A later U.S. EPA (2001) survey conducted in the 1990s estimated about 18,000 industrial impoundments. Energy related industrial surface impoundments are of particular concern, as these can hold many sorts of materials including coal combustion residues, water associated with *in situ* uranium leaching, and/or brines associated with deep oil and gas development. The large number of impoundments provides a significant threat to groundwater resources (OTA 1984).

Mine wastes Mining can produce spoils, or unneeded soil, sediment, and rock moved during the mining process, and tailings, or solid waste left over after the processing of ore. These wastes may be piled on the land surface, used to fill low areas, used to restore the land to pre-mining contours, or placed in engineered landfills with leachatecollection systems. Mine wastes can generate leachate as rainwater passes through them. If sulfate or sulfide minerals are present, sulfuric acid can be generated, and the resulting drainage water can be acidic. This is likely to occur with coal-mining wastes, copper and gold ores, and ores from massive sulfide mineralization. Mine-waste leachate may also contain heavy metals and, in the case of uranium and thorium mines, radionuclides. Neutralization of the mine wastes can prevent the formation of acidic leachate and prevent the mobilization of many, but not all, metallic ions and radionuclides. The mine-waste disposal issue is a large one. In the United States, mining is estimated to produce waste material annually with a weight of nearly nine times that of refuse generated by all cities and towns (U.S. EPA 2003). The mining of many metals traditionally requires huge quantities of rock to be removed, for example, the production of a single ton of copper ore typically generates well over 100 times the tonnage of waste rock and about 200 times the tonnage of mined overburden, depending on the local geology. Leachate produced by unneutralized or uncontained mine wastes is a threat to surface and groundwater.

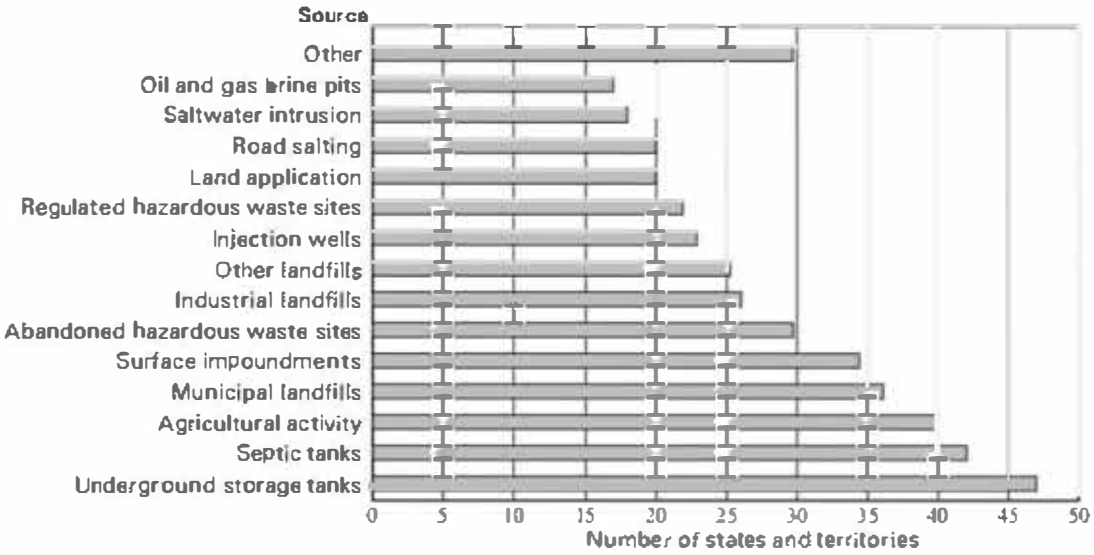
In some cases, *in situ* leach mining is used instead of physical removal of ore-containing rock. In these instances, a chemical mobilizing agent called a lixiviant is pumped down a well where it flows into an ore-bearing formation. After ore is dissolved, the pregnant solution circulating underground is removed using extraction wells. Problems can arise with *in situ* leach mining as the geologic structures associated with many ore

1.6 Relative Ranking of Groundwater-Contamination Sources and Substances

Every site of groundwater contamination is unique in its geology, contaminant mixtures, surrounding human-made structures, and pollutant sources. Therefore the risks associated with different localities and their contaminants can vary greatly, and the approaches for site characterization and remediation are typically tailored to each individual site. Although there are many potential sources of groundwater contamination, some pose much more of a threat to groundwater than others. Section 305(b) of the Federal Clean Water Act requires individual States in the U.S. to submit reports to the Environmental Protection Agency on the sources of groundwater contamination in the state and the type of contaminants observed. The data submitted were used to compile *National Water Quality Inventory—1988 Report to Congress* (U.S. EPA 1990).

The states indicated all the groundwater-contamination sources that they considered to be major threats to groundwater in their state. Figure 1.3 shows that more than half the states and territories listed underground storage tanks, septic tanks, agricultural activities, municipal landfills, and abandoned hazardous-waste sites as major threats to groundwater. Other frequently listed sources include industrial landfills, other landfills, injection wells, regulated hazardous-waste sites, land application, road salt, saltwater intrusion, and brine pits from oil and gas wells.

FIGURE 1.3 Frequency of various contamination sources considered by states and territories of the United States to be major threats to groundwater quality.



Source: UNICEF 2012.

Additionally, every two years the Agency for Toxic Substance and Disease Registry (ATSDR) and the Environmental Protection Agency in the United States prepare a list of hazardous substances most commonly found at facilities on the National Priorities List (NPL), also called the "Superfund" program. The list is a prioritization of harmful substances based on a combination of their frequency of occurrence, their toxicity, and

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compounds that was denser than water and had limited solubility in water. Large volumes of tar were generated and due to routine leaks and spills, leaking tar storage tanks and deliberate disposal, tar was released into the environment. When some of the plants were decommissioned tanks containing tar were just buried in place. Today many of the former manufactured gas plant sites still have soil and groundwater contamination associated with the tar (Luthy et al., 1994).

1.8 Review of Mathematics and the Flow Equation

1.8.1 Derivatives

Soil-moisture movement, groundwater flow, and solute transport may be described by means of partial differential equations. Thus, a brief review is in order.

If a bicyclist is traveling down a highway, we can measure the time that it takes the rider, who has a flying start, to go from a starting point ($S(t_1)$, or the location at the starting time, (t_1), to a point somewhere down the highway ($S(t_2)$, or the location at elapsed time t_2). If we wish to know the average speed of the rider over this distance, we divide the distance from point $S(t_1)$ to point $S(t_2)$ by the elapsed time, $t_2 - t_1$.

$$\frac{\Delta S}{\Delta t} = \frac{S(t_2) - S(t_1)}{t_2 - t_1} \tag{1.1}$$

The rider will be going more slowly uphill and faster downhill. The average speed will thus include a lot of variation. If we were to measure the rider's speed over a shorter part of the course, there would be less variation in speed. As the length of time over which the distance traveled is measured becomes shorter and shorter, the variation in speed decreases. If the time becomes infinitesimally small—for example, the time that it takes the rider to travel a few microns—we obtain an instantaneous speed. This is known as the first derivative of distance with respect to time and is defined by

$$\frac{dS(t_1)}{dt} = \lim_{t \to t_1} \frac{S(t) - S(t_1)}{t - t_1} \tag{1.2}$$

where t is any arbitrary time. Figure 1.4 shows a graph of distance traveled by our bicyclist as a function of time. The slope of the line from time t_1 to time t_2 is the average speed over that part of the highway and is expressed as $\Delta S/\Delta t$. *The instantaneous speed at time* t_1 is the slope of the tangent to the curve at that point, which is expressed as dS/dt.

Note that the slope of distance versus time on Figure 1.4 keeps changing. This reflects the changes in speed that occur as the rider goes up and down hills. As the rider goes over the crest of a hill, he or she will perhaps be going rather slowly. As the rider goes downhill, the velocity will increase. We can compare the crest-of-the-hill velocity with the bottom-of the-hill velocity and see that it has increased. This is a measure of the acceleration that occurs as gravity and the leg muscles of the bicyclist combine to increase speed. Figure 1.5 shows the speed of the rider as he or she goes over a hill. At $t = 0$ the rider is coming over the crest of the hill and the speed is 10 mi/hr. At $t = 30$ sec, when the rider is near the bottom of the hill, the speed is 26 mi/hr. The average rate of change in speed is (26 mi/hr–10 mi/hr)/

FIGURE 1.4 Graph of distance traveled versus time graphically showing speed, which is the first derivative of distance with respect to time.

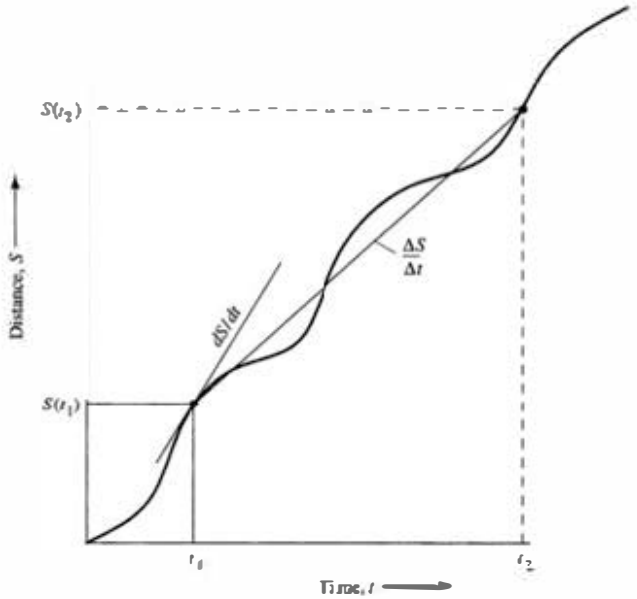
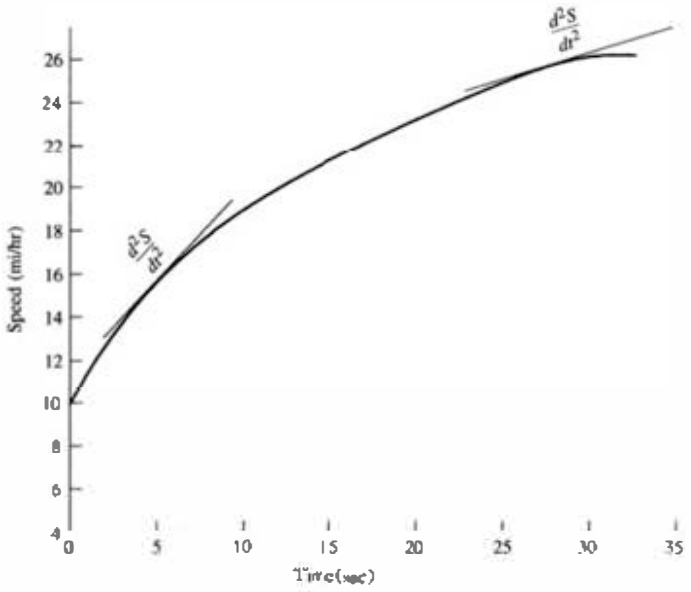


FIGURE 1.5 Graph of speed versus time graphically showing acceleration, which is the second derivative of distance with respect to time.



30 sec, or 0.53 mi/hr/sec. The rate of change is faster near the top of the hill where the slope is steeper and there is less wind resistance, since the rider is moving more slowly. From 0 to 5 sec the speed changes from 10 to 15 mi/hr, or 1.0 mi/hr/sec. Acceleration

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is the rate of change of speed with time, which is a second derivative. It is the slope of a tangent to the curve at a given time. It can be expressed as

$$\frac{d\left(\frac{dS}{dt}\right)}{dt} \quad \text{or} \quad \frac{d^2S}{dt^2}$$

The tangent at 5 sec. can be seen to be steeper than the tangent at 30 sec, where the rate of change is less.

In hydrogeology we have many parameters that are a function of more than one independent variable. For example, hydraulic head is a function of the three space variables: $h = h(x, y, z)$. We frequently differentiate head with respect to one of the space variables while holding the other two variables constant. Such derivatives of a parameter with respect to a single variable are called partial derivatives. The second derivative of hydraulic head with respect to the space variables is

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}$$

1.8.2 Darcy's Law

The first experimental study of water movement through a porous medium was performed by Henry Darcy (Darcy 1856). He found that the one-dimensional flow of water through a pipe filled with sand was proportional to the cross-sectional area and the head loss along the pipe and inversely proportional to the flow length. Darcy's law can be expressed as

$$Q = -KA\frac{dh}{dl} \tag{1.3}$$

where

Q = volumetric discharge
K = proportionality constant known as hydraulic conductivity
A = cross-sectional area
dh/dl = gradient of hydraulic head

This equation can also be expressed in terms of specific discharge, or Darcy flux, q, which is the volumetric flow rate, Q, divided by the cross-sectional area, A.

$$q = -K\frac{dh}{dl} \tag{1.4}$$

Darcy's law was obtained for one-dimensional flow. However, as was previously stated, head is a function of all three dimensions: $h = h(x, y, z)$.

The hydraulic conductivity is the measure of the ability of the fractured or porous media to transmit water. It can have different values, depending upon the actual

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direction that the water is flowing through the porous media. In such a case the medium is said to be **anisotropic**. The value of the hydraulic conductivity can be measured in three principle directions, K_x, K_y, and K_z. If the hydraulic conductivity is the same in all directions, then $K_x = K_y = K_z = K$ and the medium is said to be **isotropic**.

1.8.3 Scalar, Vector, and Tensor Properties of Hydraulic Head and Hydraulic Conductivity

We first need to define some terms relating to tensors. A zero-order tensor, also called a scalar, is a quantity characterized only by its size or magnitude. Examples in hydrogeology include hydraulic head, chemical concentration, and temperature. A first-order tensor, or vector, is a quantity that has both a magnitude and a direction. Vectors require three components, each having a magnitude and direction. Velocity, specific discharge, mass flux, and heat flux are examples. A second-order tensor—or, simply, tensor—acts like the product of two vectors, requiring nine components to account for all possible products of the three components of each vector. Examples in hydrogeology are intrinsic permeability, hydraulic conductivity, thermal conductivity, and hydrodynamic dispersion.

The hydraulic head is a scalar. However, the gradient of the head is a vector as it has both a magnitude and a direction. The gradient of h is designated as grad h:

$$\text{grad } h = i\frac{\partial h}{\partial x} + j\frac{\partial h}{\partial y} + k\frac{\partial h}{\partial z} \tag{1.5}$$

where **i**, **j**, and **k** are unit vectors in the x, y, and z directions. An equivalent notation is the use of the vector differential operator, del, which has the symbol ∇. This operator is equivalent to

$$i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z} \tag{1.6}$$

Another vector is the specific discharge, **q**. It has three components, q_x, q_y, and q_z, when measured along the Cartesian coordinate axes. Associated with any vector is a positive scalar with a value equal to the magnitude of the vector. If q is the magnitude of the vector **q**, this can be expressed as

$$q = |q| \tag{1.7}$$

A second-order tensor, such as **K**, hydraulic conductivity, can be described by nine components. In matrix form they are expressed as:

$$K = \begin{bmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{bmatrix} \tag{1.8}$$

If the tensor is symmetric, $K_{ij} = K_{ji}$; then inspection of (1.8) shows that there are only six independent components of **K**.

If the coordinate system is oriented along the principal axes, the tensor becomes

$$K = \begin{bmatrix} K_{xx} & 0 & 0 \\ 0 & K_{yy} & 0 \\ 0 & 0 & K_{zz} \end{bmatrix} \tag{1.9}$$

For the special case of an isotropic media—that is, the value of **K** does not depend upon the direction in which it is measured—the tensor becomes

$$K = \begin{bmatrix} K & 0 & 0 \\ 0 & K & 0 \\ 0 & 0 & K \end{bmatrix} \tag{1.10}$$

The three components of the specific discharge vector, q, are

$$q_x = -K_{xx}\frac{\partial h}{\partial x} - K_{xy}\frac{\partial h}{\partial y} - K_{xz}\frac{\partial h}{\partial z}$$

$$q_y = -K_{yx}\frac{\partial h}{\partial x} - K_{yy}\frac{\partial h}{\partial y} - K_{yz}\frac{\partial h}{\partial z} \tag{1.11}$$

$$q_z = -K_{zx}\frac{\partial h}{\partial x} - K_{zy}\frac{\partial h}{\partial y} - K_{zz}\frac{\partial h}{\partial z}$$

For the special case where we orient the axes of the *x*, *y*, and *z* coordinate system with the three principal directions of anisotropy, **K** is the matrix shown in (1.9) and the three components of the specific discharge vector are

$$q_x = -K_{xx}\frac{\partial h}{\partial x}$$

$$q_y = -K_{yy}\frac{\partial h}{\partial y} \tag{1.12}$$

$$q_z = -K_{zz}\frac{\partial h}{\partial z}$$

For an isotropic material, **K** is represented by the matrix in (1.10) and

$$q = -K\frac{\partial h}{\partial x} - K\frac{\partial h}{\partial y} - K\frac{\partial h}{\partial z} \tag{1.13}$$

or

$$q = -K \text{ grad } h \tag{1.14}$$

If we multiply two vectors together and the result is a scalar, then the product is called a **dot product, or inner product**. For example, the del operator dotted into a vector

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yields a scalar, called the divergence. Based on grad h, we can find a velocity vector v such that the magnitude and direction vary throughout the porous media. If we apply the del operator to v, we obtain the following:

$$\nabla \cdot v = \mathrm{div}\, v = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \tag{1.15}$$

If we apply the del operator to grad h, the result is the second derivative of head:

$$\nabla \cdot \mathrm{grad}\, h = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} \tag{1.16}$$

1.8.4 Derivation of the Flow Equation in a Deforming Medium

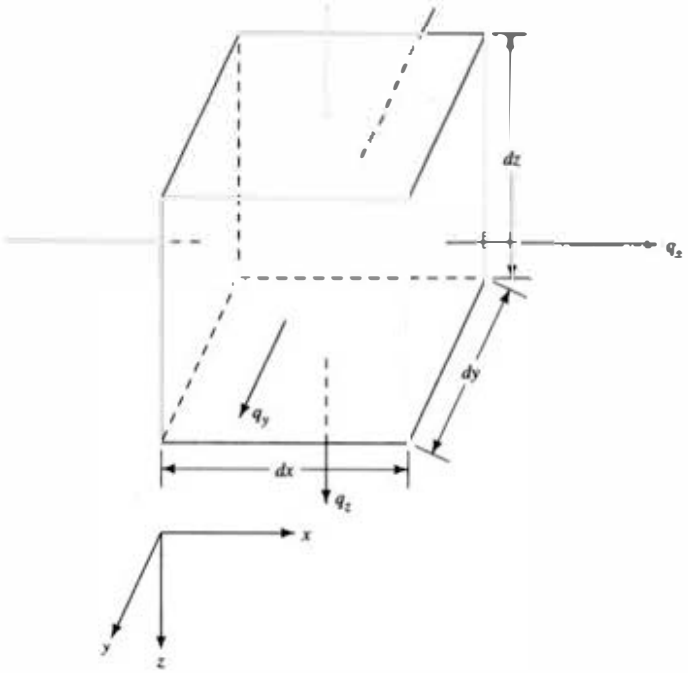
The law of mass conservation states that there can be no net change in the mass of fluid in a small representative elementary volume (REV) of a porous medium. In other words, the mass entering the REV less the mass leaving the REV is equal to the change in mass storage with time.

The representative elementary volume is shown on Figure 1.6. The three sides have length dx, dy, and dz, respectively. The area of the two faces normal to the x axis is $dy\,dz$, the area of the faces normal to the y axis is $dx\,dz$, and the area of the faces normal to the z axis is $dx\,dy$.

The component of mass flux into the REV parallel to the x axis is the fluid density times the flux rate:

$$\text{Mass influx along } x \text{ axis} = \rho_w q_x\, dy\, dz \tag{1.17}$$

FIGURE 1.6 Representative elementary volume for fluid flow.



where

ρ_w = fluid density (M/L^3)
q_x = specific discharge or volume of flow per crosssectional area (L/T)
$dy\,dz$ = cross-sectional area (L^2)

The units of mass inflow are mass per unit time (M/T).*
The mass outflow rate will be different than the inflow rate and can be given as:

$$\text{Mass outflow rate parallel to } x \text{ axis} = \left[\rho_w q_x + \frac{\partial(\rho_w q_x)dx}{\partial x} \right] dy\,dz \qquad (1.18)$$

The net mass accumulation within the control volume due to the flow component parallel to the x axis is the mass inflow minus the mass outflow, or

$$\frac{-\partial(\rho_w q_x)dx\,dy\,dz}{\partial x}$$

Similar terms exist for the net mass accumulation due to flow components parallel to the y and z axes:

$$\frac{-\partial(\rho_w q_y)dy\,dx\,dz}{\partial y}$$

$$\frac{-\partial(\rho_w q_z)dz\,dx\,dy}{\partial z}$$

These three terms can be summed to find the total net mass accumulation within the control volume.

$$-\left[\left(\frac{\partial}{\partial x}(\rho_w q_x) + \frac{\partial}{\partial y}(\rho_w q_y) + \frac{\partial}{\partial z}(\rho_w q_z) \right) \right] dx\,dy\,dz \qquad (1.19)$$

The mass of water in the REV, M, is the density of water, ρ_w, times the porosity, n, times the volume, $dx\,dy\,dz$. The change in mass with respect to time is

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial t}(\rho_w n dx dy dz) \qquad (1.20)$$

From the law of conservation of mass, Equation 1.19 must equal Equation 1.20.

$$-\left[\frac{\partial}{\partial x}(\rho_w q_x) + \frac{\partial}{\partial y}(\rho_w q_y) + \frac{\partial}{\partial z}(\rho_w q_z) \right] dx\,dy\,dz = \frac{\partial}{\partial t}(\rho_w n)\,dx\,dy\,dz \qquad (1.21)$$

* The units of a variable can be expressed in terms of their fundamental dimensions. These are length, L, mass, M, and time, T. The fundamental dimensions for density are mass per unit volume. Volume is length cubed, so the shorthand expression for the fundamental dimensions of density is M/L^3. Specific discharge has the dimensions of velocity, so the fundamental dimensions are L/T, and area has fundamental dimensions of L^2.

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We can assume that although density of the fluid may change with time, at any given time it will be the same everywhere in the REV. Under this assumption Equation 1.21 can be simplified to

$$-\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right]=\frac{1}{p_w}\frac{\partial}{\partial t}(p_w n) \tag{1.22}$$

We may substitute Darcy's law for the specific discharge components given on the left side. If the *xyz* coordinate system is aligned with the principal axes of anisotropy, then Equation 1.12 may be used, and the left side of Equation 1.22 becomes

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) \tag{1.23}$$

The change in mass within the REV is due to changes in the porosity and the density of water as the head changes with time. Thus the change in the volume of water in storage is proportional to the change in head with time. The right side of Equation 1.22 can be expressed as a proportionality constant, *Ss*, the specific storage, times the change in head with time.

$$\frac{1}{p_w}\frac{\partial}{\partial t}(p_w n)=S_s\frac{\partial h}{\partial t} \tag{1.24}$$

Combining Equations 1.22, 1.23, and 1.24 we obtain the main equation for transient flow in an anisotropic medium when the coordinate system is oriented along the principal axes of anisotropy:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)=S_s\frac{\partial h}{\partial t} \tag{1.25}$$

1.8.5 Mathematical Notation

In del and tensor notation Equation 1.25 becomes

$$\nabla\cdot K\cdot\nabla h=S_s\frac{\partial h}{\partial t} \tag{1.26}$$

Another form of expression is called Einstein's summation notation. For example, Darcy's law in the familiar, one-dimensional form is

$$q=-K\frac{dh}{dl} \tag{1.27}$$

It is implied in the preceding equation that the specific discharge is parallel to the direction of *dh/dl* and that the medium is isotropic. In a more general form, specific discharge, q, is a vector with components q_1, q_2, and q_3. Grad *h* is a vector that we will call **h**. This vector also has components h_1, h_2, and h_3. Hydraulic conductivity, **K**, is a

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tensor with nine components. To describe Darcy's law in the most general form, we need three equations.

$$q_1 = K_{11}h_1 + K_{12}h_2 + K_{13}h_3 \tag{1.28a}$$

$$q_2 = K_{21}h_1 + K_{22}h_2 + K_{23}h_3 \tag{1.28b}$$

$$q_3 = K_{31}h_1 + K_{32}h_2 + K_{33}h_3 \tag{1.28c}$$

The inner product can be expressed in index notation as

$$q_i = \sum_j K_{ij}h_i \quad (i,j=1,2,3) \tag{1.29}$$

In Einstein's summation notation, the Σ is dropped with the understanding that the summation is over the repeated indices:

$$q_i = K_{ij}h_j \quad (i,j=1,2,3) \tag{1.30}$$

In vector notation this can be expressed as either

$$q = K \cdot \mathbf{grad}h \tag{1.31}$$

$$q = K \cdot h \tag{1.32}$$

In del notation this is

$$q = K \cdot \nabla h \tag{1.33}$$

In general, we will use the standard form of differential equations rather than any of the shorthand notation. However, the literature cited in this text often uses the compact forms and the reader should be aware of them.

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2

Mass Transport in Saturated Media

2.1 Introduction

In this chapter we will consider the transport of solutes dissolved in groundwater. This is known as mass or solute transport. The methods presented in this chapter are based on partial differential equations for dispersion that have been developed for homogeneous media (Ogata and Banks 1961; Ogata 1970; Bear 1972; Bear and Verruijt 1987). These equations are similar in form to the familiar partial differential equations for fluid flow. Since those pioneering developments, much work has been done on the theories of mass transport in response to the great interest in problems of groundwater contamination (e.g., Bedient et al. 1994; Zhang and Bennett 1997; Grathwohl 1998; Domenico and Schwartz 1998; Yoram 2003; Yeh et al. 2015; Essaid et al. 2015). One of the outcomes has been the development of what is essentially a new branch of subsurface hydrology, where the flow of fluid and solutes is treated by statistical models; these models can account for the role of varying hydraulic conductivity and other spatially variable hydraulic parameters that accompany aquifer heterogeneity.

Many of the contaminant transport and fate concepts discussed in this chapter were developed based on tracer tests conducted in the field and at the laboratory scale. While a discussion of how tracer tests should be conducted and how the data can be interpreted is beyond the scope of this book, there are ample references and textbooks devoted to this topic (e.g., Davis et al. 1980; U.S. EPA 1985; Payne et al. 2008; Leibundgut et al. 2009; Suthersan et al. 2014).

2.2 Transport by Concentration Gradients

A solute in water will move from an area of greater concentration toward an area where it is less concentrated. This process is known as molecular diffusion, or diffusion. Diffusion will occur as long as a concentration gradient exists, even if the fluid is not moving. The mass of fluid diffusing is proportional to the concentration gradient, which can be expressed as Fick's first law; in one dimension, Fick's first law is

$$F = -D_d \left(dC / dx \right) \tag{2.1}$$

where

F = mass flux of solute (M/L^2T) per unit area per unit time

D_d = diffusion coefficient (L^2/T)

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TABLE 2.1 Diffusion coefficients in water.

Cations		
H^+	9.31×10^{-9} m²/sec	1.00×10^{-7} ft²/sec
Na^+	1.33×10^{-9} m²/sec	1.43×10^{-8} ft²/sec
K^+	1.96×10^{-9} m²/sec	2.11×10^{-8} ft²/sec
Rb^+	2.06×10^{-9} m²/sec	2.22×10^{-8} ft²/sec
Cs^+	2.07×10^{-9} m²/sec	2.23×10^{-8} ft²/sec
Mg^{2+}	7.05×10^{-10} m²/sec	7.59×10^{-9} ft²/sec
Ca^{2+}	7.93×10^{-10} m²/sec	8.54×10^{-9} ft²/sec
Sr^{2+}	7.94×10^{-10} m²/sec	8.55×10^{-9} ft²/sec
Ba^{2+}	8.48×10^{-10} m²/sec	9.13×10^{-9} ft²/sec
Ra^{2+}	8.89×10^{-10} m²/sec	9.57×10^{-9} ft²/sec
Mn^{2+}	6.88×10^{-10} m²/sec	7.41×10^{-9} ft²/sec
Fe^{2+}	7.19×10^{-10} m²/sec	7.74×10^{-9} ft²/sec
Cr^{3+}	5.94×10^{-10} m²/sec	6.39×10^{-9} ft²/sec
Fe^{3+}	6.07×10^{-10} m²/sec	6.53×10^{-9} ft²/sec
Anions		
OH^-	5.27×10^{-9} m²/sec	5.67×10^{-8} ft²/sec
F^-	1.46×10^{-9} m²/sec	1.57×10^{-8} ft²/sec
Cl^-	2.03×10^{-9} m²/sec	2.19×10^{-8} ft²/sec
Br^-	2.01×10^{-9} m²/sec	2.16×10^{-8} ft²/sec
HS^-	1.73×10^{-9} m²/sec	1.86×10^{-8} ft²/sec
HCO_3^-	1.18×10^{-9} m²/sec	1.27×10^{-8} ft²/sec
SO_4^{2-}	1.07×10^{-9} m²/sec	1.15×10^{-8} ft²/sec
CO_3^{2-}	9.55×10^{-10} m²/sec	1.03×10^{-8} ft²/sec
Organic Compounds		
Tetrachloroethene (PCE)*	7.5×10^{-10} m²/sec	8.07×10^{-9} ft²/sec
Trichloroethene (TCE)*	8.3×10^{-10} m²/sec	8.93×10^{-9} ft²/sec
1,1,1,-Trichloroethane (TCA)*	8.0×10^{-10} m²/sec	8.61×10^{-9} ft²/sec
Benzene**	9.0×10^{-10} m²/sec	9.69×10^{-9} ft²/sec
Toluene**	8.0×10^{-10} m²/sec	8.61×10^{-9} ft²/sec
Ethylbenzene**	7.2×10^{-10} m²/sec	7.75×10^{-9} ft²/sec
1,4-Dioxane***	1.6×10^{-9} m²/sec	1.72×10^{-8} ft²/sec

Source: Y.-H. Li and S. Gregory, 1974. Diffusion of ions in sea water and in deep-sea sediments. Geochemica et Cosmochemica Acta, Vol. 38. © 1974, with the kind permission of Elsevier Science. *Cohen and Mercer, 1993; **U.S.EPA, 2015; ***Mohr 2010. Diffusion coefficients of ions at 25°C; organic compounds are in pure water at 20°C.

C = solute concentration (M/L³)

dC/dx = concentration gradient (M/L³/L)

The negative sign indicates that the movement is from areas of greater concentration to those of lesser concentration. Values of D_d for ions and select organic compounds in water at 25°C can be found in Table 2-1. They do not vary much with concentration, but they are somewhat temperature-dependent, being about 50% less at 5°C (Robinson and Stokes 2002). The values of D_d are only applicable when studying diffusion in aqueous systems. For systems where the concentrations are changing with time, Fick's second law applies. In one dimension this is

$$\partial C / \partial t = D_d \, \partial^2 C / \partial x^2 \tag{2.2}$$

where $\partial C / \partial t$ = change in concentration with time (M/L³/T).

In porous media, diffusion cannot proceed as fast as it can in water because the ions must follow longer pathways as they travel around mineral grains. To account for this, an effective diffusion coefficient, D^*, must be used.

$$D^* = \omega D_d \tag{2.3}$$

where ω is a coefficient that is related to the tortuosity (Bear 1972). Tortuosity is a measure of the effect of the shape of the flowpath followed by water molecules in a porous media. If L is the straight-line distance between the ends of a tortuous flowpath of length L_e, the tortuosity, T, can be defined as $T = L_e/L$. Tortuosity in a porous media is always greater than 1, because the flowpaths that water molecules take must diverge around solid particles. Flowpaths across a representative sample of a well-sorted sediment would tend to be shorter than those across a poorly sorted sediment in which the smaller grains were filling the voids between the larger grains. Thus the well-sorted sediment would tend to have a lower value for tortuosity than the poorly sorted sediment. (Tortuosity has also been defined as $(L/L_e)^2$ (Carman 1997; Bear 1972). With this definition, tortuosity always has a value less than 1. This definition will nor be used in this text.)

The value of ω, which is always less than 1, can be found from diffusion experiments in which a solute is allowed to diffuse across a volume of a porous medium. Perkins and Johnson (1963) found that ω was equal to 0.7 for sand column studies using a uniform sand. For laboratory studies using limestone and sandstone cores, Boving and Grathwohl (2001) found that ω ranges from 0.35 to 0.098 and that ω is related to the porosity, n, of these rocks by:

$$\omega = n^{-1.2}$$

Diffusion will cause a solute to spread away from the place where it is introduced into a porous medium, even in the absence of groundwater advective flow. Figure 2.1 shows the distribution of a solute introduced at concentration C_0, at time t_0, over an interval $(x - a)$ to $(x + a)$. At succeeding times t_1 and t_2, the solute has spread out, resulting in a lower concentration over the interval $(x - a)$ to $(x + a)$ but increasing concentrations outside of this interval.

The solute concentration follows a normal, or Gaussian, distribution and can be described by two statistical properties, the mean, C and variance, σ_c^2, which are defined in Section 2.12.2.

The effective diffusion coefficient, D^*, can be defined as (De Josselin and De Jong 1958)

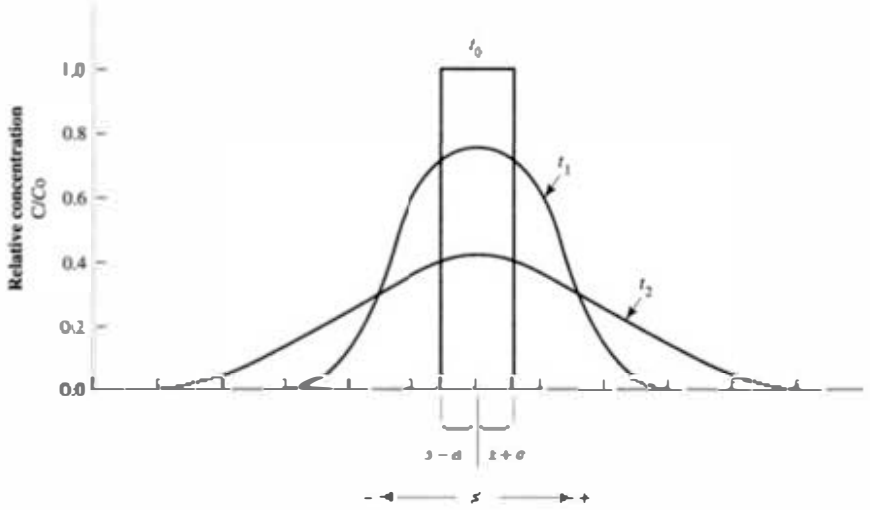
$$D^* = \frac{\sigma_c^2}{2t} \tag{2.4}$$

This is an alternative definition of effective diffusion coefficient to the one given in Equation 2.3.

The process of diffusion is complicated by the fact that the ions must maintain electrical neutrality as they diffuse. If we have a solution of NaCl, the Na^+ cannot diffuse faster than the Cl^- unless there is some other negative ion in the region into which

the Na^+ is diffusing. If the solute is adsorbed onto the mineral surfaces of the porous medium, the net rate of diffusion will be obviously less than for a nonadsorbed species.

Figure 2.1 Spreading of a solute slug with time due to diffusion. A slug of solute was injected into the aquifer at time t_0 with a resulting initial concentration of C_0.



Diffusion can occur when the concentration of a chemical species is greater in one stratum than in an adjacent stratum. For example, solid waste containing a high concentration of chloride ion may be placed directly on the clay liner of a landfill. The concentration of chloride in the leachate contained in the solid waste is so much greater than the concentration of chloride in the pore water of the clay liner that the latter may be considered to be zero as a simplifying assumption in determining a conservative estimate of the maximum diffusion rate. If the solid waste and the clay are both saturated, the chloride ion will diffuse from the solid waste, where its concentration is greater, into the clay liner, even if there is no fluid flow. The concentration of chloride in the solid waste, C_0, will be assumed to be a constant with time, as it can be replaced by dissolution of additional chloride. The concentration of chloride in the clay liner, $C_i(x, t)$, at some distance x from the solid waste interface and sometime t after the waste was placed, can be determined from Equation 2.5 (Crank 1956). This is a solution to Equation 2.2 for the appropriate boundary and initial conditions.

$$C_i(x,t) = C_0 \operatorname{erfc} \frac{x}{2(D^* t)^{0.5}} \tag{2.5}$$

where

C_i = the concentration at distance x from the source at time t since diffusion began

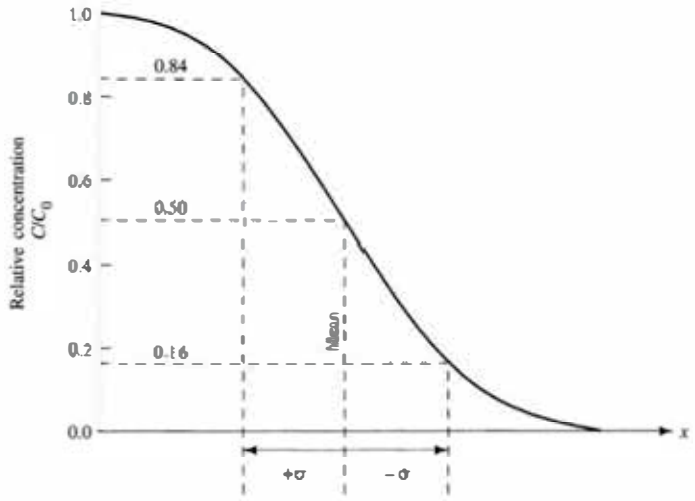
C_0 = the original concentration, which remains a constant

erfc = the complementary error function (Appendix A)

The complementary error function, erfc, is a mathematical function that is related to the normal, or Gaussian, distribution. This means that the solution described by Equation 2.5 is normally distributed, as is expected for a diffusional process. Figure 2.2

shows the profile of relative concentration for a solute diffusing from a region where the concentration is C_0 to a region where it was initially zero. Because the profile is normally distributed, 84% of the values will be less than the value that is one standard deviation more than the mean and 16% of the values will be less than the value that is one standard deviation less than the mean. The standard deviation is the square root of the variance.

Figure 2.2 The profile of a diffusing front as predicted by the complementary error function.



The complementary error function is tabulated in Appendix A or it can be calculated in the spreadsheet program Excel using the syntax: ERFC(x). It is related to the error function, erf, by

$$\text{erfc}(B) = 1 - \text{erf}(B)$$

The value of erfc(B) is 0 for all positive values of B greater than 3.0 and 1.0 for a B of 0. For some applications it may be necessary to find erfc of a negative number. Appendix A does not give values for erfc(B) for negative values of B. These must be computed from the relationship

$$\text{erfc}(-B) = 1 + \text{erf}\, B$$

The error function, erf(B) is defined as:

$$\text{erf}(B) = \frac{2}{\sqrt{\pi}} \int_0^B e^{-t^2}\, dt$$

The above equation cannot be solved analytically. However, it is tabulated in Appendix A. It can also be approximated by the analytical expression:

$$\text{erf}(B) = \sqrt{1 - \exp\left(\frac{-4B^2}{\pi}\right)}$$

Thus values of erfc(B) range from 0 to +2, since the maximum value of erf(B) is 1.0 for 3.0 and all greater numbers.

EXAMPLE PROBLEM

Assume a D of 1×10^{-9} m²/sec and an ω of 0.5, to give a D^* of 5×10^{-10} m²/sec. Find the value of the concentration ratio, C_i/C_0, at a distance of 5m after 100 yr of diffusion.

1. Convert 100 yr to seconds:

$$100\text{yr} \times 365\text{da/yr} \times 1440\text{ min/da} \times 60\text{ sec/min} = 3.15 \times 10^9\text{ sec}$$

2. Insert values into Equation 2.5:

$$\frac{C_i}{C_0} = \text{erfc}\frac{5}{2(5\times10^{-10}\text{m}^2/\text{sec}\times 3.15\times10^9\text{ sec})^{0.5}}$$

3. Solve:

$$\frac{C_i}{C_0} = \text{erfc}\left(\frac{5}{2.51}\right) = \text{erfc}\,1.99 = 0.005$$

In 100 yr, diffusion over a 5-m distance would yield a concentration that is 0.5% of the original.

From the preceding example problem it is obvious that diffusion is not a particularly rapid means of transporting dissolved solutes. Diffusion is the predominant mechanism of transport only in low-permeability hydrogeologic regimes. However, it is possible for solutes to move through a porous or a fractured medium by diffusion even if the groundwater is not flowing.

2.3 Transport by Advection

Dissolved solids are carried along with the flowing groundwater. This process is called advective transport, or advection. The amount of solute that is being transported is a function of its concentration in the groundwater and the quantity of the groundwater flowing. For one-dimensional flow normal to a unit cross-sectional area of the porous media, the quantity of water flowing is equal to the *average linear velocity* times *the effective porosity*. **Average linear velocity**, v_x, is the rate at which the flux of water across the unit cross-sectional area of pore space occurs. It is not the average rate at which the water molecules are moving along individual flowpaths, which is greater than the average linear velocity due to tortuosity. The **effective porosity**, n_e, is the porosity through which flow can occur. Noninterconnected and dead-end pores are not included in the effective porosity, so that $n_e < n$.

$$v_x = \frac{K}{n_e}\frac{dh}{dl} \tag{2.6}$$

where

v_x = average linear velocity (L/T)
K = hydraulic conductivity (L/T)

n_e = effective porosity
dh/dl = hydraulic gradient (L/L)

Note that the abbreviation n is used in the context of flow and transport under saturated conditions. When discussing unsaturated flow, θ is preferred because it refers to the water content of the porous matrix, as defined in Chapter 4. When the matrix is fully saturated n equals θ. The one-dimensional mass flux, F_x, due to advection is equal to the quantity of water flowing times the concentration of dissolved solids and is given by Equation 2.7:

$$F_x = v_x n_e C \tag{2.7}$$

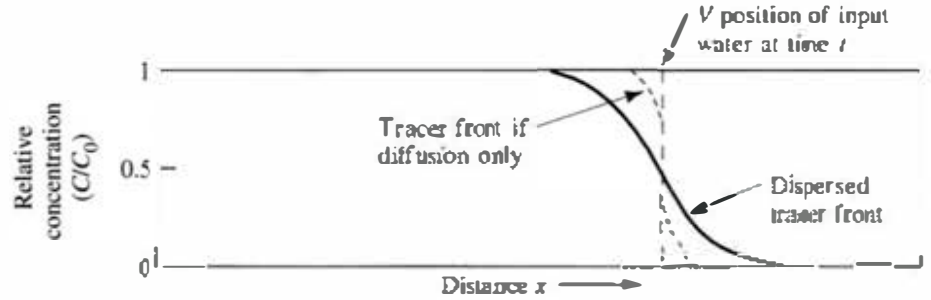
The one-dimensional advective transport equation is

$$\frac{\partial C}{\partial t} = -v_x \frac{\partial C}{\partial x} \tag{2.8}$$

(The derivation of this equation is given in Section 2.6.)

Solution of the advective transport equation yields a sharp concentration front. On the advancing side of the front, the concentration is equal to that of the invading groundwater, whereas on the other side of the front it is unchanged from the background value. This is known as plug flow, with all the pore fluid being replaced by the invading solute front. The sharp interface that results from plug flow is shown in Figure 2.3. The vertical dashed line at V represents an advancing solute front due to advection alone.

Figure 2.3 Advective transport and the influence of longitudinal dispersion and diffusion on the transport of a solute in one-dimensional flow.



Source: C.W. Fetter, 1994, *Applied Hydrogeology*, 3rd ed. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Due to the heterogeneity of geologic materials, advective transport in different strata can result in solute fronts spreading at different rates in each stratum. If one obtains a sample of water for purposes of monitoring the spread of a dissolved contaminant from a borehole that penetrates several strata, the water sample will be a composite of the water from each stratum. Due to the fact that advection will transport solutes at different rates in each stratum, the composite sample may be a mixture of water containing the transported solute coming from one stratum and uncontaminated groundwater coming

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from a different stratum where the average linear velocity is lower. The concentration of the contaminant in the composite sample would thus be less than in the source.

EXAMPLE PROBLEM

Dissolved nitrate in a concentration of 18.0 mg/L is being advected with flowing groundwater at a velocity of 0.331 m/day in an aquifer with a porosity of 0.225. Groundwater from the aquifer discharges into a stream. What is the mass flux of nitrate into the stream if the aquifer is 1.80 m thick and 123 m wide where it discharges into the stream?

From Equation 2.7 the one dimensional mass flux is

$$F_x = v_x n_e C$$

Given: $v_x = 0.331$ m/da

$n_e = 0.225$

$C = 18.0$ mg/L

For consistent units the concentration should be in gm/m^3.

$C = 18.0$ mg/L $\times$ 1/1000 gm/mg $\times$ 1000 L/m^3

$C = 18.0$ gm/m^3

The one dimensional mass flux is:

$F_x = 0.331$ m/da $\times$ 0.225 $\times$ 18.0 gm/m^3

$F_x = 1.34$ gm/da-m^2

The flux into the stream is the one dimensional mass flux times the cross sectional area where the aquifer discharges into the stream.

Total flux = 1.34 gm/da-m^2 $\times$ 123 m $\times$ 1.80 m

Total flux = 297 gm/da

2.4 Mechanical Dispersion

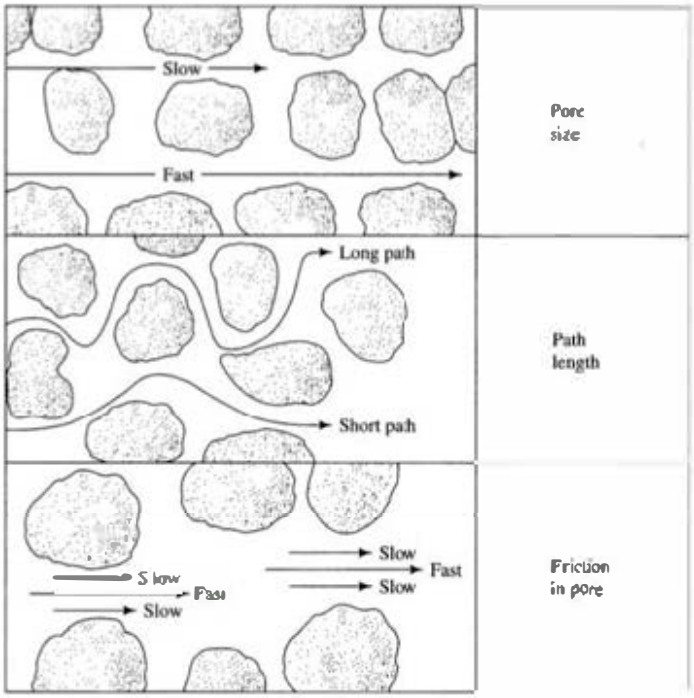
Groundwater is moving at rates that are both greater and less than the average linear velocity. At the macroscopic scale—that is, over a domain including a sufficient volume that the effects of individual pores are averaged (Bear 1972)—there are three basic causes of this phenomenon: (1) As fluid moves through the pores, it will move faster in the center of the pores than along the edges. (2) Some of the fluid particles will travel along longer flow paths in the porous media than other particles to go the same linear distance. (3) Some pores are larger than others, which allows the fluid flowing through these pores to move faster. These factors are illustrated in Figure 2.4.

If all groundwater containing a solute were to travel at exactly the same rate, it would displace water that does not contain the solute and create an abrupt interface between the two waters. However, because the invading solute-containing water is not all traveling at the same velocity, mixing occurs along the flowpath. This mixing is called **mechanical dispersion**, and it results in a dilution of the solute at the advancing edge of flow. The mixing that occurs along the direction of the flowpath is called **longitudinal dispersion**.

An advancing solute front will also tend to spread in directions normal to the direction of flow because at the pore scale the flowpaths can diverge, as shown in Figure 2.5. The result of this is mixing in directions normal to the flow path called **transverse dispersion**.

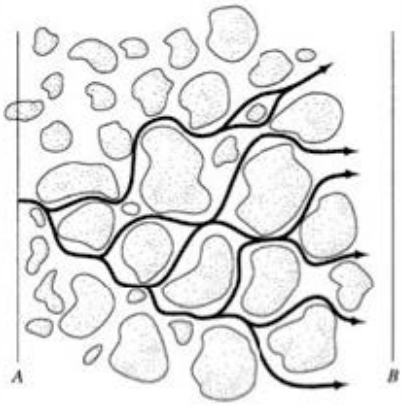
If we assume that mechanical dispersion can be described by Fick's law for diffusion (Equations 2.1 and 2.2) and that the amount of mechanical dispersion is a function of the average linear velocity, then we can introduce a coefficient of mechanical dispersion. This is equal to a property of the medium called *dynamic dispersivity*, or

FIGURE 2.4 Factors causing longitudinal dispersion at the scale of individual pores.



Source: C. W. Fetter. 1994. *Applied Hydrogeology, 3d ed.* Upper Saddle River, New Jersey: Prentice-Hall, Inc.

FIGURE 2.5 Flowpaths in a porous medium that cause lateral (transverse) hydrodynamic dispersion.



Source: C. W. Fetter. 1994. *Applied Hydrogeology, Third Edition.* Upper Saddle River, New Jersey: Prentice-Hall, Inc.

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simply *dispersivity*, α, times the average linear velocity. If i is the principle direction of flow, the following definitions apply:

$$\text{Coefficient of longitudinal mechanical dispersion} = \alpha_i v_i \tag{2.9}$$

where

v_i = the average linear velocity in the i direction (L/T)

α_i = the dynamic dispersiviry in the i direction (L)

and

$$\text{Coefficient of transverse mechanical dispersion} = \alpha_j v_i \tag{2.10}$$

where

v_i = the average linear velocity in the i direction (L/T)

α_j = the dynamic dispersivity in the j direction (L)

2.5 Hydrodynamic Dispersion

The process of molecular diffusion cannot be separated from mechanical dispersion in flowing groundwater. The two are combined to define a parameter called the **hydrodynamic dispersion coefficient**, D. It is represented by the following formulas:

$$D_L = \alpha_L v_i + D^* \tag{2.11a}$$

$$D_T = \alpha_T v_i + D^* \tag{2.11b}$$

where

D_L = hydrodynamic dispersion coefficient parallel to the principal direction of flow (longitudinal)

D_T = hydrodynamic dispersion coefficient perpendicular to the principal direction of flow (transverse)

α_L = longitudinal dynamic dispersiviry

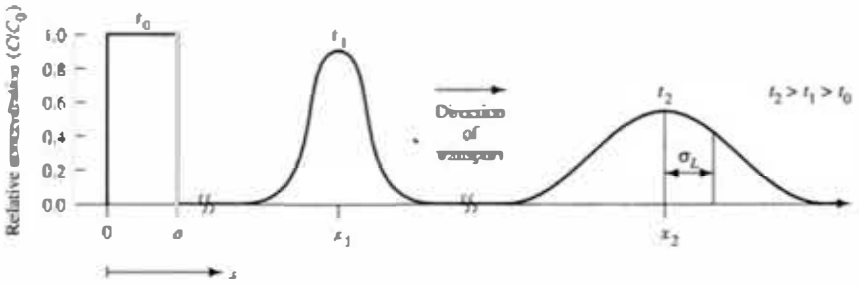
α_T = transverse dynamic dispersivity

Figure 2.3 shows the effect of diffusion and mechanical dispersion on the relative concentration (C'/C_0) of a solute acting as a tracer that has been injected into a porous medium under one-dimensional flow conditions. The vertical line at V represents the advective transport without dispersion. Effects of diffusion and mechanical dispersion are shown.

The process of hydrodynamic dispersion can be illustrated by Figure 2.6. A mass of solute is instantaneously introduced into the aquifer at time t_0 over the interval $x = 0 + a$. The resulting initial concentration is C_0. The advecting groundwater carries the mass of solute with it. In the process the solute slug spreads out, so that the maximum concentration decreases with time, as shown for times t_1 and t_2. The diffusional model of hydrodynamic dispersion predicts that the concentration curves will have a Gaussian distribution that is described by the mean and the variance. With this distribution the coefficients of longitudinal and transverse hydrodynamic dispersion can be defined as

$$D_L = \frac{\sigma_L^2}{2t} \tag{2.12a}$$

FIGURE 2.6 Transport and spreading of a solute slug with time due to advection and dispersion. A slug of solute was injected at $x = 0 + a$ at time t_0 with a resulting concentration of C_0. The groundwater flow is to the right.



$$D_T = \frac{\sigma_T^2}{2t} \tag{2.12b}$$

where

t = time

σ_T^2 = variance of the transverse spreading of the plume

σ_L^2 = variance of the longitudinal spreading of the plume

2.6 Derivation of the Advection-Dispersion Equation for Solute Transport

This derivation of the advection-dispersion equation is based on work by Freeze and Cherry (1979), Bear (1972), and Ogata (1970). Working assumptions are that the porous medium is homogeneous, isotropic, and saturated with fluid and that flow conditions are such that Darcy's law is valid.

The derivation is based on the conservation of mass of solute flux into and out of a small representative elementary volume (REV) of the porous media. The REV is the smallest volume that is representative for the entirety of whole medium. A measurement made at the REV scale will yield a value typically of the whole (Hill 1963). The REV concept serves as a cornerstone in the continuum modeling of transport phenomena in porous media (Bachmat and Bear 1987). The flow is at a macroscopic scale, which means that it accounts for the differences in flow from pore to pore. A representative elementary volume is illustrated in Figure 1.6.

The average linear velocity, v, has components v_x, v_y, and v_z. The concentration of solute, C, is mass per unit volume of solution. Mass of solute per unit volume of aquifer is the product of the effective porosity, n_e, and C. Porosity is considered to be a constant because the aquifer is homogeneous.

The solute will be transported by advection and hydrodynamic dispersion. In the i direction the solute transport is given by

$$\text{Advective transport} = v_i n_e C \, dA \tag{2.13}$$

$$\text{Dispersive transport} = n_e D_i \frac{\partial C}{\partial i} dA \tag{2.14}$$

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where dA is the cross-sectional area of the element and the i direction is normal to that cross-sectional face.

The total mass of solute per unit cross-sectional area transported in the i direction per unit time, F_i, is the sum of the advective and the dispersive transport and is given by

$$F_i = v_i n_e C - n_e D_i \frac{\partial C}{\partial i} \tag{2.15}$$

The negative sign indicates that the dispersive flux is from areas of greater to areas of lesser concentration.

The total amount of solute entering the representative elementary volume is

$$F_x\,dz\,dy + F_y\,dz\,dx + F_z\,dx\,dy$$

The total amount of solute leaving the representative elementary volume is

$$\left(F_x + \frac{\partial F_x}{\partial x}dx\right)dz\,dy + \left(F_y + \frac{\partial F_y}{\partial y}dy\right)dz\,dx + \left(F_z + \frac{\partial F_z}{\partial z}dz\right)dx\,dy$$

The difference between the mass of the solute entering the representative elementary volume and the amount leaving it is

$$-\left(\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z}\right)dx\,dy\,dz$$

The rate of mass change in the representative elementary volume is

$$n_e \frac{\partial C}{\partial t}dx\,dy\,dz$$

By the law of mass conservation, the rate of mass change in the representative elementary volume must be equal to the difference in the mass of the solute entering and the mass leaving.

$$\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z} = -n_e \frac{\partial C}{\partial t} \tag{2.16}$$

Equation 2.15 can be used to find the values of F_x, F_y, and F_z. These are substituted in Equation 2.16, which becomes, after cancellation of n_e from both sides,

$$\left[\frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right)\right]$$

$$-\left[\frac{\partial}{\partial x}(v_x C) + \frac{\partial}{\partial y}(v_y C) + \frac{\partial}{\partial z}(v_z C)\right] = \frac{\partial C}{\partial t} \tag{2.17}$$

Equation 2.17 is the three-dimensional equation of mass transport for a *conservative* solute—that is, one that does not interact with the porous media or undergo biological or radioactive decay.

In a homogeneous medium, D_x, D_y, and D_z do not vary in space. However, because the coefficient of hydrodynamic dispersion is a function of the flow direction, even in an isotropic, homogeneous medium, $D_x \neq D_y \neq D_z$. For those domains where the

average linear velocity, v_x, is uniform in space, Equation 2.17 for one-dimensional flow in a homogeneous, isotropic porous media is

$$D_L \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \tag{2.18}$$

In a homogeneous medium with a uniform velocity field, Equation 2.17 for two-dimensional flow with the direction of flow parallel to the x axis is

$$D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial y^2} - v_x \frac{\partial C}{\partial x} = \frac{\partial C}{\partial t} \tag{2.19}$$

where

D_L = the longitudinal hydrodynamic dispersion (L^2/T)

D_T = the transverse hydrodynamic dispersion (L^2/T)

Equation 2.17 for radial flow from a well can be written in polar coordinates (Ogata 1970) as

$$\frac{\partial}{\partial r}\left(D\frac{\partial C}{\partial r}\right) + \frac{D}{r}\frac{\partial C}{\partial r} - u\frac{\partial C}{\partial r} = \frac{\partial C}{\partial t} \tag{2.20}$$

where

r = radial distance to the well

u = average pore velocity of injection, which is found from

$$u = \frac{Q}{2\pi n_e R r^2}$$

where

Q = the rate of injection into the well

n_e = effective porosity

R = length of well screen or open bore hole

2.7 Diffusion versus Dispersion

In the previous section the mass transport equation was derived on the basis of hydrodynamic dispersion, which is the sum of mechanical dispersion and diffusion. It would have been possible to separate the hydrodynamic dispersion term into the two components and have separate terms in the equation for them. However, as a practical matter, under most conditions of groundwater flow, diffusion is insignificant and is neglected.

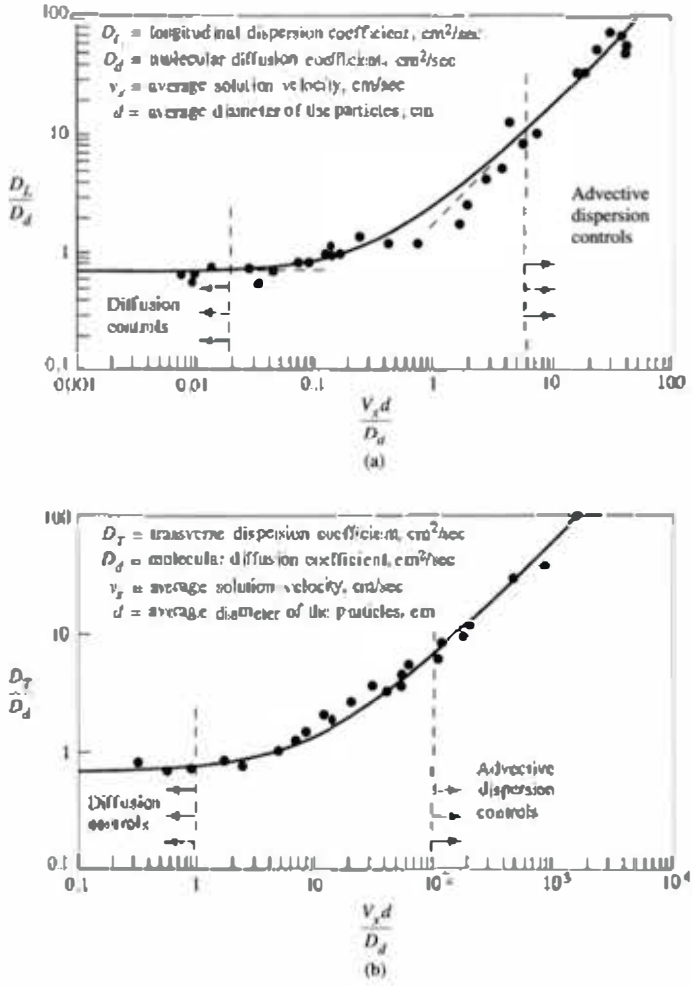
It is possible to evaluate the relative contribution of mechanical dispersion and diffusion to solute transport. A Peclet number, P_e, is a dimensionless number that can relate the effectiveness of mass transport by advection to the effectiveness of mass transport by either dispersion or diffusion. Peclet numbers have the general form of $v_x d/D_d$ or $v_x L/D_L$, where v_x is the advective velocity, d and L are characteristic flow lengths, D_d is the coefficient of molecular diffusion, and D_L is the longitudinal hydrodynamic dispersion coefficient. The column Peclet number, which defines the ratio of transport

by advection to the rate of transport by molecular diffusion in column studies, is a dimensionless parameter defined as $v_x d/D_d$, where d is the average grain diameter and D_d is the coefficient of molecular diffusion. A plot of the ratio of D_L/D_d versus the Peclet number is given in Figure 2.7a. Shown on this figure are the results of a number of experimental measurements using sand columns and tracers as well as some experimental curves from several investigators (Perkins and Johnson 1963). Delgado (2007) presents empirical correlations for the prediction of the dispersion coefficients (D_T and D_L) based Peclet number and Schmidt number (S_c). The dimensionless Schmidt number relates the viscous diffusion rate to the molecular diffusion rate. S_c is defined as:

$$S_c = \frac{\mu}{\rho D}$$

where μ and ρ are the dynamic viscosity (M/LT) and density of the fluid, respectively. D is the diffusion coefficient.

FIGURE 2.7 Graph of dimensionless dispersion coefficients versus Peclet number, $P_e = v_x d/D_d$. (a) D_L/D_e versus P_e and (b) D_T/D_e versus P_e.



Source: T.K. Perkins and O.C. Johnson. 1963. *Society of Petroleum Engineers Journal* 3:70–84. Society of Petroleum Engineers.

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At zero flow velocity D_L is equal to D^*, since $D_L = a_L v_x + D^*$. In this manner the value of ω, the tortuosity factor, can be experimentally determined as $D^* = \omega D_d$. At very low velocities, the ratio of D_L/D_d is a constant with a value of about 0.7, which is the experimentally determined value of ω for uniform sand. This shows up on the left side of Figure 2.7(a) as a horizontal line. In this zone diffusion is the predominant force, and dispersion can be neglected. Between a Peclet number of about 0.4 to 6 there is a transition zone, where the effects of diffusion and longitudinal mechanical dispersion are more or less equal.

Figure 2.7(b) shows the plot of D_T/D_e as a function of Peclet number. Although the curve has the same shape as in (a), it occurs at Peclet numbers roughly 100 times greater. This means that diffusion has more control over transverse dispersion at higher Peclet numbers than it does for longitudinal dispersion. Higher Peclet numbers occur with higher velocities and/or longer flow paths. At higher Peclet numbers mechanical dispersion is the predominant cause of mixing of the contaminant plume (Perkins and Johnson 1963; Bear 1972; Bear and Verruijt 1987) and the effects of diffusion can be ignored. Under these conditions D_L can be replaced with $a_L v_x$ in the advection-dispersion equations.

2.8 Moment Analysis

Contaminant hydrogeologists, like other scientists, have to work with a lot of data, such as periodic measurements of pollutant concentrations in monitoring wells or hydraulic values that determine the flow and transport of these pollutants. If writing a report or publishing data in peer reviewed manuscripts, one is expected to back up the significance of the data with a proper statistical analysis. A review of statistical concepts and methods is not the focus of this book, but excellent introductions into groundwater statistics are provided by Helsel and Hirsch (2002) or Interstate Technology and Regulatory Council (2013).

One statistical method, however, that is quite useful for the analysis of contaminant fate and transport data, especially results from laboratory or fieldscale tracer tests, warrants a more detailed discussion. The method is known as moment analysis. This method can be an important tool for calculating mass recoveries in tracer experiments, travel velocities of a plume, and the description of the shape of the plume in terms of dispersivity, skewness, and kurtosis. Both temporal and spatial data can be used for this analysis. The relationship between the spatial and temporal moments and the properties of an evolving solute plume are based on work by Aris (1956) and subsequent modifications by Goltz and Roberts (1987), who developed moment concepts for the analysis of threedimensional solute transport data. The spatial moment technique was utilized by Marle et al. (1967), Ghiiven et al. (1984) and Valocchi (1989) to study solute transport in steady horizontal flow in a perfectly stratified aquifer. Valocchi (1990) provides an overview of the usefulness of temporal moment analysis for studying reactive solute transport in aggregated porous media.

The method of moment was employed for the analysis of many natural gradient field tracer tests. For instance, the spatial moments of the bromide tracer distribution were used to calculate the tracer mass, velocity, and dispersivity during the large scale tracer test at the Canadian Air Force Base (CFB) in Borden, Ontario (Freyberg 1986; Farrell and Woodbury 1994) or the transport of nonreactive and reactive tracers in a sand and gravel aquifer on Cape Cod, Massachusetts (Leblanc et al. 1991; Garabedian et al. 1991) or at the Twin Lake aquifer test site within the property of the Chalk River

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Nuclear Laboratories, where in 1982 and 1983 a pulse of groundwater labeled with ^{131}Iodine was injected (Moltyaner and Killey 1988; Moltyaner and Wills 1991).

The analysis of moments ordinarily is accomplished by numerically solving one or more triple integrals of tracer concentration in the threedimensional space of the test domain (Freyberg 1986; Glotz and Roberts 1987; Valochhi 1989; Garabedian et al. 1991). The absolute moments (M) in three dimensions are defined as follows:

$$M_{jkn} = \int_{-\infty}^{\infty}\int\int C x^j y^k z^n dx\, dy\, dz$$

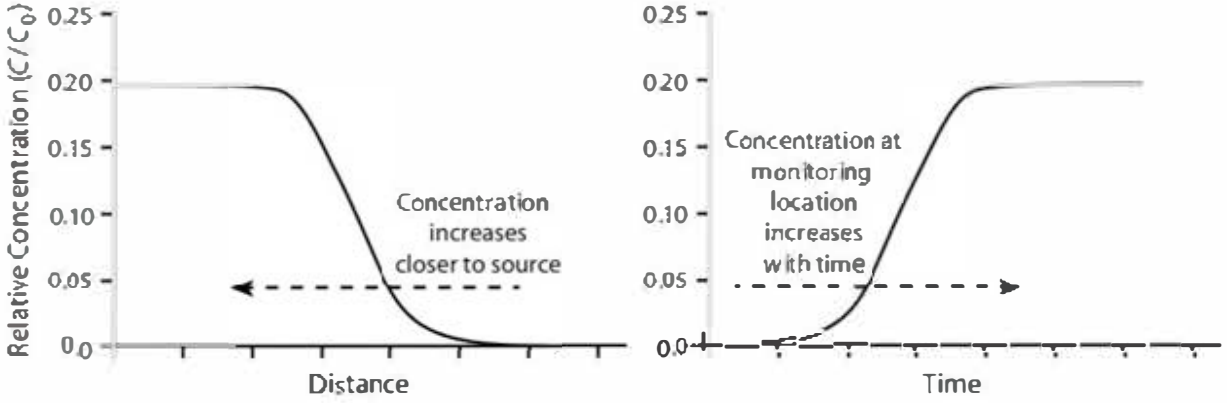
where C is the solute concentration at the spatial coordinates x, y, and z. For one-dimensional data sets, the moment analysis can be simplified to the temporal and spatial forms summarized in Table 2.2.

Temporal moments can be interpreted with the help of breakthrough curves (BTC) (Figure 2.8). A BTC is a graph of concentration versus time. This format of depiction is appropriate when the position of the observer is fixed (Eulerian approach). A BTC

TABLE 2.2 One-dimensional moments.

Moment	Temporal Moments	Spatial Moments
Zeroth Absolute Moment	$M_t^0 = \int_0^{\infty} C\, dt$	$M_s^0 = \int_0^{\infty} C\, dx$
First Normalized Moment	$M_t^1 = \frac{\int_0^{\infty} Ct\, dt}{\int_0^{\infty} C\, dt} = \frac{\int_0^{\infty} Ct\, dt}{M_t^0}$	$M_s^1 = \frac{\int_0^{\infty} Cx\, dx}{\int_0^{\infty} C\, dx} = \frac{\int_0^{\infty} Cx\, dx}{M_x^0}$
Adjusted First Temporal Moment	$M_{adj}^1 = \frac{\int_0^{x} Ct\, dt}{M_t^0} - \frac{1}{2}T_0$	Not defined
Second Central Moment	$M_t^2 = \frac{\int_0^{\infty} \left(t - M_t^1\right)^2 C\, dt}{M_t^0}$	$M_s^2 = \frac{\int_0^{\infty} \left(x - M_s^1\right)^2 C\, dx}{M_s^0}$
Third Central Moment	$M_t^3 = \frac{\int_0^{\infty} \left(t - M_t^1\right)^3 C\, dt}{M_t^0}$	$M_s^3 = \frac{\int_0^{\infty} \left(x - M_s^1\right)^3 C\, dx}{M_s^0}$
Fourth Central Moment	$M_t^4 = \frac{\int_0^{\infty} \left(t - M_t^1\right)^4 C\, dt}{M_t^0}$	$M_s^4 = \frac{\int_0^{\infty} \left(x - M_s^1\right)^4 C\, dx}{M_s^0}$

FIGURE 2.8 Representation of concentration data resulting from a continuous contaminant release scenario: (a) concentration versus distance and (b) concentration versus time. The concentration-time graph is called a breakthrough curve (BTC).



is typically used to report solute concentrations in column effluent during of tracer experiment or at the location of a specific monitoring well. In contrast, a graph of concentration versus distance is not a BTC. It represents a snapshot of concentration data collected more or less simultaneously at various locations within the test domain (Lagrangian approach). Such a graph is useful, for example, for reporting the tracer concentration in groundwater samples collected along the principal axis of a contaminant plume.

It is convenient to normalize the higher order temporal and spatial moments by scaling them to the zeroth temporal moment (M_t^0) or zeroth spatial moment (M_s^0), respectively. Higher moments are centralized by subtracting the first normalized temporal or spatial moment ($M_{t,s}^1$) from the elapsed time (t) or distance (x), respectively, since the start of the measurements.

The significance of M_t^0 is that it integrates the area under the concentration versus distance curve (Figure 2.8) and thus presents the mass of solute and a measure for calculating the solute mass recovery and mass balance. The M_s^0 aides in determining the amount of mass passing by a sampling point (i.e., monitoring well). A constant value of M_s^0 at different distances from the origin indicates that no mass loss occurred and therefore suggests a recalcitrance of a compound to sorption of degradation processes. The M_s^1 calculates the mean, i.e., the location of the center of mass of a plume and thus aides in calculating the plume travel velocity. M_t^1 describes the travel time of a dissolved compound (Figure 2.9). While not defined for spatial coordinate data, the adjusted first temporal moment, M_{adj}^1, is:

$$M_{adj}^1 = \frac{\int_0^x C\, t\, dt}{M^0} - \frac{1}{2} T_0$$

where T_0 is the pulse length, i.e., the duration of the tracer slug injection. M_{adj}^1 permits the calculation of the tracer front travel time (Figure 2.11) and therefore M_{adj}^1 can be used to calculate the retardation factor from the inflection point of the BTC, i.e., where $C/C_{max.} = 0.5$. The parameter $C_{max.}$ is the maximum concentration measured during the tracer test (Figure 2.9).

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FIGURE 2.9 Ideal breakthrough curve (BTC). The arrival time is the time for the center of mass to arrive at the monitoring location. The travel time is the breakthrough time of the tracer front.

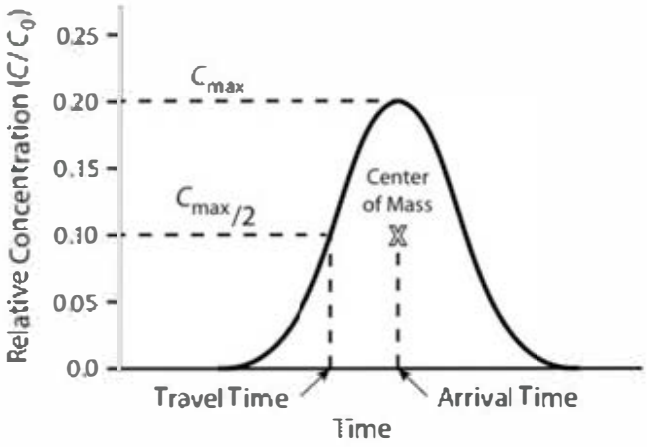
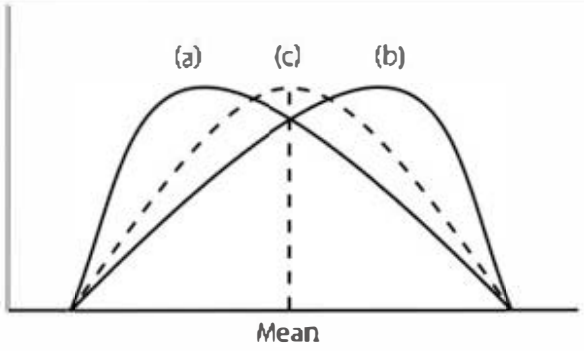


FIGURE 2.10 Skewness: (a) positive, (b) negative and (c) not skewed around the mean ($M^3 = 0$).



The second temporal moment (M_t^2) is the variance (σ^2) and provides a measure for the spread of a plume about the location of the center of mass. The analysis of the second spatial moment (M_x^2) can be used to determine the longitudinal dispersion coefficient, D_L, in either temporal or spatial coordinates:

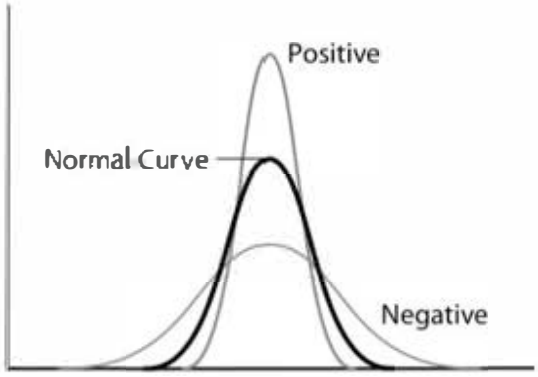
$$D_L = \frac{\sigma_L^2}{2t}$$

$$D_L = \frac{\sigma_L^2 v}{2x}$$

where σ_L^2 is the variance, t is time since the start of the tracer test and v is the linear flow velocity (constant).

The skewness of a curve is described by the third moment (M^3). A positive value indicates that the graph is skewed to the right, whereas a negative value means skewness to the left (Figure 2.10). A value of approximately zero suggests that the data is normally distributed. The fourth moment (M^4) is a measure of kurtosis (Figure 2.11). For a conservative tracer, both M^3 and M^4 should be approximately zero. Deviations

FIGURE 2.11 Negative and positive kurtosis. The M^4 is zero for when the tracer concentration data is normally distributed.



from that value indicate non-ideal transport conditions. Other applications of moment analysis are discussed in Suthersan et al. 2017.

EXAMPLE

A tracer test was conducted and concentration measurements have been collected downgradient from the injection location and at three different times ($t_1 = 30$ *d*, $t_2 = 60$ *d*, and $t_3 = 90$ *d*). Figure 2.12 shows the concentration versus distance data in terms of dimensionless concentration (C/C_0) at three observations points.

In this example, the tracer is nonreactive because the area under the curves (M^0) remains the same for all three data sets. Had the value of M^0 decreased however, it

FIGURE 2.12 The spatial position of the tracer concentrations profiles at times t_1, t_2, and t_3.

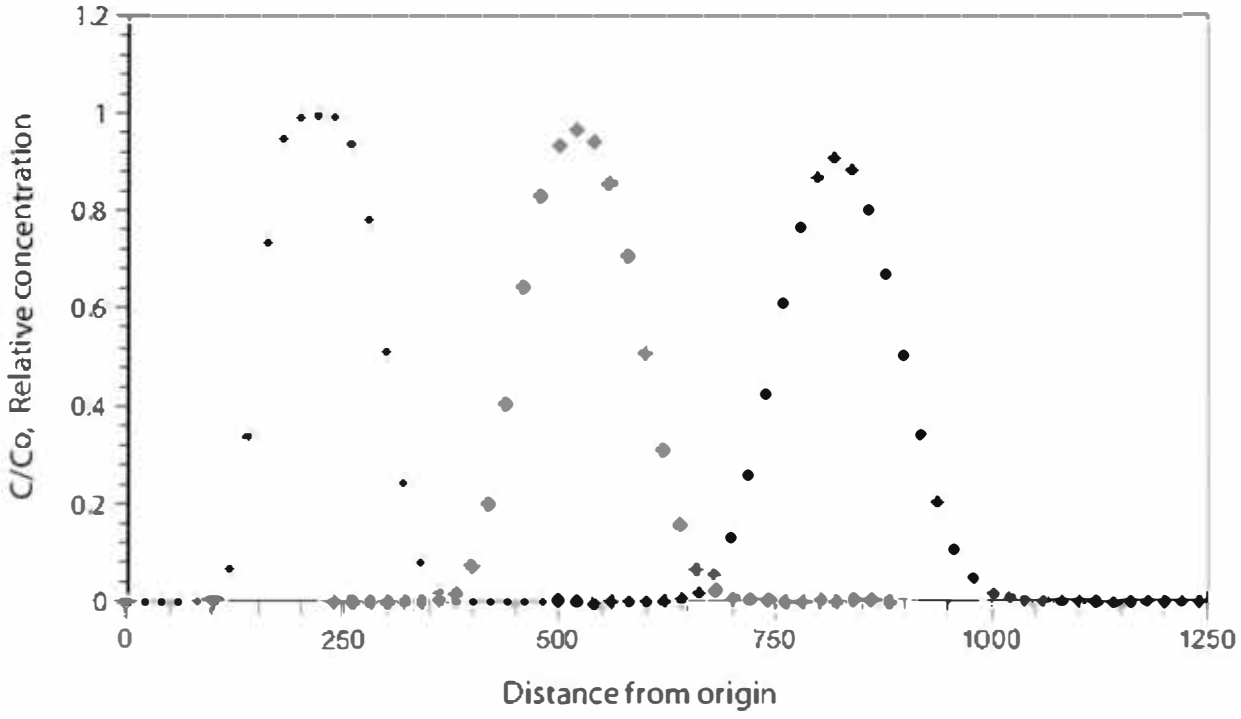
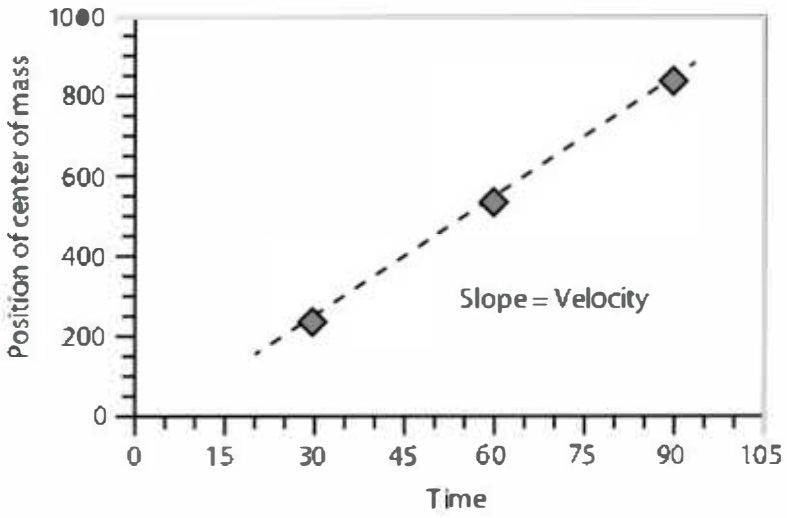


FIGURE 2.13 The velocity of a migrating plume can be estimated from the location of the center of mass (First spatial moment).



would have indicated that a fraction of the tracer was lost during the experiment. In that case, a plot of M^0 versus distance would reveal if the rate of loss is linear or nonlinear.

The velocity of a migrating plume was estimated from the location of the center of mass (M^1) at different times (Figure 2.12). In this example, the velocity remained constant throughout the experiment, which is expected for a nonreactive tracer. If the flow velocity is identical to the groundwater flow velocity, the tracer can be considered "conservative," i.e., its flow is not retarded. By comparing the M^1 of a conservative tracer with that of other tracers that might have been co-injected at the start of the tracer test, one can calculate the relative travel times or relative travel distances and thus the retardation factors for each tracer.

When plotting M^2 for each of the three data sets against the time of measurement, the slope of the regression line is equal to $2D_L$. The M^3 and M^4 values indicate that the three data sets are not skewed and that they do not show kurtosis; once again indicating that the tracer was nonreactive.

2.9 Analytical Solutions of the Advection-Dispersion Equation

2.9.1 Methods of Solution

The advection-dispersion equations can be solved by either numerical or analytical methods. Analytical methods involve the solution of the partial differential equations using calculus based on the initial and boundary value conditions. They are limited to simple geometry and in general require that the aquifer be homogeneous. A number of analytical solutions are presented in this chapter. They are useful in that they can be solved with spreadsheet, like EXCEL, or even a pencil and paper, if one is so inclined.

Numerical methods involve the solution of the partial differential equation by numerical methods of analysis. They are more powerful than analytical solutions in the sense that aquifers of any geometry can be analyzed and aquifer heterogeneities can be accommodated. However, there can be other problems with numerical models, such as numerical errors, which can cause solutions to show excess spreading of solute fronts or plumes that are not related to the dispersion of the tracer that is the subject of the modeling. Bear and Verruijt (1987) present a good introduction to the use of numerical models to solve mass transport equations. These solutions are normally found by methods of computer modeling, a topic beyond the scope of this text. Instead, the reader is referred to Bear and Cheng (2010), who offer an overview about the methodology and procedures for constructing conceptual and mathematical models for groundwater flow and the fate and transport of contaminants in both saturated and unsaturated zones. Also, Kuzmin (2010) provides a guide to numerical methods for solving transport equations with particular focus on finite element models.

2.9.2 Boundary and Initial Conditions

In order to obtain a unique solution to a differential equation it is necessary to specify the initial and the boundary conditions that apply. The initial conditions describe the values of the variable under consideration, in this case concentration, at some initial time equal to 0. The boundary conditions specify the interaction between the area under investigation and its external environment.

There are three types of boundary conditions for mass transport. The boundary condition of the first type is a fixed concentration. The boundary condition of the second type is a fixed gradient. A variable flux boundary constitutes the boundary condition of the third type.

Boundary and initial conditions are shown in a shorthand form. For one-dimensional flow we need to specify the conditions relative to the location, x, and the time, t. By convention this is shown in the form

$$C(x,t) = C(t)$$

where $C(t)$ is some known function.

For example, we can write

$$C(0,t) = C_0, \quad t \geq 0$$
$$C(x,0) = 0, \quad x \geq 0$$
$$C(\infty,t) = 0, \quad t \geq 0$$

The first statement says that for all time t equal to or greater than zero, at $x = 0$ the concentration is maintained at C_0. This is a fixed-concentration boundary condition located at $x = 0$ (first-type boundary). The second statement is an initial condition that says at time $t = 0$, the concentration is zero everywhere within the flow domain, that is, where x is greater than or equal zero. As soon as flow starts, solute at a concentration of C_0 will cross the $x = 0$ boundary.

The third condition shows that the flow system is infinitely long and that no matter how large time gets, the concentration will still be zero at the end of the system (first-type boundary condition at $x = \infty$).

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We could also have specified an initial condition that within the domain the initial solute concentration was C_i. This would be written as

$$C(x,0) = C_i, \quad x \geq 0$$

Other examples of concentration (first-type) boundary conditions are exponential decay of the source term and pulse loading at a constant concentration for a period of time followed by another period of time with a different constant concentration.

Exponential decay for the source term can be expressed as

$$C(0, t) = C_0 e^{-it}$$

where i = a decay constant.

Pulse loading where the concentration is C_0 for times from 0 to t_0 and then is 0 for all time more than t_0 is expressed as

$$C(0,t) = C_0 \qquad 0 < t \leq t_0$$

$$C(0,t) = 0 \qquad t > t_0$$

Fixed-gradient boundaries are expressed as

$$\left.\frac{dC}{dx}\right|_{x=0} = f(t) \quad \text{or} \quad \left.\frac{dC}{dx}\right|_{x=\infty} = f(t)$$

where $f(t)$ is some known function. A common fixed-gradient condition is $dC/dx = 0$, or a no-gradient boundary.

The variable-flux boundary, a third type, is given as

$$-D\frac{\partial C}{\partial x} + v_x C = v_x C(t)$$

where $C(t)$ is a known concentration function. A common variable-flux boundary is a constant flux with a constant input concentration, expressed as

$$\left(-D\frac{dC}{dx} + vC\right)\Big|_{x=0} = C_0$$

2.9.3 One-Dimensional Step Change in Concentration (First-Type Boundary)

Sand column experiments have been used to evaluate both the coefficients of diffusion and dispersion at the laboratory scale. A tube is filled with sand and then saturated with water. Water is made to flow through the tube at a steady rate, creating, in effect, a permeameter. A solution containing a tracer is then introduced into the sand column in place of the water. The initial concentration of the solute in the column is zero, and the concentration of the tracer solution is C_0. The tracer in the water exiting the tube is analyzed, and the ratio of C, the tracer concentration at time t, over C_0, the injected tracer concentration, is plotted as a function of time. This is called a **fixed-step function.**

The boundary and initial conditions are given by

$$C(x,0) = 0 \qquad x \geq 0 \qquad \text{Initial condition}$$

$$\left.\begin{aligned} C(0,t) &= C_0 \qquad t \geq 0 \\ C(\infty,t) &= 0 \qquad t \geq 0 \end{aligned}\right\} \quad \text{Boundary conditions}$$

The solution to Equation 2.18 for these conditions is (Ogata and Banks 1961)

$$C = \frac{C_0}{2}\left[\operatorname{erfc}\left(\frac{L - v_x t}{2\sqrt{D_L t}}\right) + \exp\left(\frac{v_x L}{D_L}\right)\operatorname{erfc}\left(\frac{L + v_x t}{2\sqrt{D_L t}}\right)\right] \tag{2.21}$$

This equation may be expressed in dimensionless form as

$$C_R(t_R, P_e) = 0.5\left\{\operatorname{erfc}\left[\left(\frac{P_e}{4t_R}\right)^{1/2} \times (1 - t_R)\right] + \exp(P_e)\operatorname{erfc}\left[\left(\frac{P_e}{4t_R}\right)^{1/2} (1 + t_R)\right]\right\} \tag{2.22}$$

where

t_R = $v_x t / L$

C_R = C / C_0

P_e = Peclet number when flow distance, L, is chosen as the reference length ($P_e = v_x L / D_L$)

erfc = complementary error function

Equation 2.21 can be solved in Microsoft Excel after installing the *PlumeID()* add-in (Renshaw 2015a).

2.9.4 One-Dimensional Continuous Injection into a Flow Field (Second-Type Boundary)

In nature there are not many situations where there would be a sudden change in the quality of the water entering an aquifer. A much more likely condition is that there would be leakage of contaminated water into the groundwater flowing in an aquifer. For the one-dimensional case, this might be a canal that is discharging contaminated water into an aquifer as a line source (Figure 2.14).

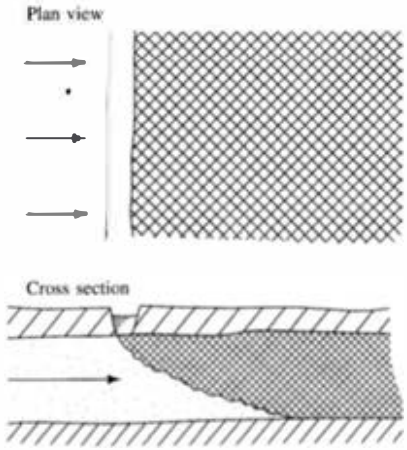
The rate of injection is considered to be constant, with the injected mass of the solute proportional to the duration of the injection. The initial concentration of the solute in the aquifer is zero, and the concentration of the solute being injected is C_0. The solute is free to disperse both up-gradient and down-gradient.

The boundary and initial conditions are

$$C(x,0) = 0 \qquad -\infty < x < +\infty \qquad \text{Initial condition}$$

$$\left.\begin{aligned} \int_{-\infty}^{+\infty} n_e C(x,t)\,dx &= C_0 n_e v_x t \qquad t > 0 \\ C(\infty,t) &= 0 \qquad t \geq 0 \end{aligned}\right] \quad \text{Boundary conditions}$$

FIGURE 2.14 Leakage from a canal as a line source for injection of a contaminant into an aquifer.



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The second boundary condition states that the injected mass of contaminant over the domain from $-\infty$ to $+\infty$ is proportional to the length of time of the injection.

The solution to this flow problem (Sauty 1980) is

$$C = \frac{C_0}{2}\left[\operatorname{erfc}\left(\frac{L - v_x t}{2\sqrt{D_L t}}\right) - \exp\left(\frac{v_x L}{D_L}\right)\operatorname{erfc}\left(\frac{L + v_x t}{2\sqrt{D_L t}}\right)\right] \tag{2.23}$$

In dimensionless form this is

$$C_R(t_R, P_e) = 0.5\left\{\operatorname{erfc}\left[\left(\frac{P_e}{4t_R}\right)^{1/2}(1 - t_R)\right]\right. \tag{2.24}$$

$$\left. -\exp(P_e)\operatorname{erfc}\left[\left(\frac{P_e}{4t_R}\right)^{1/2}(1 + t_R)\right]\right\}$$

It can be seen that Equations 2.21 and 2.23 are very similar, the only difference being that the second term is subtracted rather than added in 2.23.

Sauty (1980) gives an approximation for the one-dimensional dispersion equation as

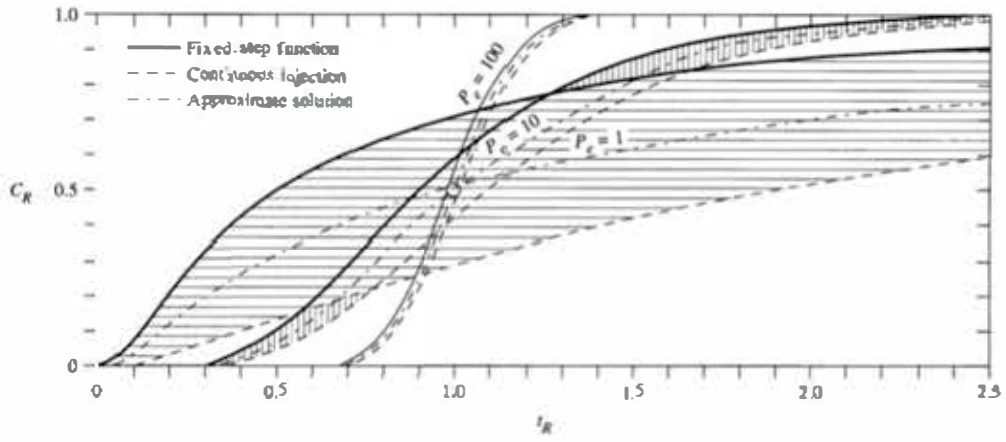
$$C = \frac{C_0}{2}\left[\operatorname{erfc}\left(\frac{L - v_x t}{2\sqrt{D_L t}}\right)\right] \tag{2.25}$$

In dimensionless form this is

$$C_R(t_R, P_e) = 0.5\operatorname{erfc}\left[\left(\frac{P_e}{4t_R}\right)^{1/2}(1 - t_R)\right] \tag{2.26}$$

This approximation comes about because for large Peclet numbers, the second term of Equations 2.21 and 2.23 is much smaller than first term and can be neglected. Figure 2.15 demonstrates under what conditions this approximation is valid. In Figure 2.15 the dimensionless concentration, C_R, is plotted as a function of dimensionless time, t_R, for continuous tracer injection using the fixed-step function, Equation 2.22, the continuous-injection function, Equation 2.24, and the approximate solution, Equation 2.26. Curves are plotted for three Peclet numbers, 1, 10, and 100 (Section 2.7). The Peclet number defines the rate of transport by advection to the rate of transport by hydrodynamic dispersion. For Peclet number 1, the fixedstep function and the continuous-injection function give quite different results, whereas for Peclet number 100 they are almost identical. The approximate solution lies midway between the other two. This figure suggests that for Peclet numbers less than about 10, the exact solutions need to be considered, whereas for Peclet numbers greater than 10, the approximate solution is probably acceptable, especially as the Peclet number approaches 100. This Peclet number increases with flow-path length as advective transport becomes more dominant over dispersive transport. Thus for mass transport near the inlet boundary, it is important to use the correct equation, but as one goes away from the inlet boundary, it is less important that the correct form of the equation is employed.

FIGURE 2.15 Dimensionless-type curves for the continuous injection of a tracer into a one-dimensional flow field.



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EXAMPLE PROBLEM

Pickles are made in large wooden vats. At the Happy Gherkin Pickle Factory one of the vats has been leaking brine directly into the water table. The concentration of chloride in the brine is 1575 mgL^{-1}. The flow in the aquifer that receives the brine is essentially one-dimensional and has the following characteristics.

Hydraulic conductivity = 2.93×10^{-6} ms^{-1}

Hydraulic gradient = 0.00678

Effective porosity = 0.259

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The estimated effective diffusion coefficient for chloride is $2 \times 10^{-9}\ m^2s^{-1}$.

Calculate the concentration of chloride above any background value at a distance 125 m from the leaking vat 0.50 years after the leak began.

We will apply equation 2.25 to this problem. Note that this is an approximate solution as the second term of equation 2.23 has been dropped.

$$C = \frac{C_0}{2}\left[\operatorname{erfc}\left(\frac{L - v_x t}{2\sqrt{D_L t}}\right)\right]$$

1. Calculate v_x

$$v_x = \frac{K}{n_e}\frac{dh}{dl}$$

$$v_x = \frac{2.93\times10^{-4} ms^{-1}}{0.259} \times 0.00678$$

$$v_x = 7.67\times10^{-6} ms^{-1}$$

2. Find the value of the coefficient of longitudinal hydrodynamic dispersion, D_L. This can be found from equation 2.11a.

$$D_L = \alpha_L v_x + D^*$$

   a. The first step is to find the value of α_L. This can be estimated from equation 2.48, which will be introduced in a later section.

$$\alpha_L = 0.83(\log L)^{2.414}$$

$$\alpha_L = 083(\log 125)^{2.414}\ m$$

$$\alpha_L = 4.96\ m$$

   b. The next step is to calculate D_L.

$$D_L = 4.96m\times7.67\times10^{-6} ms^{-1} + 2\times10^{-9} m^2s^{-1}$$

$$D_L = 3.80\times10^{-5} m^2s^{-1} + 2\times10^{-9} m^{2-1}$$

The second term reflecting the effective diffusion coefficient can be neglected as it is so much smaller than the first term.

3. In order to have consistent units, the time must be expressed in seconds.

$$0.5\ y \times 365\ d/y \times 1440\ min/d \times 60\ s/min = 1.578 \times 10^7\ s.$$

4. The values of the variables are then substituted into Equation 2.25.

$$C_0 = 1575\ mgL^{-1}$$

$$v_x = 7.67 \times 10^{-6} ms^{-1}$$

$$L = 125m$$

$$D_L = 3.80 \times 10^{-5} m^2s^{-1}$$

$$t = 1.578 \times 10^7 s$$

$$C = \frac{1575\,mgL^{-1}}{2}\,erfc\left(\frac{125m-(7.67\times10^{-6}ms^{-1}\times1.578\times10^{7}s)}{2\sqrt{3.80\times10^{-5}m^{2}s^{-1}\times1.578\times10^{7}s}}\right)$$

$$C = 787.5erfc\left(\frac{125m-121.0m}{2\sqrt{5.99\times10^{2}m^{2}}}\right)mgL^{-1}$$

$$C = 787.5erfc\left(\frac{4.0m}{2\times24.49m}\right)mgL^{-1}$$

$$C = 787.5erfc(0.0816)\ mg/L$$

$$C = 787.5\times0.908mgL^{-1} = 715mgL^{-1}$$

2.9.5 Third-Type Boundary Condition

A solution for Equation 2.18 for the following boundary condition was given by van Genuchten (1981).

$$C(x,0) = 0 \qquad \text{Initial condition}$$

$$\left(-D\frac{\partial C}{\partial x} + v_x C\right)\Big|_{x=0} = v_x C_0 \qquad \text{Boundary conditions}$$

$$\left.\frac{\partial C}{\partial x}\right|_{x\to\infty} = (\text{finite})$$

The third condition specifies that as x approaches infinity, the concentration gradient will still be finite. Under these conditions the solution to Equation 2.18 is:

$$C = \frac{C_0}{2}\left[erfc\left[\frac{L-v_x t}{2\sqrt{D_L t}}\right] + \left(\frac{v_x^{2} t}{\pi D_L}\right)^{1/2}\exp\left[-\frac{(L-v_x t)^{2}}{4D_L t}\right]\right.$$

$$\left. -\frac{1}{2}\left(1+\frac{v_x L}{D_L}+\frac{v_x^{2} t}{D_L}\right)\exp\left(\frac{v_x L}{D_L}\right)erfc\left[\frac{L-v_x t}{2\sqrt{D_L t}}\right]\right] \qquad (2.27)$$

This equation also reduces to the approximate solution, Equation 2.25, as the flow length increases.

2.9.6 One-Dimensional Slug Injection into a Flow Field

If a slug of contamination is instantaneously injected into a uniform, one-dimensional flow field, it will pass through the aquifer as a pulse with a peak concentration, C_{max}, at some time after injection, t_{max}. The solution to Equation 2.18 under these conditions (Sauty 1980) is in dimensionless form:

$$C_R = (t_R, P_e) = \frac{E}{(t_R)^{1/2}}\exp\left(-\frac{P_e}{4t_R}(1-t_R)^{2}\right) \qquad (2.28)$$

R000286

with

$$E = (t_{R\max})^{1/2} \exp\left(\frac{P_e}{4t_{R\max}}(1 - t_{R\max})^2\right) \quad (2.29)$$

where

$t_{R\max}$ = $(1 + P_e^{-2})^{1/2} - P_e^{-1}$ (dimensionless time at which peak concentration occurs)

C_R = C/C_{max}

In Figure 2.16, C_R (C/C_{max}) for a slug injected into a uniform one-dimensional flow field is plotted against dimensionless time, t_R, for several Peclet numbers. It can be seen that the time for the peak concentration (C_{max}) to occur increases with the Peclet number, up to a limit of $t_R = 1$. Breakthrough becomes more symmetric with increasing P_e.

2.9.7 Continuous Injection into a Uniform Two-Dimensional Flow Field

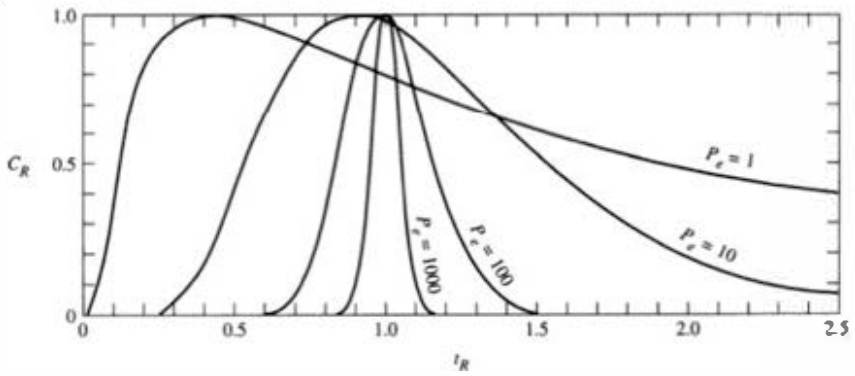
If a tracer is continuously injected into a uniform flow field from a single point that fully penetrates the aquifer, a two-dimensional plume will form that looks similar to Figure 2.16. It will spread along the axis of flow due to longitudinal dispersion and normal to the axis of flow due to transverse dispersion. This is the type of contamination that would spread from the use of an injection well, which would be a point source.

Flow is governed by Equation 2.19, the mass transport equation in two dimensions. The well is located at the origin ($x = 0$, $y = 0$), and there is a uniform flow velocity at a rate v_x parallel to the x axis. There is a continuous injection at the origin, of a solute with a concentration C_0 at a rate Q over the aquifer thickness, b.

The solution of Equation 2.19 can be found from a Green function (Bear 1972; Fried 1975) for the injection of a unit amount of a contaminant as:

$$C(x,y,t) = \frac{I}{4\pi(D_L D_T)^{0.5}} \exp\left[-\frac{(x - v_x t)^2}{4D_L t} - \frac{y^2}{4D_T t}\right]$$

FIGURE 2.16 Dimensionless-type curve for the injection of a slug of a tracer into a one-dimensional flow field.



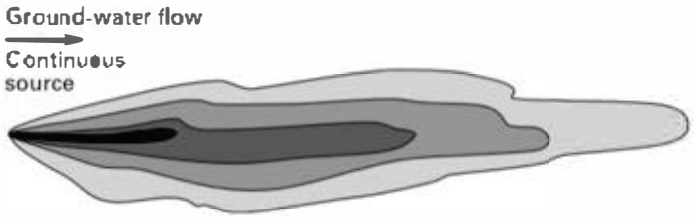
Source: J. P. Sauty, 1980, *Water Resources Research* 16:145–158. Copyright by the American Geophysical Union. Reproduced with permission.

Since the Green function is for a unit injection, and we have an injection rate that can be defined as $C_0(Q/b)$, the solution to the above is:

$$C(x,y,t) = \frac{C_0(Q/b)dt}{4\pi t(D_L D_T)^{0.5}} \exp\left[-\frac{(x-v_x t)^2}{4D_L t} - \frac{y^2}{4D_T t}\right]$$

If the injection rate, Q/b, is continuous then the solution at time t is:

FIGURE 2.17 Plume resulting from the continuous injection of a tracer into a two-dimensional flow field. (Source: C. W. Fetter. 1994. *Applied Hydrogeology, Third Edition*. Upper Saddle River, New Jersey: Prentice-Hall, Inc.)



$$C(x,y,t) = \frac{C_0(Q/b)}{4\pi(D_L D_T)^{0.5}} \int_{\theta=0}^{\theta=t} \exp\left[-\frac{(x-v_x\theta)^2}{4D_L\theta} - \frac{y^2}{4D_T\theta}\right]\frac{d\theta}{\theta} \qquad \textbf{(2.30)}$$

Steady-state conditions are obtained when time approaches infinity. Therefore equation 2.30 is integrated from 0 to ∞. The result is:

$$C(x,y) = \frac{C_0(Q/b)}{2\pi(D_L D_T)^{1/2}} \exp\left(\frac{v_x x}{2D_L}\right) K_0\left[\left(\frac{v_x^2}{4D_L}\left(\frac{x^2}{D_L} + \frac{y^2}{D_T}\right)\right)^{1/2}\right] \qquad \textbf{(2.30a)}$$

where

K_0 = the modified Bessell function of the second kind and zero order (values are tabulated in Appendix B)

Q = the rate that the contaminant is injected

b = the thickness of the aquifer over which the contaminant is injected

Equation 2.30a can be solved in EXCEL after installing the Plume2DSS() add-in (Renshaw 2015b).

EXAMPLE PROBLEM

A waste liquid containing fluoride at a concentration of 133 mg/L was pumped into a shallow disposal pit located above a thin, 1.75 m thick, (two-dimensional) aquifer at a rate of 3.66 m³/day for many years. The average linear velocity of the groundwater was 0.187 m/day. Assume that the transverse dispersion is 10% of the longitudinal dispersion. If the disposal pit is assumed to be at a location of $x_0 = 0$ and $y_0 = 0$, what would the concentration of fluoride be in a monitoring well located at $x = 123$ m and $y = 16$ m? Assume that the fluoride is non-reactive and non-adsorbed by the aquifer.

R000288

1. First the value of α_L must be calculated using equation 2.48.

   $\alpha = 0.83(\log(L))^{2.414}$

   L is equal to $x - x_0$ or 123 m.

   $\alpha_L = 0.83(\log(123))^{2.414}$

   $\alpha_L = 4.919$ m

2. Next the value of D_L and D_T must be found.

   $D_L = v_x \alpha_L$

   $D_L = 0.187 \text{ m/da} \times 4.919 \text{ m} = 0.920 \text{ m}^2/\text{da}$

   $D_T = 0.10 D_L$

   $D_T = 0.092 \text{ m}^2/\text{da}$

   The variables are then inserted into equation 2.30a.

   $C_0 = 133$ mg/L

   $Q = 3.66 \text{ m}^3/\text{da}$

   $b = 1.75$m

$$C = \frac{C_0(Q/b)}{2\pi(D_L D_T)^{1/2}} \exp\left(\frac{v_x x}{2D_L}\right) K_0\left[\left(\frac{v_x^2}{4D_L}\left(\frac{x^2}{D_L} - \frac{y^2}{D_T}\right)\right)^{1/2}\right]$$

$$C = \frac{133\text{mg/L} \times (3.66\text{m}^3/\text{da}/1.75\text{m})}{2 \times \pi \times (0.92\text{m}^2/\text{da} \times 0.092\text{m}^2/\text{da})^{1/2}} \times \exp\left(\frac{0.187\text{m/da} \times 123\text{m}}{2 \times 0.92\text{m}^2/\text{da}}\right)$$

$$K_0\left[\left(\frac{0.187^2\text{m}^2/\text{da}^2}{4 \times 0.92\text{m}^2/\text{da}}\left(\frac{123^2\text{m}^2}{0.92\text{m}^2/\text{da}} + \frac{16^2\text{m}^2}{0.092\text{m}^2/\text{da}}\right)\right)^{1/2}\right]$$

$$C = \frac{278.0\text{mg/L}}{1.828} \exp\left(\frac{23.0}{1.84}\right) K_0\left[\left[0.0095 \times (16445 + 2783)\right]^{1/2}\right]$$

$$C = 152.1 \exp(12.5) K_0(13.52)\text{mg/L}$$

$$C = 152.1 \times 268337 \times 4.544 \times 10^{-7}\text{mg/L}$$

Note: Although K_0, a modified Bessell function of the zero order and second kind, can be obtained from Appendix B for a limited range of values, the table did not contain K_0 of 13.52. The value listed above, 4.54×10^{-7} was generated by a EXCEL function BESSELK(x,n).

According to Equation 2.30, as the value of D_L approaches zero, the concentration will approach infinity. As this is a physical impossibility, if the value of D_L is very small, then the one-dimensional equation, 2.23, should be used with a large value for time.

Equation 2.30 can also be solved for a specific value of time, so that the spread of a two-dimensional plume with time can be determined. In order to solve for time, Equation 2.30 can be written thusly:

$$C(x,y,t)=\frac{C_0(Q/b)}{4\pi(D_L D_T)^{1/2}}\exp\left(\frac{v_x x}{2D_L}\right)\int_{\theta=0}^{\theta=t}\exp\left[-\frac{\theta}{4D_L}-\left(\frac{x^2}{4D_L}+\frac{y^2}{4D_T}\right)\frac{1}{\theta}\right]\frac{d\theta}{\theta}$$

If we set $t_D = v_x^2/4\,D_L$, then the above becomes:

$$C(x,y,t)=\frac{C_0(Q/b)}{4\pi(D_L D_T)^{1/2}}\exp\left(\frac{v_x x}{2D_L}\right)\int_{t_{D=0}}^{t_{D=\infty}}\exp\left[-t_D-\frac{B^2}{4t_D}\right]\frac{dt_D}{t_D}$$

with

$$B^2=\frac{v_x^2 x^2}{4D_L^2}+\frac{v_x^2 y^2}{4D_L D_T}$$

The integral in the above equation was solved by Hantush (1956). This solution is

$$C(x,y,t)=\frac{C_0(Q/b)}{4\pi(D_L D_T)^{1/2}}\exp\left(\frac{v_x x}{2D_L}\right)\left[W(0,B)-W(t_D,B)\right] \qquad (2.31)$$

with t_D and B as defined above.

It should be noted that in effect t_D is a dimensionless form of time. The values of $W[t_D, B]$ can be found in Hantush (1956) and a limited series is tabulated in Appendix C. It can also be determined in EXCEL after installing the Leaky() add-in (Renshaw 2015c). In well hydraulics this is known as the leaky well function, $W[u, r/b]$.

EXAMPLE PROBLEM

An underground tank which formerly held benzene but now holds water is leaking at a rate of 1.93m³/year. However, the water still contains some benzene at a concentration of 12,950 µg/L. The groundwater which flows beneath the leaking tank goes directly north. A drinking water supply well is located at a spot that can be located by going 123.5m due north of the leaking tank and then 7.2m due east. Assume that the average linear velocity of the groundwater is 0.235 m/day and the longitudinal dispersivity is 12m and the lateral dispersivity is 1.2m and the aquifer thickness is 1.00m. What would the benzene concentration be after 2.00 years?

This is an example of a continuous leakage into a two dimensional flow field; equation 2-31.

1. The values of D_L and D_T must be calculated from equations 2-11a and 2-11b. We will ignore the effective diffusion coefficient as it is so much smaller than dispersivity.

$$D_L = \alpha_L v_X = 12\text{ m} \times 0.235\text{ m/day} = 2.82\text{ m}^2/\text{day}$$

$$D_T = \alpha_T v_X = 1.2\text{ m} \times 0.235\text{ m/day} = 0.282\text{ m}^2/\text{day}$$

R000290

2. The value of B must be calculated.

$$B = \left[\frac{(v_x x)^2}{4D_L^2} + \frac{(v_x y)^2}{4D_L D_T} \right]^{\frac{1}{2}}$$

$$B = \left[\frac{(0.235\text{m/da} \times 123.5\text{m})^2}{4 \times (28\text{m}^2/\text{da})^2} + \frac{(0.235/\text{da} \times 7.2\text{m})^2}{4 \times 28\text{m}^2/\text{da} \times 0.28\text{m}^2/\text{da}} \right]^{\frac{1}{2}}$$

$$B = \left[\frac{842\text{m}^4/\text{da}^2}{31.4\text{m}^4/\text{da}^2} + \frac{2.86\text{m}^4/\text{da}^2}{3.14\text{m}^4/\text{da}^2} \right]^{\frac{1}{2}}$$

$$B = \sqrt{26.8 + 0.91}$$

$$B = 5.26$$

3. The next step is to find t_D. Convert time in years to time in days by multiplying by 365 days per year.

$$t_D = \frac{v_x^2 t}{4D_L}$$

$$t_D = \frac{(0.235\text{m/da})^2 \times 730\text{da}}{4 \times 2.82\text{m}^2/\text{da}}$$

$$t_D = 3.57$$

4. One must now find W[0, B] and W[t_D, B] from Appendix C.

   W[0, B] = W[0, 5.26] = 0.0098

   W[t_D, B] = W[3.57, 5.26] = 0.0019

5. The values are then substituted into Equation 2.31. The rate of leakage, Q, is converted into cubic meters per day by dividing by 365. The aquifer thickness is 100m.

   $Q = 1.93\ \text{m}^3/\text{year}/365\ \text{da/year} = 0.0053\ \text{m}^3/\text{da}$

$$C(x,y,t) = \frac{C_0 Q/b}{4\pi(D_L D_T)^{1/2}} \exp\left(\frac{v_x x}{2D_L}\right)\left[W(0,B) - W(t_D,B)\right]$$

$$C(x,y,t) = \frac{12{,}950\,\mu\text{g/L} \times 0.0053\text{m}^3/\text{da}/1\text{m}}{4\pi(2.82\text{m}^2/\text{da} \times 0.28\text{m}^2/\text{da})^{1/2}} \exp\left(\frac{0.236\text{m/da} \times 123.5\text{m}}{2 \times 2.82\text{m}^2/\text{da}}\right)[0.0098 - 0.0019]$$

$$C(x,y,t) = 0.0061 \exp(5.16)[0.0079]\,\mu\text{g/L}$$

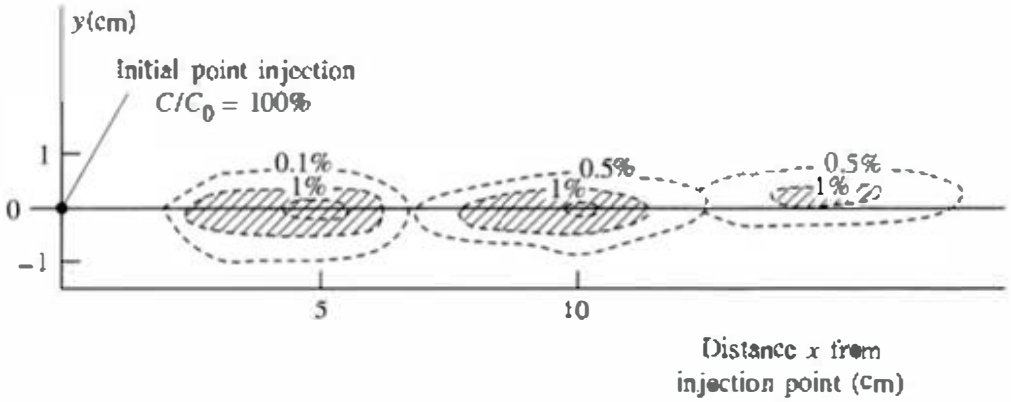
$$C(x,y,t) = 0.0061 \times 174 \times 0.0079\,\mu\text{g/L}$$

$$C(x,y,t) = 0.0084\,\mu\text{g/L}$$

2.9.8 Slug Injection into a Uniform Two-Dimensional Flow Field

If a slug of contamination is injected over the full thickness of a two-dimensional uniform flow field in a short period of time, it will move in the direction of flow and spread with time. This result is illustrated by Figure 2.18 and represents the pattern of contamination at three increments that result from a one-time spill. Figure 2.18 is based on the results of a laboratory experiment conducted by Bear (1961). Figure 2.19 shows the spread of a plume of chloride that was injected into an aquifer as a part of a large-scale field test (Mackay et al. 1986). The plume that resulted from the field test is more complex than the laboratory plume due to the heterogeneities encountered in the real world and the fact the plume may not be following the diffusional model of dispersion.

FIGURE 2.18 Injection of a slug of a tracer into a two-dimensional flow field shown at three time increments.



Experimental results from J. Bear. 1961. *Journal of Geophysical Research* 66:2455–2467. Copyright by the American Geophysical Union. Reproduced with permission.

De Josselin and De Jong (1958) derived a solution to this problem on the basis of a statistical treatment of lateral and transverse dispersivities. Bear (1961) later verified it experimentally. If a tracer with concentration C_0 is injected into a two-dimensional flow field over an area A at a point (x_0, y_0), the concentration at a point (x, y), at time t after the injection is

$$C(x,y,t) = \frac{C_0 A}{4\pi(D_L D_T)^{1/2}} \exp\left[-\frac{((x-x_0)-v_x t)^2}{4D_L t} - \frac{(y-y_0)^2}{4D_T t}\right] \quad (2.32)$$

EXAMPLE PROBLEM

A tank truck, which is carrying water containing 1275 mg/L of dissolved benzene overturns and spills a volume of water sufficient to saturate a thin aquifer over an area of 5 m^2. The aquifer contains groundwater flowing with an average linear velocity of 0.45 m/day. Assume that the values of D_L and of D_T are 2.1 m^2/day and 0.21 m^2/day respectively.

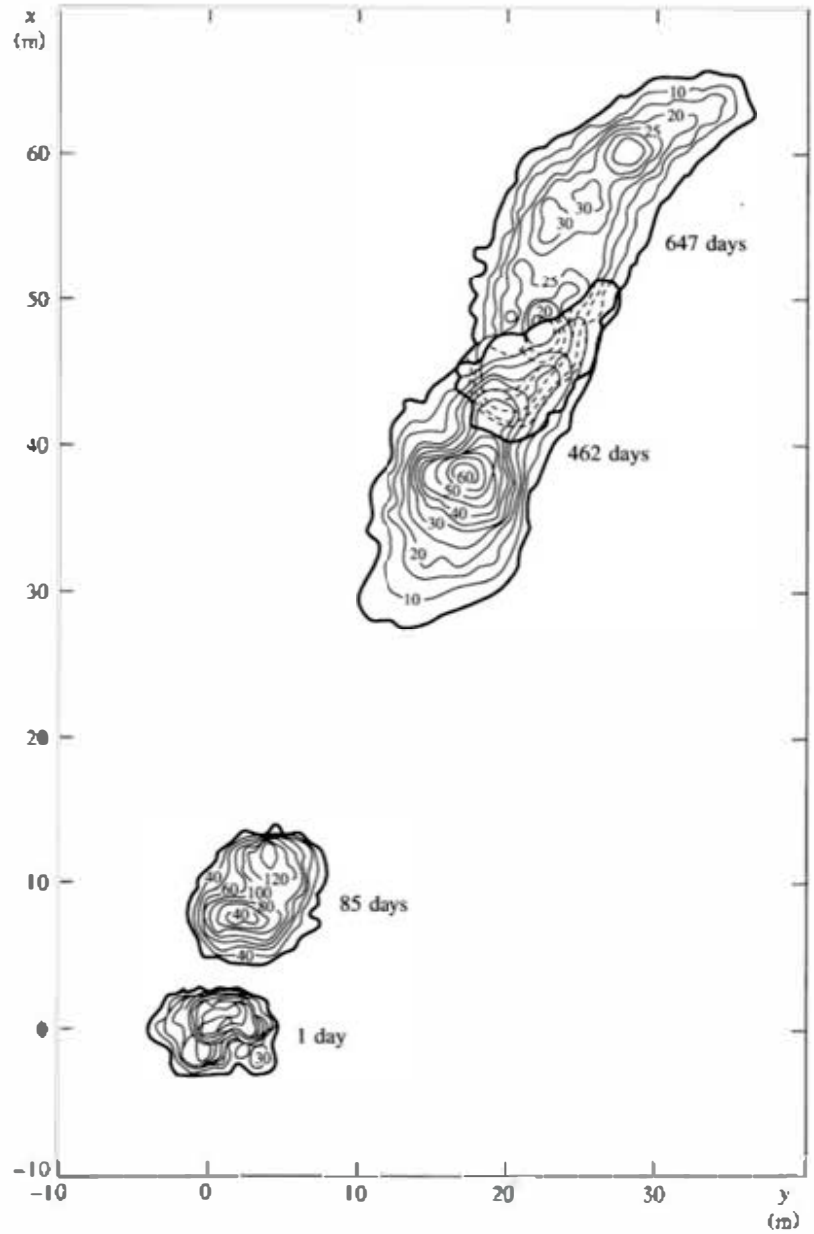
There is a nearby private well at a seasonal cottage. If the center of the spill is at location $x_0 = 0$ and $y_0 = 0$, then the location of the well is $x = 72$ m and $y = 5.5$ m. The owners of the private well are away for the season and will not return for another 200 days.

R000292

If there is no degradation or retardation of the benzene as it moves through the aquifer, what will the concentration of benzene be in the private well when the owner returns.

The correct equation to use is 2.32 for a slug injection of contamination into a two dimensional aquifer.

FIGURE 2.19 Vertically averaged chloride concentration at 1 day, 85 days, 462 days, and 647 days after the injection of a slug into a shallow aquifer.



Source: D.M. Mackay et al. 1986. *Water Resources Research* 22:2017–2029. Copyright by the American Geophysical Union. Reproduced with permission.

$$C = \frac{C_0 A}{4\pi t\sqrt{D_L D_T}} \exp\left[-\frac{((x-x_0)-v_x t)^2}{4D_L t} - \frac{(y-y_0)^2}{4D_T t}\right]$$

$$C = \frac{1275\text{mgL}^{-1} \times 5\text{m}^2}{4 \times \pi \times 200\text{da} \times \sqrt{2.1\text{m}^2\text{da}^{-1} \times 0.21\text{m}^2\text{da}^{-1}}} \times$$

$$\exp\left[-\frac{((72\text{m} - 0) - (0.45\text{mda}^{-1} \times 200\text{da}))^2}{4 \times 2.1\text{md}^{-1} \times 200\text{da}} - \frac{(5.5\text{m})^2}{4 \times 0.21\text{m}^2\text{da}^{-1} \times 200\text{da}} \right]$$

$$C = \frac{6375\text{mgL}^{-1} \times \text{m}^2}{4 \times \pi \times 200\text{da} \times 0.664\text{m}^2\text{da}^{-1}} \exp[-\frac{(72-90)^2\text{m}^2}{1680\text{m}^2} - \frac{30.25\text{m}^2}{168\text{m}^2}]$$

$$C = 3.82\text{mgL}^{-1} \exp[-0.192 - 0.180]$$

$$C = 3.82 \exp(-0.372) = 3.82 \times 0.6892 = 2.63\text{mgL}^{-1}$$

The maximum concentration of a contaminant from a slug injection is found in the center of the plume, or the *center of mass.* If the flow is in the direction of the x axis, and the spill was at location $x_0 = 0$ and $y_0 = 0$, the center of mass of a conservative substance at any time t since the spill will be at a location where $x = v_x t$ and $y = 0$. If we substitute these values into equation 2–32, we obtain:

$$C_{max} = \frac{C_0 A}{4t\pi\sqrt{D_T D_L}} \exp\left[-\frac{((v_x t - 0) - v_x t))^2}{4 D_L t} - \frac{(0-0)^2}{4 D_T t} \right]$$

$$C_{max} = \frac{C_0 A}{4t\pi\sqrt{D_T D_L}} \exp(0)$$

$$C_{max} = \frac{C_0 A}{4t\pi\sqrt{D_T D_L}} \qquad \textbf{(2.32a)}$$

The distribution of contamination in the plume will follow a normal or Gaussian distribution. From equations 2-12a and 2-12b the standard deviation of the distribution is given by:

$$\sigma_x = \sqrt{2 D_L t} \qquad \sigma_y = \sqrt{2 D_T t}$$

By definition, 99.7% of the mass of contamination will be contained within an area represented by three standard deviations away from the center of mass of the plume. Thus the plume can be defined by the location of the center of mass, $3\sigma_x$ and $3\sigma_y$.

EXAMPLE PROBLEM

A truck carrying dilute brine with 2130 mg/L chloride from the cleanup of a pond containing waste from a producing oil well overturns and spills the dilute brine over an area of 455 square feet. The underlying thin aquifer has an average linear groundwater velocity of 1.23 ft/day. Where would the center of mass of the plume be in

133 days, what would the maximum concentration be and how far beyond and to the side of the center of mass would the plume spread?

1. The plume would be advected by the flowing groundwater so that the center of mass would be at $x = v_x t$.

$$x = 1.23 \text{ ft/da} \times 133 \text{ da} = 164 \text{ feet.}$$

2. The maximum concentration at the center of mass can be found from equation 2.32a.

$$C_{max} = \frac{C_0 A}{4t\pi\sqrt{D_T D_L}}$$

a. We need to find the values of D_L and D_T. This can be done using equations 2.11a and 2.11b; but, first we need to use equation 2.82 to estimate α_L

$$\alpha_L = 0.83(\log(L))^{2.414}$$
$$= 5.66 \text{ ft}$$
$$D_L = \alpha_L v_x$$
$$= 5.66 \text{ ft} \times 1.23 \text{ ftda}^{-1}$$
$$= 6.96 \text{ ft}^2\text{da}^{-1}$$

We can assume D_T to be 10% of D_L

$$D_T = 0.696 \text{ ft}^2\text{da}^{-1}$$

The appropriate variables are substituted into equation 2.32.

$$C_{max} = \frac{2130 mgL^{-1} \times 455 ft^2}{4 \times \pi \times 133 da \sqrt{6.96 \, ft^2 da^{-1} \times 0.696 \, ft^2 da^{-1}}}$$

$$C_{max} = 263 mgL^{-1}$$

3. The size of the plume can be determined from the standard deviations

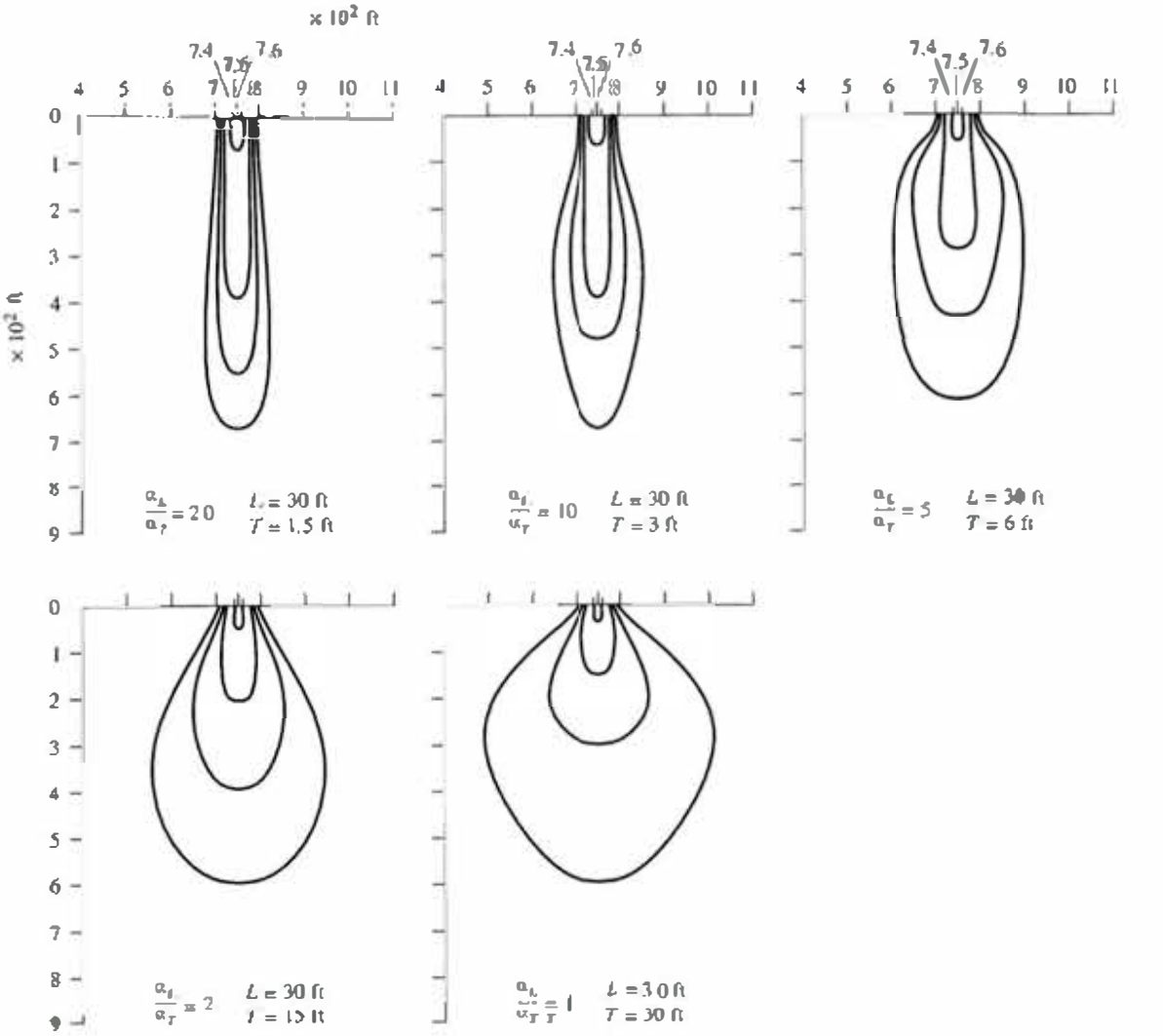
$$\sigma_x = \sqrt{2D_L t} \qquad \sigma_y = \sqrt{2D_T t}$$
$$\sigma_x = \sqrt{2} \times 6.96 \text{ft}^2\text{da}^{-1} \times 133 \text{da} \qquad \sigma_y = \sqrt{2 \times 6.96 \text{ ft}^2\text{da}^{-1} \times 133 \text{ da}}$$
$$\sigma_x = 43.0 \text{ ft} \qquad \sigma_y = 13.6 \text{ ft}$$

The leading edge of the plume is $3\sigma_x$ feet ahead of the center of mass or 129 feet and the plume had spread out $3\sigma_y$ feet on either side of the center of the mass or 40.8 feet.

2.10 Effects of Transverse Dispersion

The ratio of longitudinal to transverse dispersivity (α_L / α_T) in an aquifer is an important control over the shape of a contaminant plume in two-dimensional mass transport. The lower the ratio, the broader the shape of the resulting plume will be. Figure 2.20 shows various two-dimensional shapes of a contaminant plume, where the only factor varied was the ratio of longitudinal to transverse dispersivity. This illustrates the fact that it is important to have some knowledge of the transverse dispersivity in addition to the longitudinal dispersivity. There is a paucity of data in the literature on the relationships of longitudinal to transverse dispersivities. From the few field studies available, α_L / α_T is in the range of 6 to 20 (Anderson 1979; Klotz et al. 1980). In addition, dispersivity ratios based on field studies are based on fitting the diffusional model of dispersion to cases where it might not be applicable.

FIGURE 2.20 The effect of changing dispersivity ratio on the spread of a contaminant plume from a continuous source.



Source: Robert L. Stollar

chloride was 48 mgL^{-1} and after 4000 seconds, t_2, it was 252 mgL^{-1}. What is the dispersivity of the sand in the soil column?

The number of pore volumes at a given time can be calculated from Equation 2.33:

$$PV = v_x t / L$$

For the first measurement at t_1:

$$PV = 1.35 \times 10^{-2}\ cms^{-1}\ \ 500\ s/40\ cm = 0.17\ pore\ volumes$$

For the second measurement at t_2:

$$PV = 1.35 \times 10^{-2}\ cms^{-1} \times 4000\ s/40\ cm = 1.35\ pore\ volumes$$

At t_1, C/C_0 is 48/300, which equals 0.16. With a pore volume of 0.17

$$(PV-1)/PV^{1/2} = (0.17 - 1)/(0.17)^{1/2} = -2.01$$

At t_2, C/C_0 is 252/300, which equals 0.84. With a pore volume of 1.32

$$(PV - 1)/PV^{1/2} = (1.32 - 1)/(1.32)^{1/2} = 0.28$$

Since C/C_0 at t_1 is conveniently equal to 0.16, then $(PV - 1)/PV^{1/2}$ for t_1 turns out to be $J_{0.16}$. Likewise C/C_0 at t_2 is 0.84 so that $(PV - 1)/PV^{1/2}$ for t_2 is $J_{0.84}$.

The value of D_L can be found from Equation 2.35:

$$D_L = \left(\frac{v_x L}{8}\right)(J_{0.84} - J_{0.16})^{1/2}$$

$$D_L = (1/8) \times (1.35 \times 10^{-2}\ cms^{-1} \times 40\ cm) \times (0.28 - -2.01)^{1/2}$$

$$= 6.75 \times 10^{-2} \times 1.51 cm^2 s^{-1}$$

$$= 0.102\ cm^2 s^{-1}$$

2.11.2 Quantifying Dispersivity in the Field

A value for dispersivity can be determined in the field by two means. If there is a contaminated aquifer, the plume of known contamination can be mapped and the advection-dispersion equation solved with dispersivity as the unknown. Pinder (1973) used this approach in a groundwater modeling study of a plume of dissolved chromium in a sand and gravel aquifer on Long Island, New York. He started with initial guesses of α_L and α_T and then varied them during successive model runs until the computer model yielded a reasonable reproduction of the observed contaminant plume. One of the difficulties of this approach is that the concentration and volume of the contaminant source are often not known.

A much more common approach is the use of a tracer that is injected into the ground via a well. There are a variety of variations to this approach. Natural gradient tests involve the injection of a tracer into an aquifer, followed by the measurement of the plume that developed under the prevailing water table gradient (e.g., Sudicky and Cherry 1979;

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Gillham et al. 1984; Mackay et al. 1986; LeBlanc et al. 1991; Garabedian et al. 1991; Olsen and Tenbus 2004). The plume is measured by means of small amounts of water withdrawn from downgradient observation wells and multilevel piezometers. Many of these field tests showed that thin plumes with less than expected transverse dispersivity often occur in field situations. This underlines a growing acceptance of the need for high resolution, vertically discrete, multilevel aquifer monitoring. Multilevel monitoring will be discussed in Chapter 8. One and two-well tests have also been used in which a tracer is pumped into the ground and then groundwater containing the tracer is pumped back out of the ground (e.g., Fried 1975; Grove and Beetem 1971; Sauty 1978; Pickens et al. 1981; Pickens and Grisak, 1981). These so-called forced hydraulic gradient tests have the advantage that they can be completed in much shorter time relative to natural gradient tests. However, these tests require treatment if the pumped groundwater is contaminated. Also, the results of forced hydraulic gradient tests do not truly reflect the natural groundwater flow conditions. Ptak et al. (2004) reviewed the advantages and disadvantages of natural or forced hydraulic gradient tests for both nonreactive and reactive tracer compounds can be used.

2.11.3 Single-Well Tracer Test

A single-well tracer test involves the injection of water containing a conservative tracer into an aquifer via an injection well and then the subsequent pumping of that well to recover the injected fluid. The fluid velocities of the water being pumped and injected are much greater than the natural groundwater gradients.

Equation 2.20 can be written (Hoopes and Harleman 1967) as

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial r} = \alpha_L u\frac{\partial^2 C}{\partial r^2} + \frac{D^*}{r}\frac{\partial}{\partial r}\left(r\frac{\partial C}{\partial r}\right) \tag{2.37}$$

Gelhar and Collins (1971) derived a solution to Equation 2.37 for the withdrawal phase of an injection-withdrawal well test in which the diffusion term is neglected because it is very much smaller than the dispersion term. The relative concentration of the water being withdrawn from the injection well is

$$\frac{C}{C_0} = \frac{1}{2}\operatorname{erfc}\left(\frac{(U_p - U_i) - 1}{\{\frac{16}{3}(\alpha_L / R_f)[2-(1-U_p/U_i)]^{1/2}[1-(U_p/U_i)]\}^{1/2}}\right) \tag{2.38}$$

where

U_p = cumulative volume of water withdrawn during various times

U_i = total volume of water injected during the injection phase

R_f = average frontal position of the injected water at the end of the injection period, which is defined by

$$R_f = \left(\frac{Qt}{\pi b n}\right)^{1/2} \tag{2.39}$$

where

Q = rate of injection

t = total time of injection

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b = aquifer thickness

n = porosity

EXAMPLE PROBLEM

Pickens and Grisak (1981) performed a single-well injection-withdrawal tracer test into a confined sand aquifer about 8.2 m thick with an average hydraulic conductivity of 1.4×10^{-2} cm/sec and a porosity of 0.38. The sediment tested in the column study described in the dispersivity example problem above came from this aquifer.

The injection well was 5.7 cm in diameter and the full thickness of the aquifer was screened. Clear water was injected at a constant rate for 24 hr prior to the start of the test to establish steady-state conditions. The tracer used during the tests was ^{131}I, a radioactive iodine isotope, which was added to the injected water. All measurements were corrected for the radioactive decay that occurred during the test.

Two tests were performed on the well. The first test, SW1, had an injection rate of 0.886 L/sec and injection continued for 1.25 da. A total volume of 95.6 m^3 of water was injected, and the injection front reached an average radial distance away from the well of 3.13 m. Water was then pumped for 2.0 da at the same rate, so that a total of 153 m^3 of water was withdrawn. The second test, SW2, was longer. Water with the tracer was added at a rate of 0.719 L/sec for 3.93 da. A total of 244 m^3 of water was added, and the average position of the injection front reached to 4.99 m from the well. During the withdrawal phase a total of 886 m^3 of water was pumped over a period of 16.9 da at an average rate of 0.606 L/sec.

The results of the test are shown in Figure 2.22. Relative concentration, C/C_o, is plotted against U_p / U_i. The dots represent field values and the solid lines are curves, which were computed using Equation 2.38. Various curves were computed for different values of α_L, and the curves with the best fit to the field data were plotted on the graphs. In Figure 2.22(a) the calculated curve was based on a longitudinal dispersivity of 3.0 cm, whereas for curve 2.22(b) the best-fit curve was based on a longitudinal dispersivity of 9.0 cm. This test illustrates the scale-dependent nature of dispersion. The second test, in which a larger volume of water was injected, tested a larger volume of the aquifer than the first test and yielded a higher dispersivity value.

■ 2.12 Scale Effect of Dispersion

The two example problems derived from Pickens and Grisak (1981) illustrate what has been called the scale effect of dispersion (Fried 1975). At the laboratory scale the mean value of α_L was determined to be 0.035 cm (0.014 in) when the flow length was 30 cm (12 in). With the single-well injection-withdrawal test, α_L was 3 cm (1.2 in) when the solute front traveled 3.1 m (10.2 ft) and 9 cm (3.5 in) when the solute front traveled 5.0 m (16.4 ft). In a two-well recirculating withdrawal-injection tracer test with wells located 8 m (26.2 ft) apart α_L was determined to be 50 cm (19.6 in). All these values were obtained from the same site. The greater the flow length, the larger the value of longitudinal dispersivity needed to fit the data to the advection-dispersion equation.

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spread. In this region the variance of the plume will grow proportionally to the time or mean travel distance, as it does at the laboratory column scale. The advective-dispersion model is based on the assumption that dispersion follows Fick's law. Some authors contend that dispersion follows Fick's law only at the laboratory scale, where it is caused by local mechanical dispersion, and for very long flow paths, where the effects of advection through heterogeneous materials and local transverse dispersion create macroscale dispersion that follows Fick's law (e.g., Gelhar 1986; Dagan 1988). The contention that macroscale dispersion becomes Fickian (i.e., follows Fick's law) at long travel times and distances is somewhat controversial, especially if the flow is through geological formations that are heterogeneous at different scales (Anderson 1990).

2.13 Stochastic Models of Solute Transport

2.13.1 Introduction

The normal manner of determining a field-scale dispersion coefficient is to look for a natural tracer or inject a tracer into an aquifer and observe the resulting development of a plume. A solute-transport model is then constructed and the computed solute distribution is fitted to the observed field data by adjusting the dispersion coefficients. Dispersion coefficients obtained in this manner are fitted curve parameters and do not represent an intrinsic property of the aquifer. This is especially true when the aquifer is assumed to be homogeneous and is described by a single value for hydraulic conductivity and porosity. It is apparent that flow and transport modeling based on a single value for porosity and hydraulic conductivity is a gross simplification of the complexity of nature. For analytical solutions, we are constrained to use of a single value for average linear velocity, and for numerical models we often use a single value because that is all we have.

A **deterministic model** is one where a partial differential equation is solved, either numerically or analytically, for a given set of input values, aquifer parameters, and boundary conditions. The resulting output variable has a specific value at a given place in the aquifer. It is assumed that the distribution of aquifer parameters is known. The equations given earlier in this chapter are examples of deterministic models.

A **stochastic model** is a model in which there is a statistical uncertainty in the value of the output variables, such as solute distribution. The probabilistic nature of this outcome is due to the fact that there is uncertainty in the value and distribution of the underlying aquifer parameters, such as the distribution and value of hydraulic conductivity and porosity (Freeze 1975; Dagan 1988).

A widespread misconception about stochastic and deterministic models is that the latter use physical laws, while the stochastic models are largely empirical and based entirely on statistical data-analysis. In reality, any physically-based model becomes a stochastic model once its inputs, parameters, or outputs are treated as random (Bierkens and van Geer; 2014).

The idea behind stochastic modeling is very attractive. It is obvious that it takes a great effort to determine hydraulic conductivity and porosity at more than a few locations in an aquifer system. If we could determine the distribution of aquifer properties with a high degree of detail, then a numerical solution of a deterministic model would yield results with a high degree of reliability. However, with limited knowledge of aquifer

parameters, a deterministic model makes only a prediction of the value of an output variable at a given point and time in the aquifer. The stochastic model is based on a probabilistic distribution of aquifer parameters. At the outset it is recognized in the stochastic model that the result will be only some range of possible outcomes. The stochastic model thus recognizes the probabilistic nature of the answer, whereas the deterministic model suggests that there is only one "correct" answer. Of course, the experienced hydrogeologist recognizes the uncertainty even in the deterministic answer. There have been literally hundreds of papers written on various aspects of stochastic modeling of groundwater flow and solute transport. Textbooks like Zhang (2001), Rubin (2003), and Dagan and Neuman (2005) provide insights into analyzing and modeling subsurface heterogeneity using stochastics concepts and models for managing water resources, preserving subsurface water quality, storing energy and wastes, besides other applications.

2.13.2 Stochastic Descriptions of Heterogeneity

Stochastic hydrology is about combining deterministic model outcomes with a probability distribution of the errors, or alternatively, considering the hydrological variable as random and determining its probability distribution and some "best prediction" (Bierkens and van Geer 2014). The greatest uncertainty in the input parameters of a model is the value of hydraulic conductivity, because it varies over such a wide range for geologic materials. If we make a measurement of hydraulic conductivity at a given location, the only uncertainty in its value at that location is due to errors in measuring its value. However, at all locations where hydraulic conductivity is not measured, additional uncertainty exists. If we make a number of measurements of the value of hydraulic conductivity, we can estimate this uncertainty using certain statistical techniques.

Let us define Y as the log of the hydraulic conductivity, K, and assume that the log value Y is normally distributed. We will assume a one-dimensional series of Y values $\{Y_1, Y_2, Y_3, Y_4, \ldots Y_n\}$ (Freeze et al. 1990). Therefore,

$$Y_i = \log K_i \tag{2.40}$$

The population that consists of all of the values of Y has a mean value, μ_y, and a standard deviation, σ_y. The only way to obtain precise values of μ_y and σ_y would be to sample the aquifer everywhere, clearly an impossible task, but we can find estimates of their values based on the locations where we have actually measured K. If we have a series of Y values $\{Y_1, Y_2, Y_3, \ldots Y_n\}$, as in Figure 2.27(a), based on measured value of K, then our estimate of the population mean is obtained from the mean value of the sampled values, $\bar{Y}$, which can be found from

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i \tag{2.41}$$

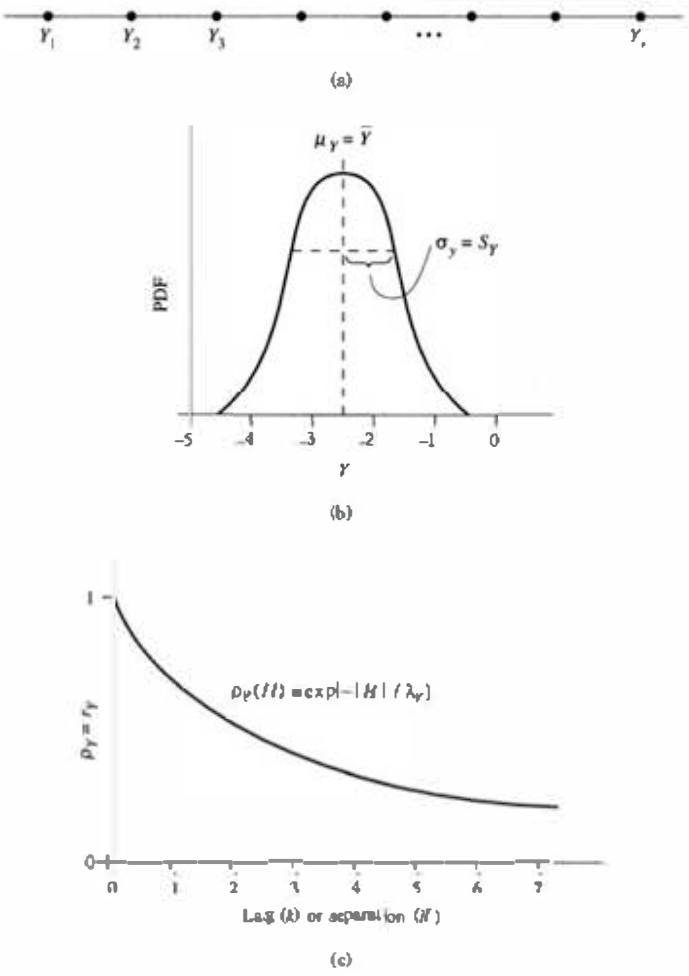
The estimate of the variance of the population is also obtained by the variance of the sampled values, S_y^2, which is found from the following equation:

$$S_Y{}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(Y_i - \bar{Y})(Y_i - \bar{Y}) \tag{2.42}$$

For a normally distributed population, the probabilistic value is called a probability density function (PDF) and is described by the mean and the variance. The variance is a measure of the degree of heterogeneity of the aquifer. The greater the value, the more heterogeneous the aquifer. The PDF can be represented as a bell-shaped curve with the peak equal to the mean, as in Figure 2.27(b), and the spread of the bell can be defined by either the variance or the standard deviation, S_Y, which is the square root of the variance.

If we have measured the value of Y_i at a number of locations and wish to estimate the value Y_j at some other location j that is not close to any of the measured values, how can we estimate the value of Y_j? One approach is to say that the most likely estimate of Y_j is the mean of the measured values of Y_i, and the uncertainty in this value is normally distributed with a standard deviation equal to the standard deviation of the measured values, S_Y. In doing so we have accepted the ergodic hypothesis. This means that there is a 16% chance that the value of Y_j is greater than $\bar{Y} - S_Y$, a 50% chance that it is greater than $\bar{Y}$, and an 84% chance that it is greater than $\bar{Y} - S_Y$. In broad terms ergodicity describes a dynamic system which has the same behavior averaged over time as averaged over space.

FIGURE 2.27(a) One-dimensional sequence of log hydraulic conductivity values, Y; (b) probability distribution function for Y; (c) autocorrelation function for Y.



Source: R.A. Freeze et al. 1990. *GroundWater* 28:738-766. Used with permission. Copyright Ground Water Publishing Co.

Hydraulic conductivity values measured at locations close to each other are likely to be somewhat similar. The farther apart the measurements, the less likely that the values will be similar. This is due to the fact that as distances become greater, the chance that there will be a change in geologic formation increases. The function that describes this is the **autocorrelation function**, ρ_Y. The value of the autocorrelation function decreases with the distance between two measurements. An estimate of the autocorrelation function, r_y, can be obtained from the measured sample values by the following equation:

$$r_Y(k) = \frac{1}{S_Y{}^2}\frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y})(Y_{i-k} - \bar{Y}) \tag{2.43}$$

with k, the lag, being a whole number representing a position in the sequence away from the i position. Figure 2.27(c) shows an autocorrelation function plotted against the lag. If the lag is zero, then Equation 2.43 reduces to $r_Y = S_Y{}^2 / S_Y{}^2 = 1$. This means that a Y value is perfectly correlated with itself.

The autocorrelation factor can be expressed in terms of either lag, ρ_{Yk} or distance, $\rho_Y(H)$. When a measurement of Y_i is made at position X_i and a measurement of Y_{i-k} is made at position X_{i-k}, the absolute value of $X_i - X_{i-k}$ is called the **separation**, H.

If the autocorrelation function has an exponential form, then it can be expressed as

$$\rho_Y(H) = \exp[-|H| / \lambda_Y] \tag{2.44}$$

where λ_Y, the **correlation length**, is representative of the length over which Y is correlated. It is the distance over which $\rho_Y(H)$ decays to a value of e^{-1}. The **integral scale**, ε_Y, is the area under the curve.

$$\varepsilon_Y = \int_0^\infty \rho_Y(H)\,dH \tag{2.45}$$

Integration of Equation 2.45 will show that $\varepsilon_Y = \lambda_Y$, so that the correlation structure can be described by either the correlation length or the integral scale.

The **autocovariance**, τ_{Yk} or $\tau_Y(H)$, is equal to the autocorrelation times the variance.

$$\tau_Y(H) = \sigma_Y{}^2 \rho_Y(H) \tag{2.46}$$

We can describe the distribution of heterogeneity of Y by the use of three stochastic functions, μ_Y, σ_Y (or σ_Y^2), and λ_Y. If a stochastic process is said to be stationary, the values of μ_Y, σ_Y (or σ_Y^2), and λ_Y do not vary in space in the region being studied. If the hydraulic conductivity of an aquifer can be described as a stationary stochastic process, the aquifer is uniformly heterogeneous.

2.13.3 Stochastic Approach to Solute Transport

If we accept the idea that we don't know the value of the hydraulic conductivity and the porosity evetywhere, then we must accept the idea that it is not possible to predict the actual concentration of a solute that has undergone transport through an aquifer. The best estimate of the concentration is the **ensemble mean concentration**, $\langle C \rangle$, or the mean of all the means of an ensemble of all possible random but equivalent populations, and the associated variance. The movement of a solute body may be described by

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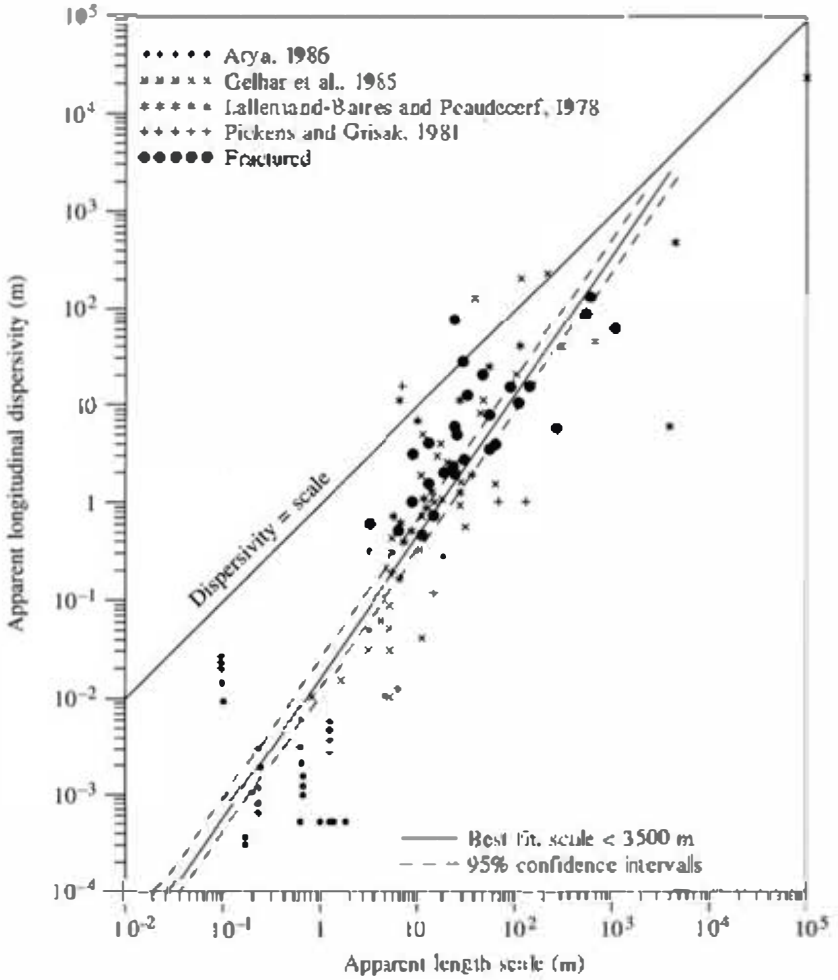
FIGURE 2.28 Apparent longitudinal dispersivity from field and laboratory studies as a function of the scale of the study. Results from the calibration of numerical models are not included.



Source: S. Neuman, 1990, *Water Resources Research* 26:1749–1758. Copyright by the American Geophysical Union. Used with permission.

the motion of the center of mass of the body and the second-order spatial moment, or the moment of inertia (Dagan 1988). Hence, from the variance of the log transformed hydraulic conductivity distribution and the correlation length, a simple stochastic model allows predicting an asymptotic macrodispersivity value. However, it is important to note that the process of advective transport dominates macrodispersion. This means that whether one uses a deterministic model or a stochastic model, the large picture of solute transport will emerge, since both account primarily for advective transport, with the dispersion factor tending to smear the leading edge of the plume.

2.14 Regression Analysis of Relationship between Apparent Longitudinal Dispersivity and Field Scale

Neuman (1990) plotted the apparent longitudinal dispersivity as measured in field and lab studies, α_{ap}, as a function of the travel distance, L_s, or apparent length scale

(Figure 2.28). Dispersivities that are measured in the field were considered apparent dispersivities because they were obtained by calculations that depend upon the theory that the observer was using. Also, Neuman (1990) excluded for theoretical reasons all data with an apparent length scale greater than 3500 m (approximately 11,500 ft). Regression analysis showed that although the data are widely scattered, a best-fit line with narrow 95% confidence bands could be obtained. The equation for the line is

$$\alpha_{app} = 0.0175 L_s^{1.46} \tag{2.47}$$

This line of best fit has a regression coefficient, r^2, of 0.74, which means that it accounts for 74% of the variation about the mean. The other 26% may be due to experimental and interpretive errors or may represent deviation of the real system from that described by Equation 2.47. The 95% confidence intervals about the coefficient of 0.0175 are 0.0113and 0.0272 and the 95% confidence intervals about the exponent of 1.46 are 1.30 and 1.61.

Equation 2.47 obtained by Neuman (1990) was based on data that he considered to be highly reliable. In doing so he discarded data that were less reliable, such as that obtained by the calibration of numerical models. Neuman recognized that as the flow path grew longer, the same equation relating apparent longitudinal dispersivity to field scale could not be used, so that he used two linear equations, one for flow distances less than 100m (328 ft) and one for flow distances greater than 100m (328 ft) (Equation 2.47). However, a discontinuity occurs in his method at 100m (328 ft); i.e., the two equations give different answers. Neuman and Di Federico (2003) demonstrated experimentally and theoretically that the scaling behavior of hydrogeologic variables is impacted strongly by their scale of spatial resolution.

Xu and Eckstein (1995) have overcome these problems by assigning different degrees of reliability to data: low, medium and high. They were then able to obtain a nonlinear relationship based on a regression analysis using all available data. The resulting equation had a correlation coefficient of 0.72, which is similar to that obtained by Neuman (1990) using only highly reliable data. Neuman (1990) also did not consider any data with a flow field longer than 3500m (~11,500 ft) because he did not consider it to be reliable, while Xu and Eckstein (1995) included these data.

The equation of Xu and Eckstein is:

$$\alpha_{app} = 0.83(\log L_s)^{2.414} \tag{2.48}$$

If one examines Figure 2.24, which includes data of low reliability, it appears that as the field scale increases, the rate of change of dispersion decreases. Being nonlinear as plotted on log-log paper, Equation 2.48 also has a decreasing rate of change of dispersion with increasing field scale. At a field scale of greater than a few thousand meters there is very little change in apparent dispersion with distance.

By analyzing jointly dispersivity values derived from models having variable scales of spatial resolution, Schulze-Makuch (2005) proposed a power law relationship that empirically best described the dispersivity data in regard to scale of measurement:

$$\alpha_L = cL^m$$

where c is a parameter characteristic for a geological medium, m is a scaling exponent, and L is the flow distance. The scaling exponent for consolidated and unconsolidated

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geological media varied between 0.40 and 0.92, and 0.44 and 0.94, respectively. For example, an unconsolidated sandy aquifer: c = 0.20 and m = 0.44. For a distance of 100 m (328 ft), the longitudinal dispersivity value is α_L = 1.6 m. Similar equations exist for other types of aquifers. No upper bound on the relationships was apparent for a flow distance up to ~10,000 m (~6 miles) for all media except for granites where this relation currently can only be extended to a flow distance of 100 m (328 ft). However, the relationship proposed by Schulze-Makuch (2005) was criticized by Neuman (2006) for neglecting the spatial resolution scales of the models from which the dispersion data had been derived. A theoretical interpretation of the scaling behavior has been summarized in a nonmathematical way in the review paper of Neuman and Di Federico (2003).

2.15 Deterministic Models of Solute Transport

Although workers in stochastic theory have asserted that the theoretical basis for the deterministic advective-dispersive solute transport equation is suspect except for long times and large distances (Anderson 1984), it has been used with a great deal of success in many field and model applications. Today, mathematical transport and fate modeling of contaminants in groundwater and soils has become an important tool for the interpretation of contaminated sites, the development of remedial strategies, and the human health risk assessment process.

Over the past decades, many papers and textbooks have been written about deterministic models for contaminant transport modeling (e.g., Anderson and Woessner 1991; Zheng and Bennet 2002). In general, a deterministic mathematical model simulates groundwater flow and/or solute fate and transport indirectly by means of a set of governing equations, such as Darcy's law and law of mass conservation, thought to represent the physical processes that occur in the system (Anderson and Woessner 1991). The first step in the modeling process is to develop a conceptual model that is simpler than reality. Simplification can be achieved, for example, by combining strata with similar hydrogeologic properties into a single layer or aquifer. The next step requires translating the conceptual model into a mathematical model, which can then be solved in a computer simulation. A numerical mathematical model solves the underlying governing partial differential equations (PDEs) within a set of suitable boundary conditions, and if the transport problem is of transient nature, initial conditions. This step usually requires that additional simplifying assumptions have to be made to reduce the complexity of the mathematical model. For example, a coarser grid can be defined in parts of the flow domain where less accuracy is required, or fixed value boundaries (e.g., no-flux or constant head boundaries) can be defined, or the length of the simulation time steps can be manipulated to reduce the number of computations. These adjustments make the model amenable to either exact or numerical solution, but the modeler must weigh the risk of oversimplifying the flow domain against the problem of no longer reproducing the system adequately. A parsimonious model therefore is a model that accomplishes a desired level of explanation or prediction with the fewest predictor variables possible.

The flow and transport equations underlying the model are solved at discrete points within the flow domain. The two classical choices for the numerical solution of PDEs are the finite difference method (FDM) and the finite element method (FEM).

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Other methods exists, such as the finite volume method (FVM) or the analytic element method (AEM), but models build around these numerical solution schemes are currently not used widely. A detailed discussion of numerical methods is beyond the scope of this textbook and the reader is referred to Peiro and Sherwin (2005).

The current standard FDM program is MODFLOW, which was developed by the U.S. Geological Survey (USGS) for three-dimensional flow modeling (McDonald and Harbaugh 1988). Over the years, many modules have been added to the MODFLOW program, including modules to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management (USGS 2014). MODFLOW can be used in conjunction with MT3DMS, which is a 3D multispecies transport model (Zheng et al. 2010). MT3DMS solves the advection-dispersion-reaction equation based on the methods of characteristics, MOC (Konikow et al. 1994). The FDM model domain is subdivided or discretized into a grid of rectangular blocks or cells within which the physical properties of the domain are assumed to be homogeneous. The block structure of the FDM models often make them difficult to adopt to more complex modeling domains. Under those circumstances, FEM models provide greater flexibility in design because the modeling domain is discretized by triangular elements. Common FDM programs include SUTRA, a variable-density, variablysaturated flow, solute or energy transport model by the U.S. Geological Survey (2015a) or FEFLOW, a commercial modelling environment for subsurface flow, solute and heat transport processes. Another versatile commercial FVM model is HYDRUS 2D/3D, which also offers unsaturated flow modeling capabilities (Simunek et al. 1999; Simunek et al. 2006) and modeling of agricultural pollutants especially those from nonpoint source pollution stemming from plant and animal production (Simunek et al. 2013). There are many more noteworthy models available and many are in public domain. The U.S. Geological Survey maintains a website from which public domain software packages for the simulation of groundwater flow and transport can be downloaded (USGS 2015b).

A model study by Davis (1986) demonstrates that deterministic models can be developed that incorporate heterogeneities. He modeled two aquifers with identical boundary conditions (Figure 2.29). One was uniform (Figure 2.30(a)) and one had variable transmissivity in the form of more permeable channels (Figure 2.30b). The deterministic model, based on the two-dimensional solute-transport equation, was used with small values of α_L and a α_T, 0.0003 m (0.01 in), and 0.00009 m (0.003 in), respectively. The resulting solute plume in the uniform media is very long and narrow. See Figure 2.31(b). If larger values of α_L and α_T are used—3 m (10 ft) and 1 m (3 ft), respectively—then a much broader plume results. See Figure 2.31(a). However, if the heterogeneous aquifer is used with the small values of dispersivity, the resulting plume, shown in Figure 2.31(c) has a size very similar to that created in the uniform media by using large values of dispersivity. This demonstrates that if deterministic models include the aquifer heterogeneities, then it may be possible to use dispersivity values that are more on the order of lab-scale values. Davis (1986) used the advectivedispersion equation in a model with varying transmissivities and with a value of α_L of only 0.01 m (0.4 in) was able to reproduce a solute plume that extended over a flow length of about 500 m (1,640 ft). He found that a fine mesh for the finite-difference model grid was necessary for accurate results. Figure 2.32 compares the results of his model results with the field data.

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FIGURE2.29 Finite-difference grid and boundary conditions for a deterministic model of solute transport.

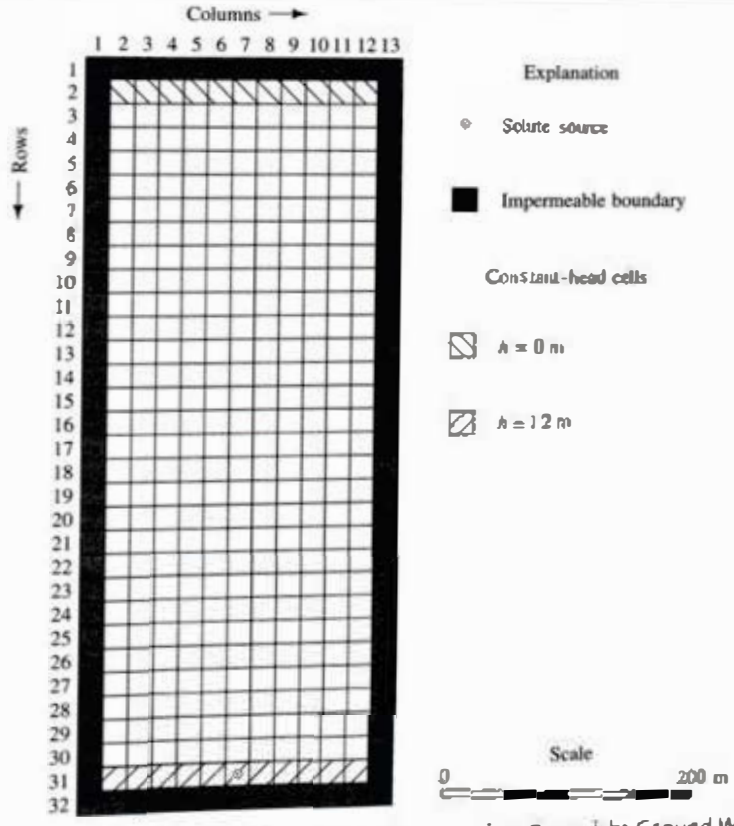

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FIGURE 2.30 Model areas for finite difference solute transport model with (a) uniform transmissivity and (b) with heterogeneous transmissivity.

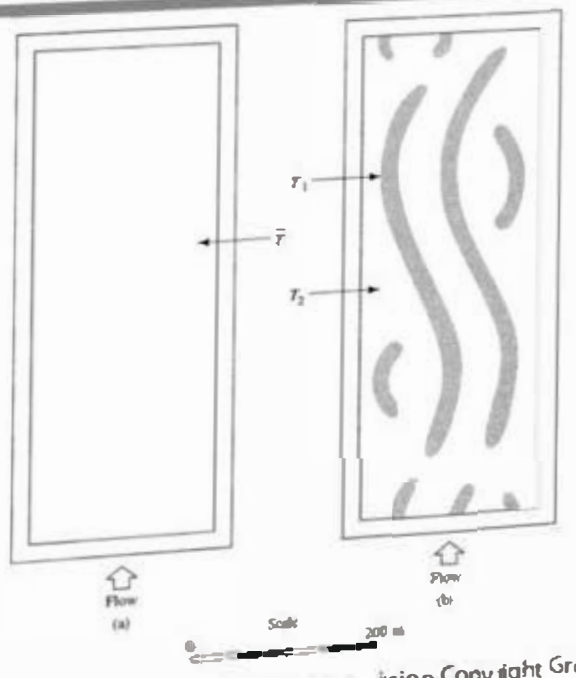

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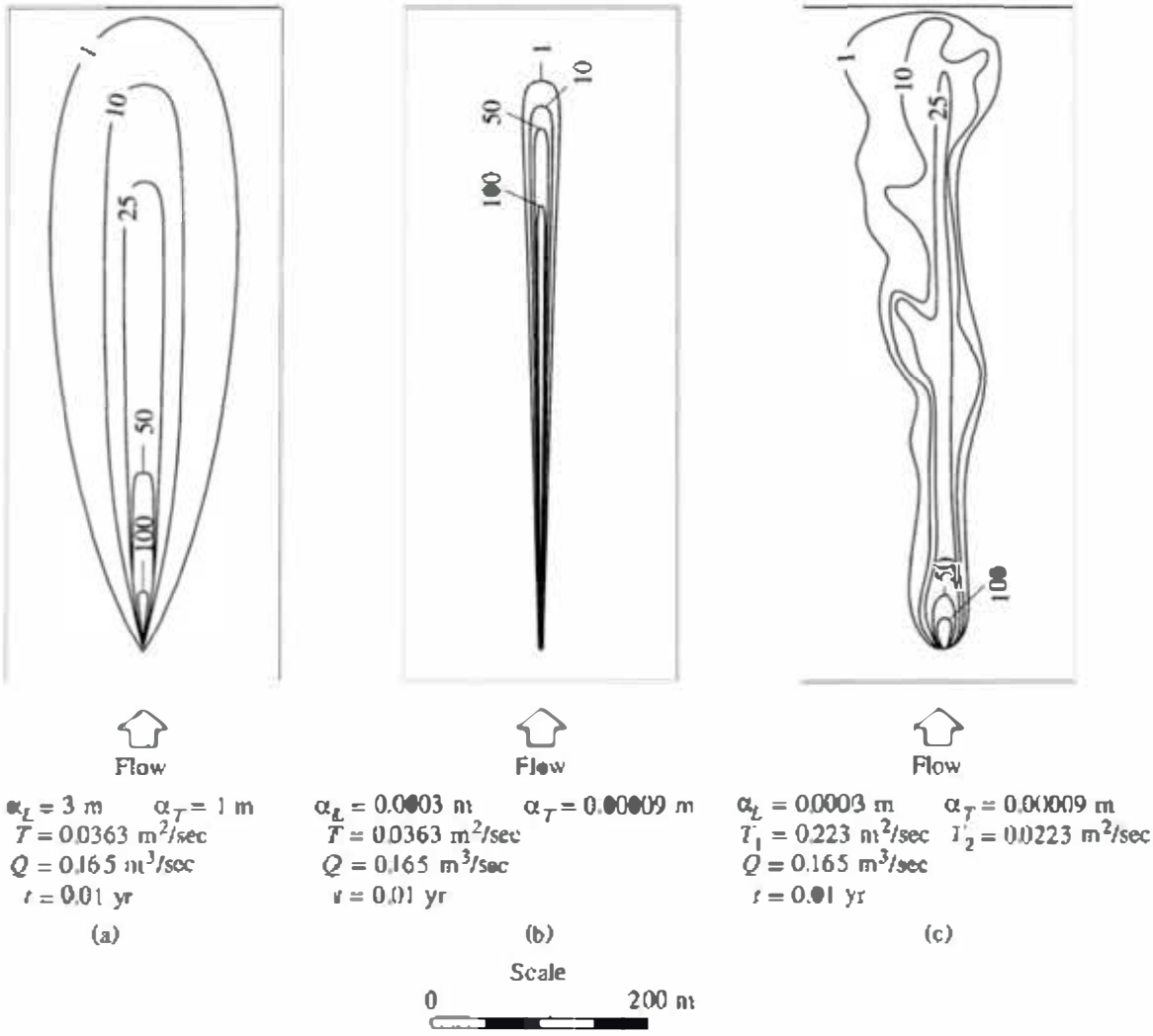
FIGURE 2.31 Model results for finite-difference solute-transport model. (a) Uniform media with large dispersivity values, (b) uniform media with small dispersivity values, and (c) heterogeneous media with small dispersivity values.



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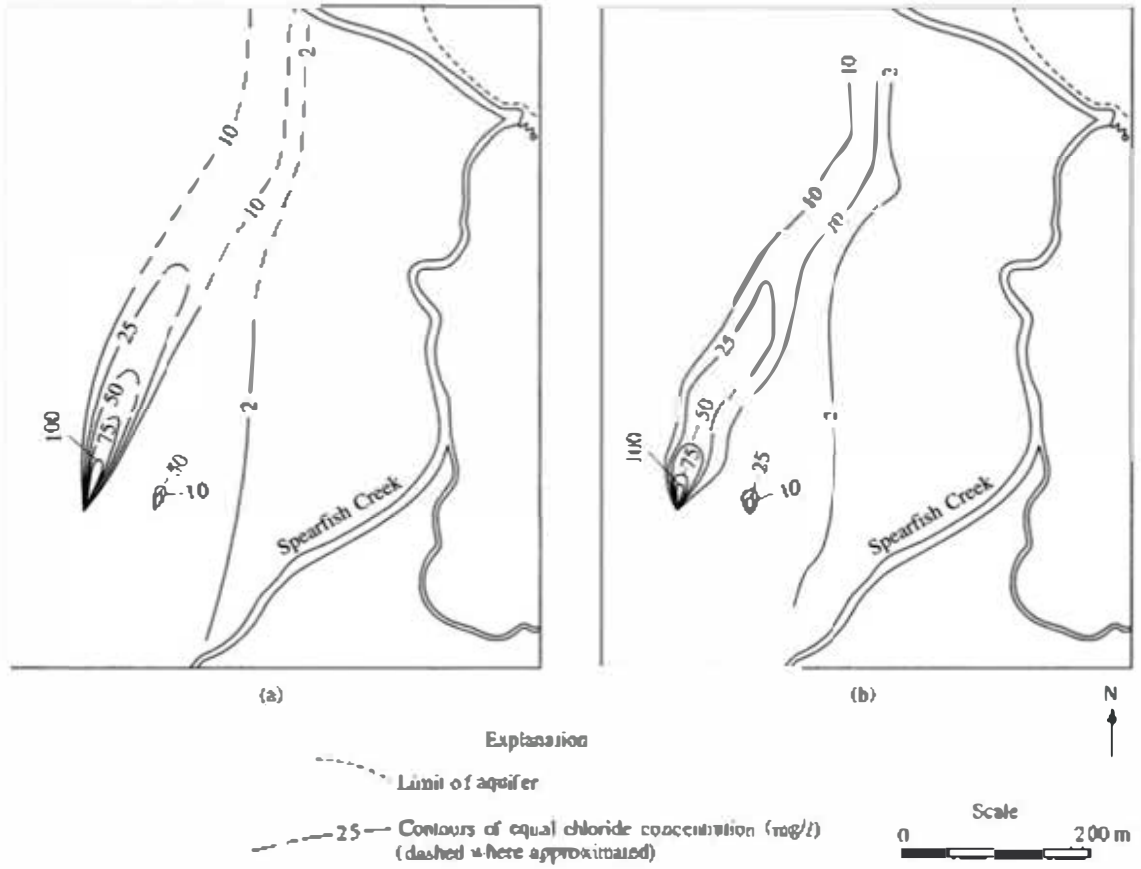
Case Study: Borden Landfill Plume

Probably the best known subsurface contaminant transport field test site is located on the Canadian Forces Base in Borden, Ontario (Sudicky and Illman 2011). An abandoned landfill in a shallow sand aquifer at Borden has been extensively studied (Cherry 1983; Macfarlane et al. 1983) and Frind and Hokkanen (1987) made a very interesting study of the plume based on a deterministic model.

The landfill was active from 1940 to 1976 and covers about 5.4 ha to a depth of 5 to 10 m (16 to 32 ft). Figure 2.33 shows the location of water table wells and multilevel sampling devices. The multilevel sampling devices are concentrated along the long axis of the plume of groundwater contamination. The vertical location of the sampling points along cross section A-A′ are shown in Figure 2.34. The aquifer is about 20 m (65 ft) thick beneath the landfill and thins to about 9.5 m (31 ft) in the direction of groundwater flow. The aquifer consists of laminated fine to medium sand. An average hydraulic conductivity of 1.16×10^{-2} cm/sec

horizontally and 5.8×10^{-4} cm/sec vertically was used in the model with a porosity of 0.38. In 1979 a very extensive study of the water quality of the plume was conducted. Figure 2.35 shows the plume of chloride contamination along cross section A-A'. In 1979 the plume extended about 750 m (2,460 ft) from the landfill and had sunk to the bottom of the aquifer and then moved laterally with the flowing groundwater. The sinking of the plume is believed to be caused by recharge concentrated in a sand pit to the north of the landfill, which is in the direction of flow.

FIGURE 2.32 Comparison of (a) field observations at solute plume in an aquifer and (b) solute plume as computed by finite-difference solute-transport model for a heterogeneous aquifer.



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The finite-difference grid system for the crosssectional model is shown in Figure 2.36. Equipotential lines for observed conditions were essentially vertical (Figure 2.37). The model was calibrated against the water-table contours for steady-state conditions.

Sensitivity analyses were performed to determine the impact of varying α_l and α_T. Field tests had indicated that the value of α_l at the site is on the order of 5 to 10 m (16 to 32 ft) (Sudicky et al. 1983). Figure 2.38 shows the sensitivity of the plume to the value of α_T. The value of α_l was kept at 10 m (32 ft) and α_T was varied from 0.005 m (0.02 in) to 1.0 m (3 ft). It can be seen that the shape of the plume is very sensitive to the value of α_T. With a high value of α_T, the plume spread through the entire vertical thickness of the aquifer, whereas with a low value it tended to sink toward the bottom. Figure 2.39 illustrates the fact that the

plume was not very sensitive to changes in the value of α_t over the range tested. The value of α_T was kept constant at 0.01 m (0.4 in), whereas α_l varied from 2.5 to 20 m (8 to 65 ft). This figure is slightly misleading in that there is a 10:1 vertical exaggeration, so that the vertical spreading is more obvious than the horizontal. Also, the value of α_T was varied by a factor of 200, whereas α_l was varied only by a factor of 8.

FIGURE 2.33 Location of landfill at Canadian Forces Base, Borden, Ontario, showing location of cross section and monitoring network.

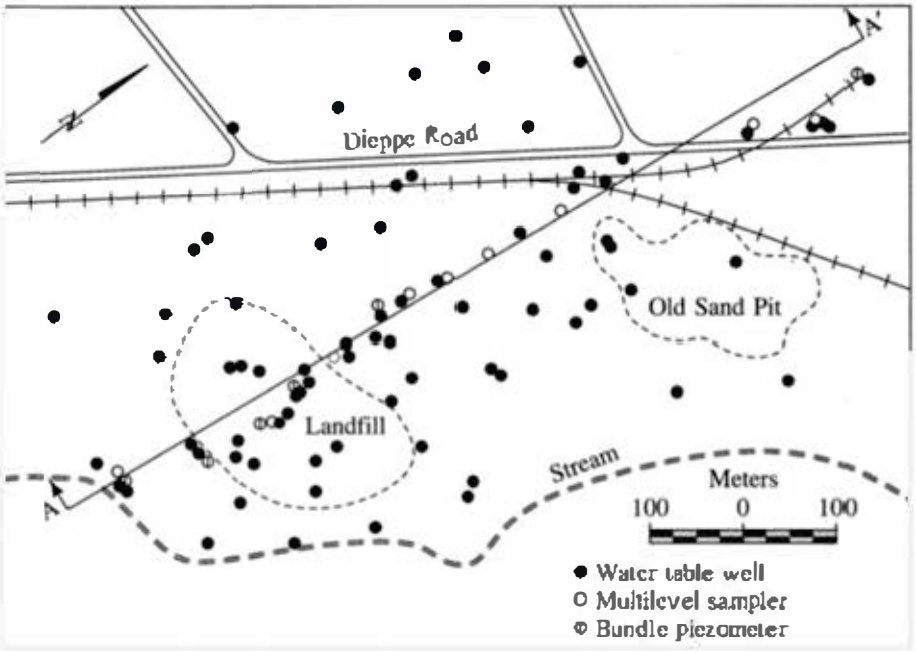

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FIGURE 2.34 Cross section of aquifer at the Border landfill showing the location of multilevel monitoring devices.

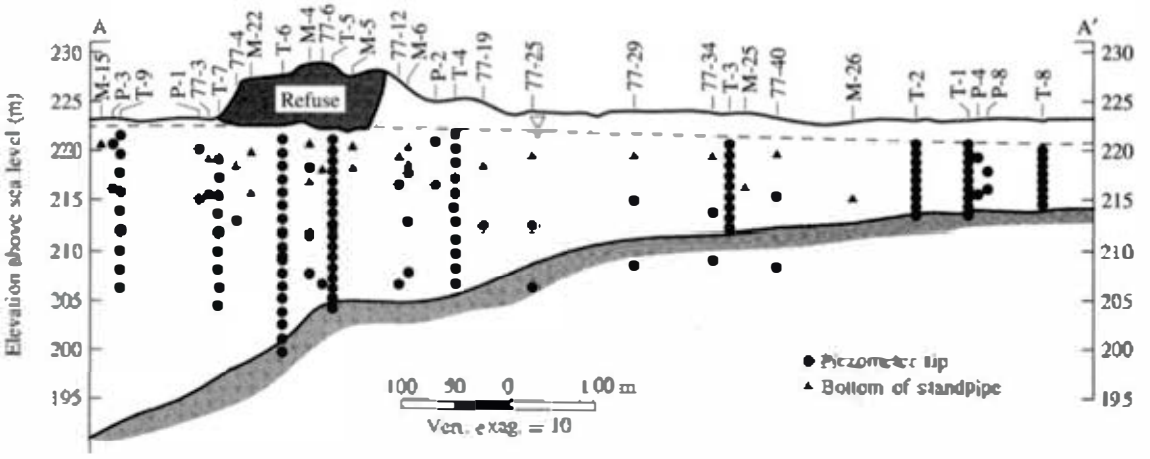

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FIGURE 2.35 Chloride plume along the Border landfill across section in 1979. Values are in milligrams per liter.

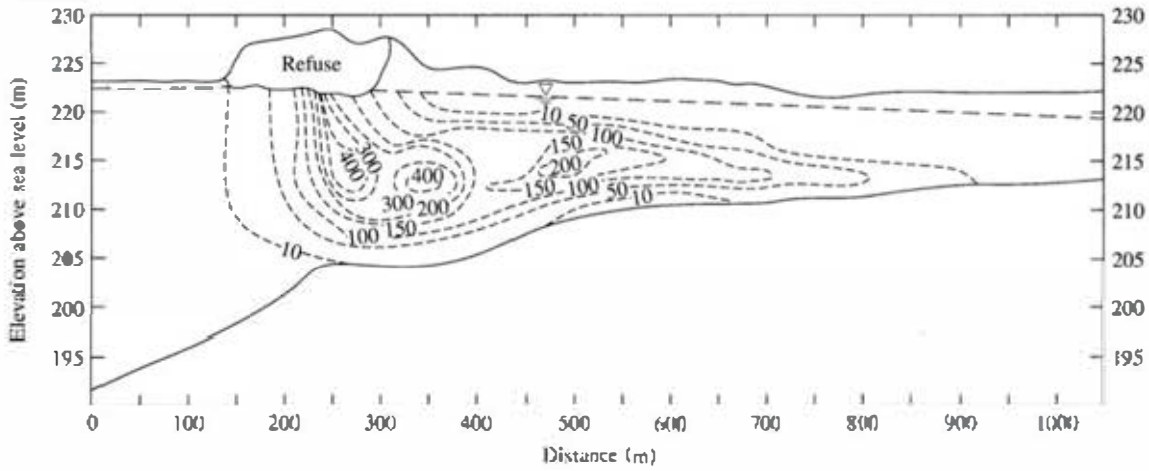

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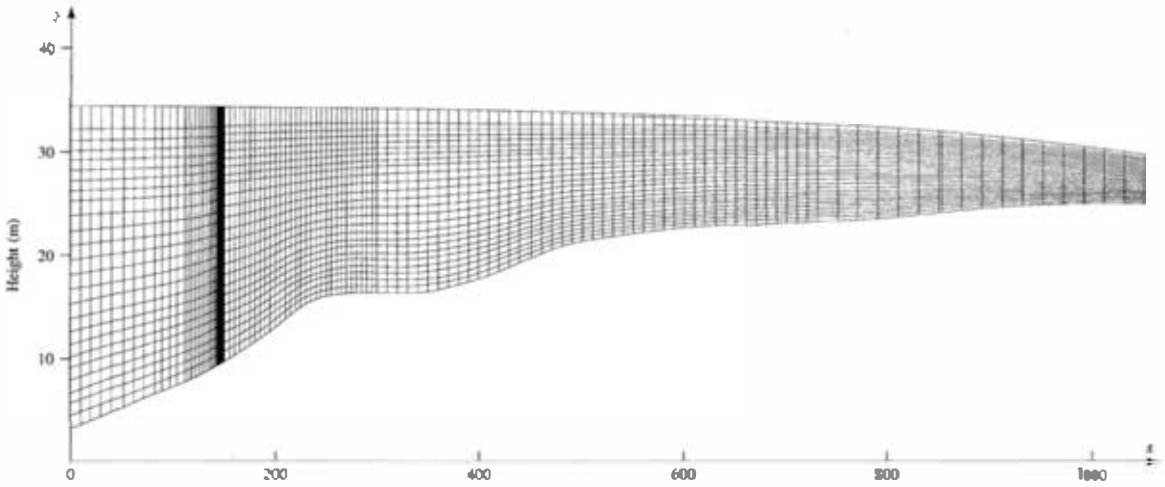
FIGURE 2.36 Finite-difference grid for Borden landfill solute transport model.



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Additional sensitivity analyses were conducted with respect to the water table boundary conditions and the concentration, size, and growth pattern of the source. The authors found that in order to reproduce the observed distribution, a source history that included multiple periods of high concentration was needed. Figure 2.40(a) shows the shape of the observed plume, Figure 2.40(b) illustrates the shape of a plume generated by a source with a history in which the concentration gradually increased (smooth source concentration), and Figure 2.40(c) contains the computed plume with the best match to the observed plume. It was generated by a run of the model in which the source concentration had two different periods of peak concentration. Although the solution was not unique—that is, several different combinations of model inputs might yield the same output—the shape of the plume could be reproduced with good accuracy. This was especially true at the leading edge of the plume, which is the most important part from the standpoint of predicting the movement of the plume into uncontaminated areas of the aquifer.

FIGURE 2.37 Equipotential lines from the calibration of the Borden landfill solute-transport model; values in meters above datum.

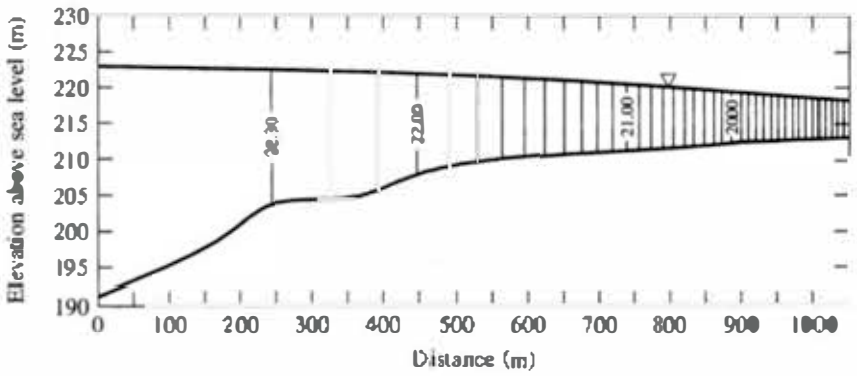

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FIGURE 2.38 Sensitivity analysis of the Borden landfill solute-transport model with respect to transverse dispersivity.

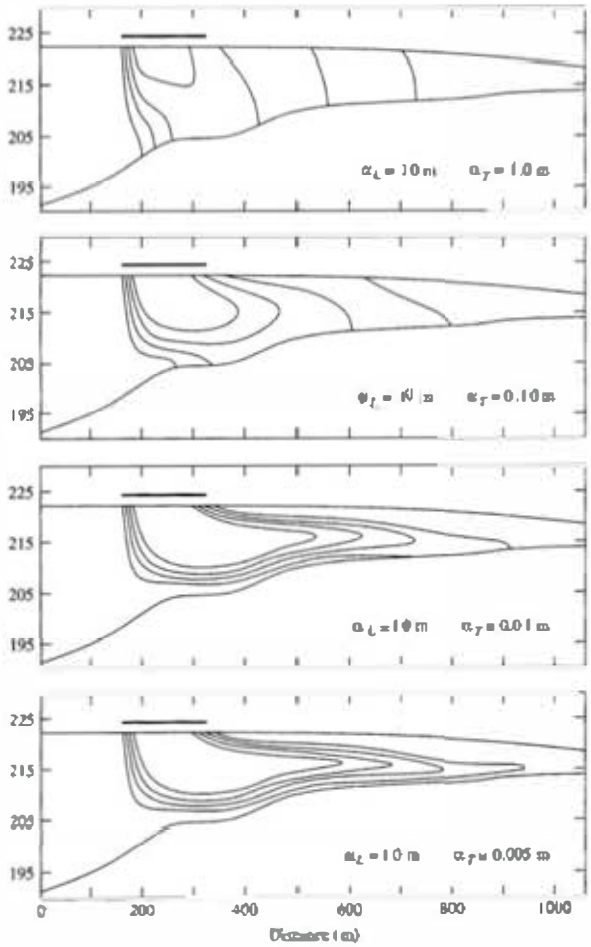

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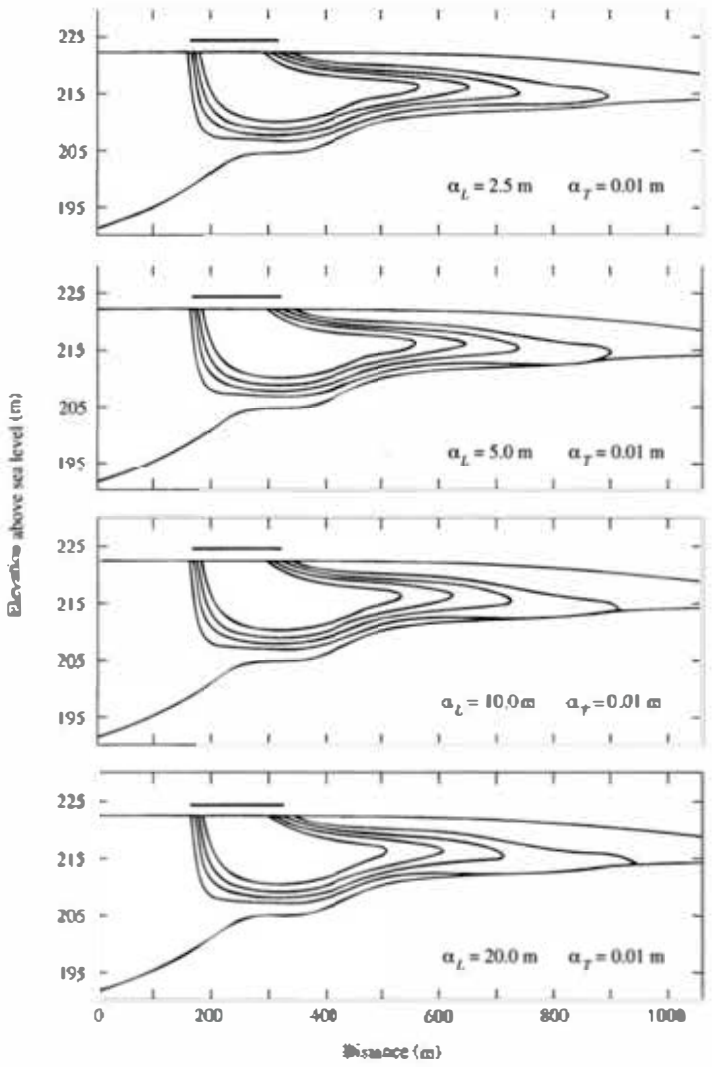
FIGURE 2.39 Sensitivity analysis of the Borden landfill solute-transport model with respect to longitudinal dispersivity.



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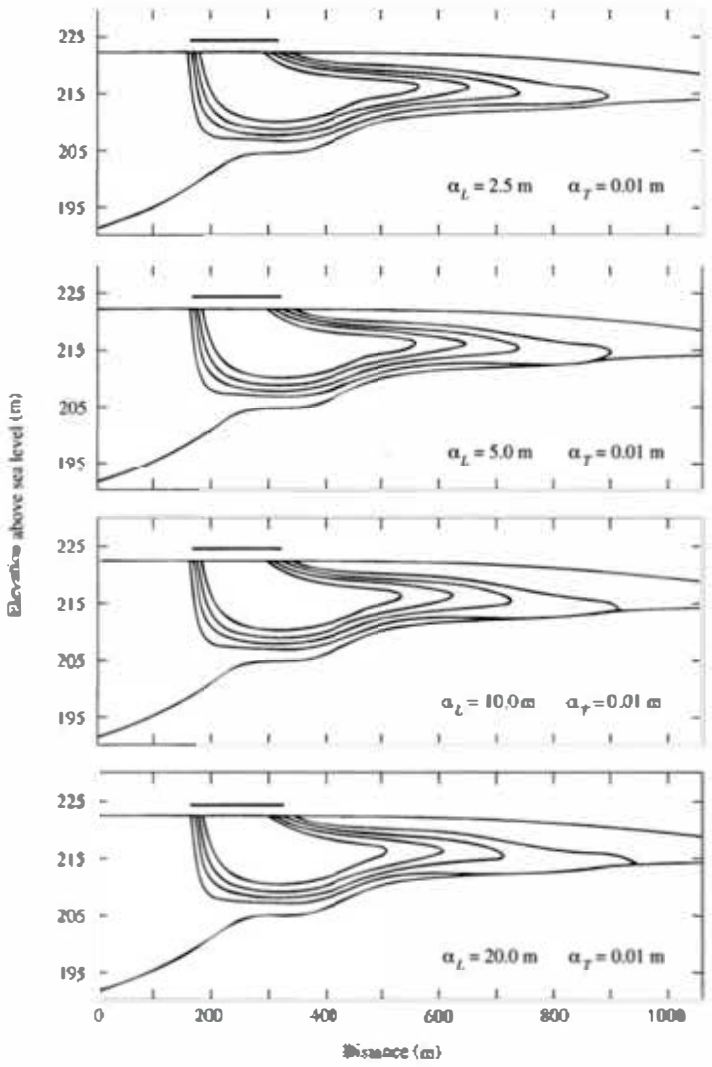
2.16 Transport in Fractured Media

Solute transport in fractured rock media is as important a process as transport in porous media. Understanding fluid flow and mass transport in fractured rocks is essential for assessing the groundwater resources of hard-rock aquifers and predicting the movement of hazardous chemicals if contamination occurs. Transport in fractured media is also important when assessing the suitability of underground sites for hazardous waste disposal, such as the heavily investigated former candidate site for a nuclear waste repository at Yucca Mountain in Nevada. However, less research has been done on this topic than on transport in porous media. One reason may is that existing theory of fluid flow through porous media is of limited usefulness when applied to fractured

FIGURE 2.39 Sensitivity analysis of the Borden landfill solute-transport model with respect to longitudinal dispersivity.



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rocks (USGS 2015c). The rock in which fractures exist is porous. Hence, fluid moves in the fractures as well as in the rock matrix. Solutes in the fractures can diffuse into the fluid contained in the rock matrix and vice versa (Neretnieks 1980; National Research Council 2015). The fractures themselves are not smooth channels but contain dead-end passages that hold nonmoving water into which solutes can diffuse (Raven et al. 1988).

Berkowitz et al. (1988) suggested that solute transport in fractured media can be considered at a number of different scales. A very-near-field scale would be a single fracture near the source. A near-field scale would include a few fractures near the source. At a larger scale, the far field, the fracture network and the porous media matrix would have separate, discernible impacts on flow. At a very-far-field scale, which exists at considerable distance from the source, the entire flow domain can be considered as an equivalent porous medium in which the repeating fractures became large pores.

A number of different approaches to solute transport in fractured media have been attempted. These include analysis of transport in a single fracture in which effects of the transport in the fractures as well as interactions with a porous matrix are considered (e.g., Grisak and Pickens 1980; 1981; Tang et al. 1981; Rasmuson and Neretnieks 1981; Rasmussen 1984; Sudicky and Frind 1984). Sudicky and Frind (1982) and Barker (1982) examined transport in a media that consists of equally spaced fractures in a porous media. Endo and others (1984) made a deterministic study of flow in an irregular network of fractures contained in an impermeable host rock, whereas Schwartz et al. (1983) and Smith and Schwartz (1984) approached the same problem using a stochastic model. Berkowitz et al. (1988) and Schwartz and Smith (1988) examined the conditions under which the porous media matrix and the fractures can be considered to be a continuum that is representative of an equivalent porous media. Raven et al. (1988) made a field study of flow through a single fracture to test a model that incorporates the effects of nonflowing water in the fractures. Tsang et al. (1988) and Moreno et al. (1988) examine fracture flow on the basis of the assumption that most of the flow is concentrated in a few channels.

Dietrich et al. (2005) proposed a multi-continuum model in which separate, coupled hydraulic components in a heterogeneous aquifer are modeled. It is assumed that each component is distributed continuously in space and satisfies the condition of a porous medium (Bear and Bachmat 1990). For fracture matrix systems, this could be two fracture continua, such as a micro- and macro-fracture system, and a matrix continuum with appropriate equivalent parameters. The matrix and fractures are locally idealized as continua and the fractures are implemented discretely at their actual locations within the domain. It is obvious that the amount of data required to set up a discrete model of the actual domain is very large and to some extent not measureable. Consequently, the discrete model concept is preferentially used for relatively small domains and it is a suitable tool for principle studies of flow and transport processes (Dietrich et al. 2005).

One of the first considerations in dealing with fracture flow is deciding how to treat flow in a single fracture. Some authors (e.g., Tang et al. 1981; Schwartz and Smith 1988) assume that the fluid in a fracture is all moving at a constant velocity. Conversely, Endo et al. (1984) treated flow in a fracture to be two-dimensional, with a parabolic velocity profile across the width of the fracture, as shown in Figure 2.41. Transport within a single fracture is due to advection, which occurs at different rates, depending upon the position between the parallel walls of the fracture, and molecular diffusion, both normal and parallel to the flow direction.

FIGURE 2.40 Comparison of (a) the observed chloride plume at the Borden landfill with (b) the chloride plume simulated by the solute transport model with a smooth source concentration and (c) the chloride plume simulated by the solute transport model with a doubly peaked source concentration.

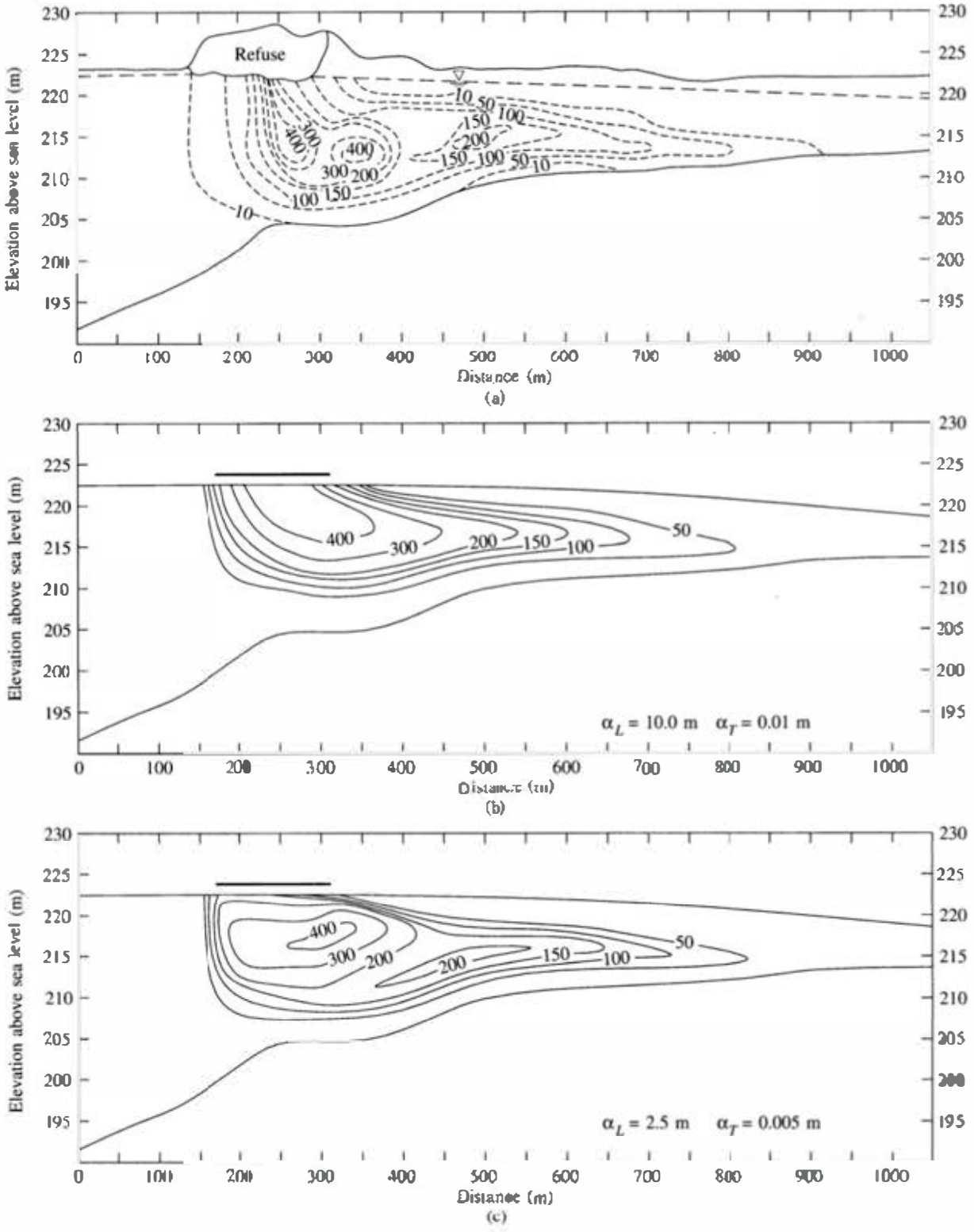

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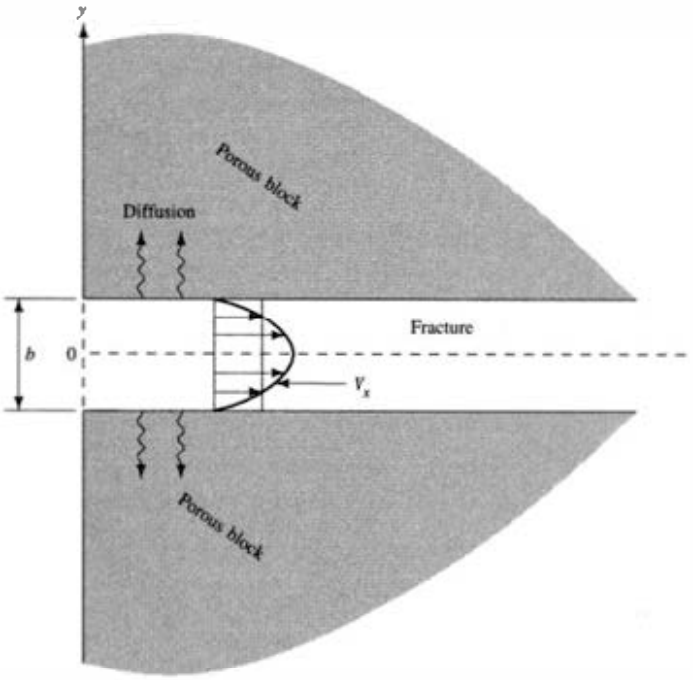
FIGURE 2.41 Horizontal distribution of flow in a vertical fracture and diffusion into the porous media matrix.



Hull et al. (1987) examined the conditions whereby diffusion within the fracture needs to be considered. In a fracture with parallel sides, the solute transport within the fracture is described by

$$\frac{\partial C}{\partial t} = D^* \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) - 6V\left[(\tau) - (\tau)^2 \right] \frac{\partial C}{\partial x} \tag{2.49}$$

where

V = average fluid velocity in a fracture

τ = fractional transverse position in a fracture

At high flow rates, advection will dominate and the concentration will follow the velocity profile of Figure 2.41. At low velocities, diffusion will be important, since the concentration gradient at the solute front will be high and the distance will be short. Under these conditions, diffusion will homogenize the solute across the width of the fracture.

If L is the length of the fracture between cross fractures and β is the aperture of the fracture, the fracture residence time is L/V. This can be compared with $(\beta/2)^2/D$ to determine if diffusion needs to be considered (Crank 1956). If diffusion induces a change in the tracer concentration of less than 2% over a distance of 10% of the width of the fracture, the diffusion can be considered negligible, and the residence time in the fracture will be

$$\frac{L}{V} < 0.003 \frac{(\beta/2)^2}{D} \tag{2.50}$$

If diffusion affects the tracer concentration to the extent that the tracer front is at 98% of the equilibrium value at all points across the fracture, the diffusion has homogenized the front, and the residence time in the fracture will be

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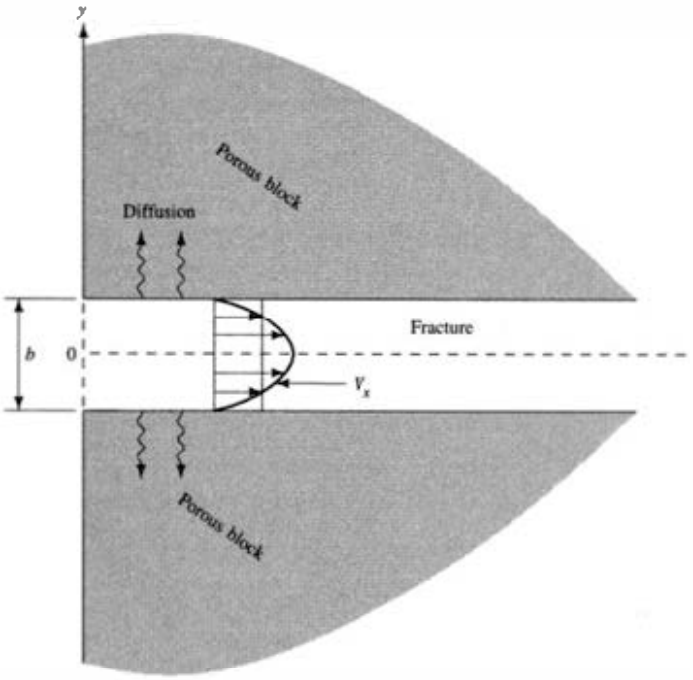

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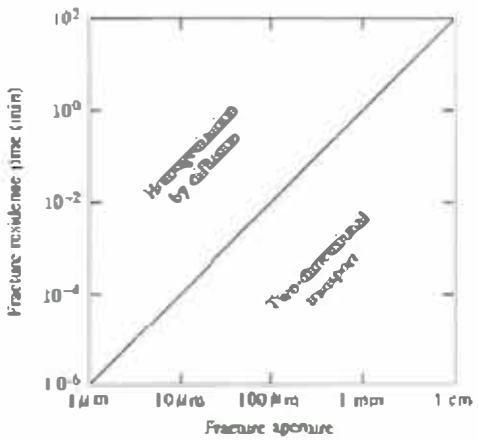
FIGURE 2.42 Fracture residence time necessary for homogenization of the tracer across the fracture width by molecular diffusion.



Source: Modified from L. C. Hull, J. D. Miller, and T. M. Clemo, 1987, *Water Resources Research* 23:1505–1513. Copyright by the American Geophysical Union. Reproduced with permission.

$$\frac{L}{V} < 0.05\frac{(\beta/2)^2}{D} \tag{2.51}$$

Figure 2.42 indicates the circumstances under which fracture flow can be considered to be one- or two-dimensional. Fracture residence time (L/V) is plotted against fracture aperture on this figure, which is based on a diffusion coefficient of 1.7×10^{-9} m²/sec (1.93×10^{-8} ft²/sec). The figure shows the conditions under which diffusion will homogenize the flow so that the transport within the fracture can be treated as one-dimensional (uniform conditions across the aperture). However, diffusion will still spread the tracer in advance of the advecting water. For even large fractures of 1mm aperture, this will occur with a residence time of 1min or more. This suggests that for most flow situations, one does not need to consider the velocity distribution across the fracture.

When the flow in a fracture is homogeneous, the mass transport can then be described by the one-dimensional advection-dispersion equation with the longitudinal dispersion coefficient equal to (Hull et al. 1987)

$$D_L = \frac{(V\beta)^2}{210D} \tag{2.52}$$

One approach to solute transport modeling is to determine the flux of water through the fractures and then use a numerical technique known as a random walk model to simulate diffusion of the solute (Hull et al. 1987). This ignores any diffusion into the porous media matrix. According to Witherspoon et al. (1980), flow through a fracture can be described by Darcy's law using an equivalent hydraulic conductivity for a fracture, K_f, given by

$$K_f = \frac{\rho g}{12\mu}\beta^2 \tag{2.53}$$

The quantity of flow, Q, can be found from the cubic law

$$Q = \frac{\rho g}{12\mu} I a \beta^3 \tag{2.54}$$

where

g = acceleration of gravity

I = hydraulic gradient along the fracture

a = width of the fracture-that is, the third dimension after length and aperture

μ = viscosity of fluid

If the velocity in the channel needs to be described in two dimensions, this can be done with three equations: one for the maximum velocity in the center of the fracture, one for the flow velocity profile across the aperture, and one for the vertical velocity profile in the fracture.

The maximum velocity can be found from (Hull et al. 1987):

$$V_x(\max) = \left[1.5 + 1.1664\left(\frac{a}{\beta}\right)^{-1.0557}\right] V \tag{2.55}$$

The velocity profile across the aperture is given by.

$$V_x(y) = 4\left(\tau - \tau^2\right) \tag{2.56}$$

where τ = fractional transverse position in a fracture, y/β.

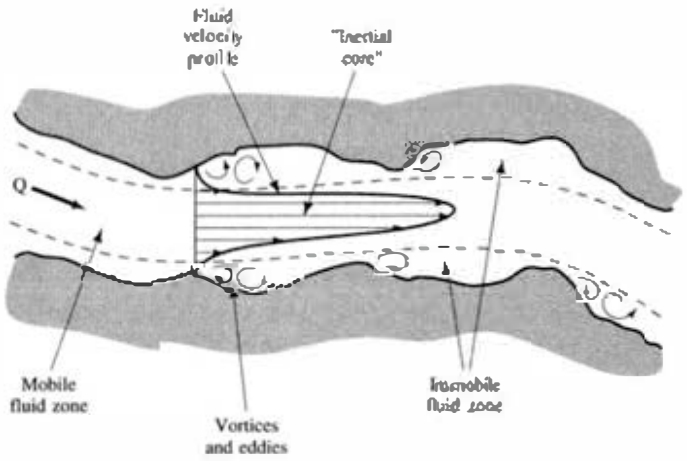
The vertical velocity profile is given by

$$V_x(\zeta) = 15.56\zeta - 97.72\zeta^2 + 308\zeta^3 - 513\zeta^4 + 431\zeta^5 - 143.7\zeta^6 \tag{2.57}$$

where ζ = fractional vertical position in a fracture, z/a.

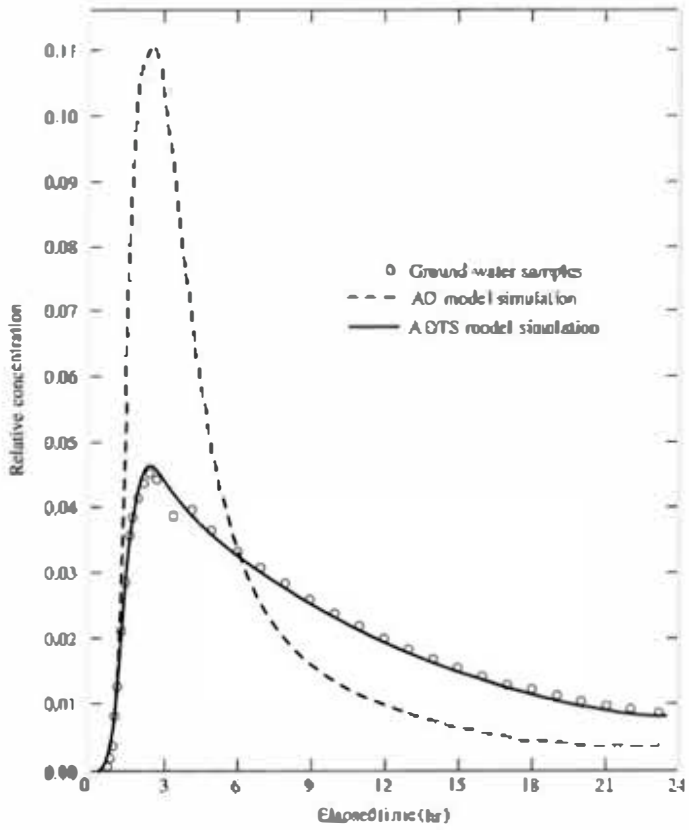
Raven et al. (1988) pointed out that the fractures through which flow occurs are not smooth, parallel plates but have irregular walls that promote the formation of zones along the edge of the fracture where the water is immobile (Figure 2.43). The fluid moves through the mobile zone, but the solutes can diffuse into the immobile fluid zones. The solute would be stored in the immobile fluid during the early part of solute transport and would be released from storage if the solute concentration in the mobile fluid would decrease—for example, as might happen during the latter part of a slug injection test. They derived an advection-dispersion equation for mass transport in the fracture with "transient solute storage in the immobile fluid zone (advection-dispersion transient storage model or ADTS). A field test was performed on the flow through a single fracture that had been isolated by packers in the borehole. Water was injected into one borehole and withdrawn from another. The water contained a tracer for the first few hours of the test, and then water without the tracer was again injected. Figure 2.44 contains circles representing the field data, in terms of relative concentration, plotted versus elapsed time. Also shown on this figure are the results of a conventional advection-dispersion (AD) model and an advection-dispersion transient storage (ADTS) model. Both models matched the observed data for the first few hours of the test. However, the ADTS model was far superior in matching the field data over the entire course of the test. The effect of transient storage was to reduce the peak concentration and to increase the concentrations above what would be produced by advection-dispersion alone during the later periods of the test.

FIGURE 2.43 Zones of mobile and immobile water in a fracture.



Source: K. G. Raven, K. S. Novakowski, and P. A. Lapcevic. 1988. *Water Resources Research* 24:2019–2032. Copyright by the American Geophysical Union. Reproduced with permission.

FIGURE 2.44 Comparison of field data from a tracer test in fractured rock with results of model simulation using an advection-diffusion (AD) model and an advection-diffusion transient storage (ADTS) model.



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2.17 Summary

Solutes dissolved in groundwater are transported in two ways. Diffusion will cause solutes to move in the direction of the concentration gradient—that is, from areas of higher to lower concentration. This transport can occur even if the groundwater is not flowing and may be the major factor in mass transport in geologic materials of very low permeability.

Solutes are also transported by the process of advection. This occurs as the flowing groundwater carries the dissolved solutes with it. At the scale of a few pore diameters, groundwater will move parallel to the flow path at different rates due to differences in pore size. This causes the solute plume to spread along the direction of the flow path, a process called longitudinal dispersion. The solute plume will also spread laterally as flow paths diverge around mineral grains, a process known as transverse dispersion. At the laboratory column scale, the movement of a contaminant through a uniform porous media can be described by the advection-dispersion equation, which accounts for advection, diffusion, and porescale dispersion.

In field-scale studies it has been found that the coefficient of longitudinal dispersion obtained from the advection-dispersion equation increases with the length of the flow path. This is due to the heterogeneous nature of aquifer materials. As the length of the flow path increases, the range of permeability values that affect the rate of groundwater flow also increases. This causes the resulting solute plume to spread out more and more. This can be called macrodispersion. An apparent diffusion coefficient can be statistically correlated with the length of the flow path by the expression $\alpha_m = 0.83(\log L)^{2.414}$.

Stochastic methods of analysis have also been developed to analyze solute transport at the field scale. Stochastic methods are based on the variation in the hydraulic conductivity values because it is that variation that causes the solute plume to spread. The groundwater velocity depends upon the porosity as well as the hydraulic conductivity, but the hydraulic conductivity varies over a much greater range than porosity.

At the field scale the spreading due to hydraulic conductivity variation is much greater than that due to pore-scale dispersion. Both stochastic and advection-dispersion models demonstrate that the primary movement of the solute plume is due to advection. The stochastic model yields the movement of the center of mass of the solute plume from the average rate of movement of the groundwater. The variance of the solute concentration about the mean position, or the second spatial moment, is also obtained from stochastic models.

Chapter Notation

A	Cross-sectional area
a	Width of a fracture
b	Aquifer thickness
B	$[(v_x x)^2/(2D_L)^2 + (v_y y)^2/(4D_L D_y)]^{1/2}$
C	Solute concentration
C_i	Concentration at some point x and time t
C_0	Inirial concentration, i.e. concenrration at time 0
C_R	Dimensionless solute concentration (C/C_0)
$\langle C \rangle$	Ensemble mean concentration
c_o	Constant related to anisotropy
d	Characteristic flow length for Peclet number, P
dh/dl	Hydraulic gradient
D^*	Effective diffusion coefficient
D	Diffusion coefficient
D_d	Molecular diffusion coefficient
D_i	Coefficient of hydrodynamic dispersion in the i direction

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D_L	Coefficient of longitudinal hydrodynamic dispersion
D_T	Coefficient of transverse hydrodynamic dispersion
E	Euler number (0.577...)
E_1	Exponential integral
f	Fractal dimension
F	Mass flux of solute per unit area per unit time
g	Acceleration of gravity
G	Topological dimension
h	Hydraulic head
H	Separation of autocorrelation function
i	Decay constant
I	Hydraulic gradient along a fracture
J	Constant length
k	Lag in autocorrelation function
K	Hydraulic conductivity
K_f	Equivalent hydraulic conductivity of a fracture
K_G	Geometric mean of hydraulic conductivity
K_n	Modified Bessel function of second kind and zero order
L	Straight-line distance between ends of a flowpath
L_e	Length of a tortuous flowpath
L_f	Length of a fractal flowpath
L_s	Straight-line length between ends of a fractal flowpath
M	Total mass of solute
N	Number of units
n	Porosity
n_e	Effective porosity
P_e	Peclet number ($v_x L / D_L$)
PV	Pore volume
Q	Rate at which a tracer is being injected into an aquifer
r	Radial distance to a well
R	Length of well screen or open borehole
R_f	Average frontal position of water injected into a well
r_Y	Autocorrelation of sampled values of Y
S_Y	Standard deviation of sampled values of Y
S_Y^2	Variance of sampled values of Y
t	Time
t'	Dimensionless time (tU/ϵ_h)
t_D	Dimensionless time $\left(\frac{V_x^2 t}{D_L}\right)$
t_R	Dimensionless time ($v_x t / L$)
T	Tortuosity
T_f	Fractal tortuosity
u	Average velocity of injection of water into a well
u	Fluctuation in the velocity vector
u_p	Covariance
U	$\langle V \rangle$ ensemble mean of velocity vectors
U_i	Total volume of water injected into a well
U_p	Cumulative volume of water withdrawn from a well
v_f	Velocity along a fracture flowpath
v_x	Average linear velocity in the x direction
V	Average fluid velocity in a fracture
V	Velocity vector
$\langle V \rangle$	Ensemble mean of the velocity vectors
$W[t, B]$	Hantush leaky well function
x	Coordinate vector
x_f	Length of fractal flowpath
(x_0, y_0)	Origin of an xy field
x_s	Straight-line distance
X'	Residual of the displacement of a particle
$\langle X \rangle$	Ensemble mean of the center of mass
$X_p(t)$	Second spatial moment of the solute mass at time t and location j, l
X_t	Total particle displacement
$\bar{Y}$	Mean of sample values of Y
Y_i	$\log K_i$
Z_o	Constant related to a semivariogram
α	Dynamic dispersivity
α_L	Longitudinal dynamic dispersivity
α_T	Transverse dynamic dispersivity
α_m	Apparent dispersivity
β	Aperture of a fracture
ϵ_h	Correlation length for horizontal hydraulic conductivity

ϵ_v	Correlation length for vertical hydraulic conductivity	ρ_Y	Autocorrelation of the population of Y
η	Fractal unit of measurement	σ_Y	Standard deviation of population of Y
η_c	Fractal cutoff limit	σ_Y^2	Variance of population of Y
γ_Y	Semivariogram of Y	τ	Fractional transverse position in a fracture
λ_Y	Correlation length of autocorrelation	τ_Y	Autocovariance
μ	Viscosity of a fluid	θ	Angle in polar coordinate system
μ_Y	Mean of population of Y	ξ	Fourier transform wave vector number
ν	Hurst coefficient for fractal dimensions	ζ	Fractional vertical position in a fracture
ω	Coefficient related to tortuosity		
Ω	Anisotropy ratio (ϵ_v/ϵ_h)		
ρ	Density of a fluid		

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6

Inorganic Chemicals in Groundwater

6.1 Introduction

Groundwater is a solvent that is in contact with various earth materials. As a result, groundwater naturally contains dissolved cations and anions as well as some nonionic inorganic material, such as silica (SiO_2). Naturally occurring groundwater can contain dissolved solids that range in concentration from less than 100 mg/L to more than 500,000 mg/L (Hem 1985). The major ion constituents of natural water include calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate/carbonate. Dissolved gasses can include nitrogen, carbon dioxide, methane, oxygen, and hydrogen sulfide. There are a number of ions that can be naturally present in small amounts that can affect the water quality. In addition, inorganic ions that impact upon water quality can be released to the subsurface via human activity. For example, at least 18 inorganic elements can be used in pesticides (chromium, chlorine, fluorine, tin, arsenic, selenium, barium, cadmium, sulfur, phosphorus, mercury, zinc, lead, copper, thallium, bismuth, boron, and antimony), and many metals can be joined with carbon to form organometalic pesticides (Clarkson 2001).

We have already seen in Chapter 3 that ions can be removed from solution by ion exchange and sorption. In this chapter we will examine other chemical processes that act to remove inorganic ions from solution. We will also examine the chemical properties of a number of inorganic materials frequently found in groundwater. The geochemical zonation that can occur near landfills that have received municipal waste will be used to illustrate some basic principles.

6.2 Units of Measurement and Concentration

Chemical analyses are usually reported on the basis of weight of solute per volume of solvent. Common units are **milligrams per liter** (mg/L) and **micrograms per liter** (μg/L). Equivalent weight units are frequently used when the chemical behavior of a solute is being considered. The equivalent weight of an ion is the formula weight divided by the electrical charge. If the concentration of the ion in milligrams per liter is divided by the formula weight, the resulting concentration is expressed in terms of **milliequivalents per liter**. One **mole** of a substance is its formula weight in grams. A 1-**molal** solution has 1 mole of solute in 1000 g of solvent. A 1-**molar** (1-*M*) solution has 1 mole of solute in a liter of solution.

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If a solution is dilute and there is no need to make density corrections, the molality can be determined from the concentration by the following equation:

$$\text{Molality} = \frac{\text{milligrams per liter} \times 10^{-3}}{\text{formula weight in grams}} \tag{6.1}$$

6.3 Chemical Equilibrium and the Law of Mass Action

The law of mass action states that the rate of a chemical reaction will be proportional to the active masses of the participating substances (Hem 1985). If there are two substances, A and B, reacting to form two other substances, C and D, and if the process is reversible, then the reaction can be written as

$$aA + bB \rightleftharpoons cC + dD \tag{6.2}$$

The rate of the forward reaction, R_1, is

$$R_1 = k_1'[A]^a[B]^b \tag{6.3}$$

whereas the rate of the reverse reaction, R_2, is

$$R_2 = k_2'[C]^c[D]^d \tag{6.4}$$

where:

[A] = active concentration of substance A
k'_1 = proportionality constant for the forward reaction
k'_2 = proportionality constant for the reverse

If the reaction progresses to a point where the forward reaction rate is equal to the reverse reaction rate, then

$$k_1'[A]a[B]b \rightleftharpoons k_2'[C]c[D]d \tag{6.5}$$

Equation 6.5 can be rearranged to yield the following expression:

$$\frac{[C]^c[D]^d}{[A]^a[B]^b} = \frac{k_1'}{k_2'} = K_{eq} \tag{6.6}$$

where K_{eq} is the equilibrium constant.

If two or more ions react to form a solid precipitate and the reaction is reversible, then it can be represented as

$$aA + bB \rightleftharpoons cAB \tag{6.7}$$

The equilibrium relationship of this reaction is:

$$K_{sp} = \frac{[A]^a[B]^b}{[AB]^c} \tag{6.8}$$

where K_{sp} is called a solubility product. The activity of the solid together with the water is defined as unity. Solubility products can be used to compute the concentration

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of a solute in equilibrium with a solid phase, either via dissolution of the solid into an undersaturated solution or following precipitation of the solid from a saturated solution.

If one is dealing with a very dilute aqueous solution, then molal concentrations can be used to determine chemical equilibrium. However, for the general case, one must use chemical activities to employ the law of mass action.

The chemical activity of ion X, $[X]$, is equal to the molal concentration of X, m_x, times a factor known as an **activity coefficient**, γ_x:

$$[X] = m_x \gamma_x \tag{6.9}$$

The activity coefficient varies with the total amount of cations and anions in solution. The concentration and charge of the various ions in a solution determine its **ionic strength**. Ionic strength can be computed from the following formula:

$$I = \frac{1}{2} \sum m_i z_i^2 \tag{6.10}$$

where

I = ionic strength
m_i = molality of the ith ion
z_i = charge of the ith ion

Once the ionic strength is determined, the activity coefficient can be calculated using the Debye-Hückel equation:

$$-\log \gamma_i = \frac{A z_i^2 \sqrt{I}}{1 + a_i B \sqrt{I}} \tag{6.11}$$

where

γ_i = the activity coefficient for ionic species i
z_i = the charge on ionic species i
I = ionic strength of the solution
A = constant equal to 0.5085 at 25°C
B = constant equal to 0.3281 at 25°C
a_i = the effective diameter of the ion from Table 6.1

The Debye-Hückel equation can be used with solutions that have an ionic strength of 0.1 or less (approximately 5000 mg/L). Figure 6.1 is a graph showing the relationship of activity coefficient to ionic strength for specific ions; it was calculated using the Debye-Hückel equation. Specific curves are for ions with the same effective diameter and charge as listed in Table 6.1. Not all the ions to which a curve applies are listed on the figure. For example, the curve labeled Ca^{2+} and Fe^{2+} can also be used for Cu^{2+}, Zn^{2+}, Sn^{2+}, Mn^{2+}, Ni^{2+}, and Co^{2+}, because all these ions have the same effective diameter and charge.

Chemical equilibrium is a useful concept in studies of contaminant hydrogeology. Ionic contaminants discharged into groundwater may react with naturally occurring

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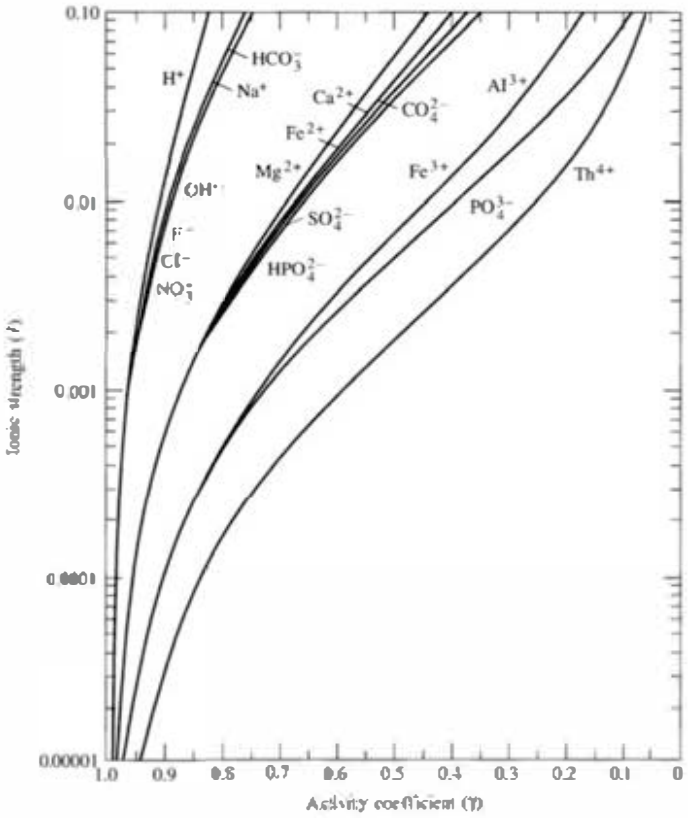
TABLE 6.1 Values of the parameter a_i in the Debye-Hückel equation.

a_i	Ion
11	Th^{4+}, Sn^{4+}
9	Al^{3+}, Fe^{3+}, Cr^{3+}, H^+
8	Mg^{2+}, Be^{2+}
6	Co^{2+}, Cu^{2+}, Zn^{2+}, Sn^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Co^{2+}, Li^+
5	$Fe(CN)_6^{4-}$, Sr^{2+}, Ba^{2+}, Cd^{2+}, Hg^{2+}, S^{2-}, Pb^{2+}, CO_3^{2-}, SO_3^{2-}, MoO_4^{2-}
4	PO_4^{3-}, $Fe(CN)_6^{3-}$, Hg_2^{2-}, SO_4^{2-}, SeO_4^{2-}, CrO_4^{3-}, HPO_4^{2-}, No^-, HCO_3^-, $H_2PO_4^-$
3	OH^-, F^-, CNS^-, CNO^-, HS^-, ClO_4^-, K^+, Cl^-, Br^-, I^-, CN^-, NO_2^-, NO_3^-, Rb^+, Cs^+, NH_4^+, Ag^+

Source: J. Kielland. 1937. Individual activity coefficients of ions in aqueous solutions *American Chemical Society Journal* 59:1676–1678. Published by the American Chemical Society. Used with permission.

FIGURE 6.1 Relationship of activity coefficients of dissolved ions as a function of the ionic strength of a solution at 25°C.



Source: J. D. Hem. 1985. *Study and interpretation of the chemical characteristics of natural waters.* Water Supply Paper 2254, U.S. Geological Survey.

ions in the groundwater to form a precipitate or they may mobilize ions sorbed on solid surfaces. They may also undergo oxidation or reduction. Both these processes are reversible and can be described by chemical equilibrium. Many geochemical processes in groundwater are not readily reversible, such as weathering of silicate minerals. These reactions must be treated using kinetics. However, as this type of reaction is

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not of significant interest in contaminant hydrogeology, we do not typically consider kinetic models.

Table 6.2 contains the solubility products for a large number of minerals, including many that can be formed from trace metals that can be ground-water contaminants.

6.4 Oxidation-Reduction Reactions

In some chemical reactions the participating elements change their valence state through the gain or loss of electron(s). If an electron is gained, there is a loss of positive valence called a reduction. A loss of negative valence is called an oxidation. Together, these are referred to as oxidation-reduction, or redox, reactions. In environmental systems they may be controlled by microorganisms that do not participate in the reaction but act as catalysts. The microbes occur as a biofilm on the surfaces of the aquifer materials. They obtain energy by oxidation of organic compounds or hydrogen or reduced inorganic forms of iron, nitrogen, and sulfur. Electron acceptors are necessary for these biologically mediated redox reactions to occur. Under aerobic conditions oxygen is the electron acceptor, whereas under anaerobic conditions nitrate, sulfate, and carbon dioxide are the electron acceptors (McCarty et al. 1984).

An example of a reduction is

$$Fe^{2+} + 2e^- \rightleftharpoons Fe^0 \qquad (6.12)$$

In this example, ferrous iron is reduced to metallic iron by the addition of two electrons. This is a half-reaction, since the electrons must be supplied either by an electrical current or by a simultaneous reaction in which another element is oxidized and releases the requisite number of electrons. The standard electrical potential of a half-reaction is the voltage represented by the flow of electrons when the reaction is at equilibrium. Under standard conditions (25°C and 1 atm pressure) the standard potential is represented by the symbol E^0. The potential is in volts, with a negative value representing reducing conditions and a positive value representing oxidizing conditions (Hem 1985). By convention, the standard potential for the reduction of H^+ to hydrogen gas is 0:

$$2H^+ + 2e^- \rightleftharpoons H_2 \quad \text{(gas)} \qquad (6.13)$$

An example of oxidation occurs where ferrous iron loses an electron to form ferric iron:

$$Fe^{2+} \rightleftharpoons Fe^{3+} + e^- \qquad (6.14)$$

Oxidation-reduction reactions involve elements that can occur in more than one valence state. In Equations 6.12 and 6.14, iron occurred in the metallic (0) as well as the +2 and +3 states Metals can usually occur in the metallic state with a zero valence and at least one other valence state. Some elements that are environmentally important can occur in several different valence states. Table 6.3 lists several elements that occur in different valence states and examples of compounds and ions formed from those elements.

In order for oxidation or reduction to occur in a chemical reaction, one element must be reduced while a second element is being oxidized. For example, the complete equation for the oxidation of ferrous iron to ferric iron is

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TABLE 6.2 Solubility products for selected minerals and compounds.

Compound	Solubility Product	Mineral Name
Chlorides		
CuCl	$10^{-6.7}$	
$PbCl_2$	$10^{-4.8}$	
Hg_2Cl_2	$10^{-17.9}$	
AgCl	$10^{-9.7}$	
Fluorides		
BaF_2	$10^{-5.8}$	
CaF_2	$10^{-10.4}$	Fluorite
MgF_2	$10^{-8.2}$	Sellaite
PbF_2	$10^{-7.5}$	
SrF_2	$10^{-8.5}$	
Sulfates		
$BaSO_4$	$10^{-10.0}$	Barite
$CaSO_4$	$10^{-4.5}$	Anhydrite
$CaSO_4 \cdot 2\,H_2O$	$10^{-4.6}$	Gypsum
$PbSO_4$	$10^{-7.8}$	Anglesite
Ag_2SO_4	$10^{-4.8}$	
$SrSO_4$	$10^{-6.5}$	Celestite
Sulfides		
Cu_2S	$10^{-48.5}$	
CuS	$10^{-36.1}$	
FeS	$10^{-18.1}$	
PbS	$10^{-27.5}$	Galena
HgS	$10^{-53.3}$	Cinnebar
ZnS	$10^{-22.5}$	Wurtzite
ZnS	$10^{-24.7}$	Sphalerite
Carbonates		
$BaCO_3$	$10^{-8.3}$	Witherite
$CdCO_3$	$10^{-13.7}$	
$CaCO_3$	$10^{-8.35}$	Calcite
$CaCO_3$	$10^{-8.22}$	Aragonite
$CoCO_3$	$10^{-10.0}$	
$FeCO_3$	$10^{-10.7}$	Siderite
$PbCO_3$	$10^{-13.1}$	
$MgCO_3$	$10^{-7.5}$	Magnesite
$MnCO_3$	$10^{-9.3}$	Rhodochrosite
Phosphates		
$AlPO_4 \cdot 2\,H_2O$	$10^{-22.1}$	Variscite
$CaHPO_4 \cdot 2\,H_2O$	$10^{-6.6}$	
$Ca_3(PO_4)_2$	$10^{-28.7}$	
$Cu_3(PO_4)_2$	$10^{-36.9}$	
$FePO_4$	$10^{-21.6}$	
$FePO_4 \cdot 2\,H_2O$	$10^{-26.4}$	

Source: K. B. Krauskopf, *Introduction to Geochemistry*, 2d ed. (New York: McGraw-Hill, 1979).

Source: K. B. Krauskopf, 1979. *Introduction to Geochemistry, Second Edition*. New York: McGraw-Hill.

TABLE 6.3 Selected elements that can exist in more than one oxidation state.

Element	Valence State	Examples
Carbon	+4	HCO_3^-, CO_3^{2-}
	0	C
	−4	CH_4
Chromium	+6	CrO_4^{2-}, $Cr_2O_7^{2-}$
	+3	Cr^{3+}, $Cr(OH)_3$
Copper	+1	CuCl
	+2	CuS
Mercury	+1	Hg_2Cl_2
	+2	HgS
Iron	+2	Fe^{2+}, FeS
	+3	Fe^{3+}, $Fe(OH)_3$
Nitrogen	+5	NO_3^-
	+3	NO_2^-
	0	N
	−3	NH_4^+, NH_3
Oxygen	0	O
	−1	H_2O_2
	−2	H_2O, O^{2-}
Sulfur	−2	H_2S, S^{2-}, PbS
	+2	$S_2O_3^{2-}$
	+5	$S_2O_6^{2-}$
	+6	SO_4^{2-}

$$4\,Fe^{2+} + O_2 + 4\,H^+ \rightleftharpoons 2\,H_2O + 4\,Fe^{3+} \qquad (6.15)$$

This complete reaction is composed of two half-reactions:

$$4\,Fe^{2+} \rightleftharpoons 4\,Fe^{3+} + 4\,e^- \qquad (6.16)$$

$$O_2 + 4\,H^+ + 4\,e^- \rightleftharpoons 2\,H_2O \qquad (6.17)$$

An aqueous solution has an oxidation potential indicated by the symbol Eh. This can be calculated from the Nernst equation:

$$Eh = E^0 - \frac{RT}{nF} \ln \frac{[\text{products}]}{[\text{reactants}]} \qquad (6.18)$$

where:

Eh = oxidation potential of the aqueous solution in volts
E° = standard potential of redox reaction in volts
R = gas constant, 0.00199 Kcal/(mole·K)
T = temperature in Kelvins
F = Faraday constant, 23.06 Kcal/V
n = number of electrons in half-reaction
[ ] = activity of products and reactants

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The standard potential for a reaction can be determined from the relationship

$$E^0 = \frac{-\Delta G_R^0}{nF} \tag{6.19}$$

where ΔG_R^0 in volts is the free energy, or Gibbs free energy, of the reaction.

The free energy of a reaction is the sum of the free energies of the products minus the sum of the free energies of the reactants. For the reaction

$$aA + bB \rightleftharpoons cC + dD$$

the free energy can be found from:

$$\Delta G_R^0 = c\Delta G_c^0 + d\Delta G_d^0 - a\Delta G_a^0 - b\Delta G_b^0 \tag{6.20}$$

Values of free energy for many elements, ions, and compounds are found in standard reference works. Table 6.4 contains values for a number of species.

The equilibrium constant for a reaction is related to the free energy of the reaction by

$$\Delta G_R^0 = -RT \ln K_{eq} \tag{6.21}$$

At standard temperature and pressure and with ΔG_R^0 in kilocalories, Equation 6.21 can be rewritten as

$$\log K_{eq} = \frac{-\Delta G_R^0}{1.364} \tag{6.22}$$

The oxidation potential of an aqueous solution can be measured using a redox or ORP electrode. If the value is positive, the solution is oxidizing, and if it is negative, the solution is reducing. Oxidation potential is measured in volts relative to the hydrogen electrode, which is at zero. Commercially available Eh meters are available that can be attached to a groundwater sampling pump. The groundwater sample is pumped under positive pressure into the flowthrough cell where the electrode is located. The water sample is never subjected to a vacuum, which could cause degassing. Moreover, it is not exposed to the atmosphere, where it can come into contact with atmospheric oxygen. This has simplified the accurate and precise measurement of Eh in groundwater. Eh is directly proportional to pE, which is defined as the logarithm of the electron concentration in a solution, and is an analogous measure of the oxidation/reduction potential, ORP.

6.5 Relationship between pH and Eh

6.5.1 pH

Water undergoes a dissociation into two ionic species:

$$H_2O \rightleftharpoons H^+ + OH^- \tag{6.23}$$

The equilibrium constant for this reaction is

$$K_{eq} = \frac{[H^+][OH^-]}{[H_2O]} \tag{6.24}$$

TABLE 6.4 Standard Gibbs free energy of formation for selected species.

Species	ΔG° kcal/mole	Species	ΔG° kcal/mole	Species	ΔG° kcal/mole
Arsenic		**Manganese**		UO_3(c) (uranite)	−246.61[a]
As_2O_5(c)	−187.0[a]	MnO_2(c) (pyrolusite)	−111.18[b]	UO_2^+(aq)	−229.69[a]
As_4O_6(c)	−275.46[a]	Mn_2O_3 (bixbyite)	−210.6[b]	UO_2^{2+} (aq)	−227.68[a]
As_2S_3(c)	−40.3[a]	Mn_3O_4 (hausmannite)	−306.7[b]	$(UO_2)_2(OH)_2^{2+}$(aq)	−560.99[a]
$FeAsO_4$(c)	−185.13[a]	$Mn(OH)_2$ (c) amorphous	−147.0[b]	$((UO_2)_3(OH)_5^+$ (aq)	−945.16[a]
H_3AsO_4(aq)	−183.1[a]	$MnCO_3$(c) (rhodochrosite)	−195.2[b]	$(UO_2)_3(OH)_7^-$	−1037.5[a]
$H_2AsO_4^-$(aq)	−180.04[a]	Mn^{2+}(aq)	−54.5[b]	$UO_2CO_3^0$(c)	−367.07[a]
$HAsO_4^{2-}$ (aq)	170.82[a]	$MnOH^+$ (aq)	−96.8[b]	$UO_2(CO_3)_2^{2-}$(aq)	−503.2[a]
AsO_4^{3-}(aq)	−155.0[a]	**Molybdenum**		$UO_2(CO_3)_3^{4-}$(aq)	−635.69[a]
$HAsO_2$(aq)	−96.25[a]	MoO_3(c)	−159.66[b]	**Miscellaneous species**	
AsO_2^- (aq)	−83.66[a]	MoO_2(c)	−127.40[b]	$ZnFe_2O_4$(c)	−254.2[a]
Chromium		$FeMoO_4$(c)	−233[b]	$CuFeO_2$(c)	−114.7[b]
Cr_2O_3(c)	−252.9[f]	MoO_4^{2-}(aq)	−199.9[b]	$CuFe_2O_4$(c)	−205.26[b]
$HCrO_4^-$	−182.8[f]	**Silver**		$NiFe_2O_4$(c)	−232.6[b]
$Cr_2O_7^{2-}$(aq)	−311.0[f]	Ag_2O(c)	−2.68[b]	H_2O(l)	−56.687[a]
CrO_4^{2-}(aq)	−173.96[f]	AgCl(c)	−26.24[b]	OH^-(aq)	−37.594[a]
Copper		Ag_2S(c)	−9.72[b]	O_2(aq)	−3.9[a]
CuO(c)	−31.0[b]	Ag_2CO_3(c)	−104.4[b]	HSO_4^-(aq)	−180.69[a]
$CuSO_4 \cdot 3Cu(OH)_2$(c) (brochantite)	−434.5[b]	Ag^+(aq)	18.43[b]	SO_4^{2-} (aq)	−177.97[a]
Cu_2O(c)	−34.9[b]	$AgOH$(aq)	−22.0[b]	H_2S(aq)	−6.66[a]
Cu_2S(c)	−20.6[b]	$Ag(OH)_2^-$ (aq)	−62.2[b]	HS^-(aq)	2.88[a]
Cu^{2+}(aq)	15.67[b]	$AgCl$(aq)	−17.4[b]	S^{2-}(aq)	20.5[a]
$CuSO_4$(aq)	−165.45[b]	$AgCl_2^-$(aq)	−51.5[b]	CO_2(g)	−94.254[a]
$HCuO_2^-$(aq)	−61.8[b]	**Vanadium**		CO_2(aq)	−92.26[a]
CuO_2^{2-}(aq)	−43.9[b]	$H_4VO_4^+$	−253.67[b]	H_2CO_3(aq)	−148.94[a]
Cu^+(aq)	11.95[b]	$H_3VO_4^0$	−249.2[b]	HCO_3^- (aq)	−140.26[a]
Iron		$H_2VO_4^-$	−244[b]	CO_3^{2-} (aq)	−126.17[a]
$Fe(OH)_3$(c) ppt	−166.0[b]	HVO_4^{2-}(aq)	−233.0[c]	Cl^-(aq)	−31.37[a]
$Fe(OH)_2$(c) ppt	−116.3[f]	VO_4^{3-}(aq)	−214.9[b]	CH_4(g)	−12.13[a]
$FeCO_3$(c) (siderite)	−159.35[b]	VO^{2+}(aq)	−106.7[c]	CH_4(aq)	−8.22[a]
FeS_2(c) (pyrite)	−39.9[b]	$V(OH)_3^0$(aq)	−212.9[b]	H^+(aq)	0.00
Fe_2O_3 (hematite)	−177.4[b]	VOH^{2+}(aq)	−111.41[b]	Cl(aq)	−31.38[a]
Fe^{3+}(aq)	−1.1[b]	$V(OH)_2^+$	−163.2[b]	PO_4^{3-} (aq)	−243.5[a]
$FeOH^{2+}$(aq)	−54.83[b]	$VOOH^+$	−155.65[b]	HPO_4^{2-} (aq)	−260.34[a]
$Fe(OH)_2^+$(aq)	−106.7[c]	V^{3+}	−57.8[b]	$H_2PO_4^-$ (aq)	−270.14[b]
Fe^{2+}(aq)	−18.85[b]	**Uranium**		$H_3PO_4^0$(c)	−273.10[a]
$FeOH^+$(aq)	−62.58[b]	U^{4+}(aq)	−126.44[a]	Na^+(aq)	−62.59[c]
$Fe(OH)_3^-$(aq)	−147.0[b]	UOH^{3+}(aq)	−182.24[a]	K^+(aq)	−67.51[a]
$Fe(OH)_4^-$(aq)	−198.4[b]	$U(OH)_4^0$(c)	−347.18[a]	NH_4^+(aq)	−18.99[c]
FeO(c)	−60.03[a]			Pb^{2+}(aq)	−5.83[a]
Fe_2S(c) (pyrite)	−38.3[a]			O_2(g)	0.00
FeS(c)	−24.22[a]				

c = solid

aq = aqueous solutions

g = gas

[a] Wageman, D.D., W.H. Evans, V.B. Parker, I. Halow, S.M. Baily, and R.H. Schumm. 1968. *Selected values of chemical thermodynamic properties*, National Bureau of Standards Technical Note 270-3; 264 pp.

[b] Wageman, D.D., W.H. Evans, V.B. Parker, I. Halow, S.M. Baily, and R.H. Schumm. 1969. *Selected values of chemical thermodynamic properties*, National Bureau of Standards Technical Note 270-4; 141 pp.

(Cont'd)

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TABLE 6.4 *Cont'd*

[c] CODATA Task Group on Key Values for Thermodynamics. 1976. Recommended key values for thermodynamics 1975. *Journal of Chemical Thermodynamics* 8:603–5.
[d] CODATA Task Group on Key Values for Themodynamics. 1977. Recommended key values for thermodynamics 1976. *Journal of Chemical Thermodynamics* 9:705-6.
[e] Giridhar J., and Donald Langmuir. 1991. Determination of E° for the UO_2^{2+}/U^{4+} couple from measurement of the equilibrium: $UO_2^{2+} + Cu(s) + 4\,H^+ = U^{4+} + Cu\,2^+ + 2\,H_2O$ at 25°C and some geochemical implications. *Rodiochemica Acta* 54: 13 3-38.
[f] *Handbook of Chemistry and Physics.* Selected Values of Chemical Thermodynamic Properties. Boca Raton, Fla.: CRC Press.
[g] Robie, R. A., B. S. Hemingway, and J. R. Fisher. 1978. *Thermodynamic properties of minerals and related substances* at 298.15 K *and* 1 bar (105 *pascals*) *pressure and higher temperotures.* U. S. Geological Survey Bulletin 1452: 456 pp.
[h] Feitknecht, Walter, and P. W. Schindler. 1963. Solubility constants of metal oxides, metal hydroxides and metal salts in aqueous solution. *Pure and applied Chemistry* 6:130–57.
[i] Baes, C. F., Jr., and R. E. Messmer. 1976. *The Hydrolysis of Cations.* New York: Wiley, 489 pp.
[j] Wageman, D. D., W. H. Evans, V. B. Parker, I. Halow, S. M. Bally, and R. H. Schumm. 1968. *Selected values of chemical thermodynamic properties.* National Bureau of Standards Technical Note 270–5.
[k] Langmuir, Donald. 1977. Uranium solution mineral equilibria at low temperatures. *Geochimico et Cosmochimico Acro* 42:547–69.

The value of this equilibrium constant depends upon the temperature, but at 25°C it is 1×10^{-14}. Water that is neutral has the same number of H^+ and OH^- ions. If there are more H^+ ions, water is acidic, and if there are more OH^- ions, it is basic.

The pH of an aqueous solution is a measure of the number of hydrogen ions or protons present. The definition of pH is the negative logarithm of the hydrogenion activity. It ranges from 0 (most acidic) to 14 (most basic), and at 25°C a pH of 7 means that the solution is neutral. Because $[H_2O]$ is unity, from Equation 6.24 we have the relationship $[H^+][OH^-] = K_w = 10^{-14}$. The pH of a solution is measured with a pH meter and an electrode. It should be measured in the field, preferably in a flowthrough cell so that dissolved gas isn't exchanged with the atmosphere prior to the measurement. The pH of a solution is especially sensitive to the amount of dissolved CO_2.

6.5.2 Relationship of Eh and pH

We thus have two ways to characterize a solution. The pH describes the number of protons present and the Eh is related to the number of electrons. Eh and pH can be related through the Nernst equation for a reaction that contains water and H^+ ions. Such a reaction can be written (Robertson 1975)

$$bB + mH^+ + ne^- \rightleftharpoons aA + wH_2O \qquad (6.25)$$

where

A = reactant
B = product
n = number of electrons released
a = moles of reactant
w = moles of water
b = moles of product
m = moles of hydrogen ions

The Nernst equation for Reaction 6.25 is

$$\mathrm{Eh} = E^{\circ} - \frac{RT}{nF}\ln\frac{[\mathrm{A}]^{a}[\mathrm{H_2O}]^{w}}{[\mathrm{B}]^{b}[\mathrm{H}^{+}]^{m}} \tag{6.26}$$

The activity of water is unity. For a particular reaction, E° is given and R, T, and F are constants. The significant variables are the Eh and the activities of the reactant, the product, and the hydrogen-ion activity, which can be expressed as a pH. Equation 6.26 can be rearranged and expressed in base 10 logs as either

$$\mathrm{Eh} = E^{\circ} - 2.303\frac{RT}{nF}\log\frac{[\mathrm{A}]^{a}}{[\mathrm{B}]^{b}[\mathrm{H}^{+}]^{m}} \tag{6.27}$$

or

$$\mathrm{Eh} = E^{\circ} - 2.303\frac{RT}{nF}\log\frac{[\mathrm{A}]^{a}}{[\mathrm{B}]^{b}} + 2.303\frac{RTm}{nF}\log[\mathrm{H}^{+}] \tag{6.28}$$

At 25°C and 1 atm of pressure, Equation 6.28 can be expressed as

$$\mathrm{Eh} = E^{\circ} - \frac{0.0592}{n}\log\frac{[\mathrm{A}]^{a}}{[\mathrm{B}]^{b}} - 0.0592\frac{m}{n}\mathrm{pH} \tag{6.29}$$

6.5.3 Eh-pH Diagrams

The Eh-pH relationship is particularly useful when applied in the form of an Eh-pH diagram, with Eh the ordinate and pH the abscissa. If a solution has several ions present that can react to form different products or occur in different valence states, the stable product or valence state at a given concentration of reactants will be a function of the pH and Eh of the solution.

Figure 6.2 is a basic Eh-pH diagram. The range of pH is 0 to 14. For Eh, it is convenient to specify a range of about +1.4 to −1.0 V. In certain regions of the Eh-pH field, water will be oxidized to O_2, and in other regions water will be reduced to H_2. We will calculate these regions as an example problem.

EXAMPLE PROBLEM

Calculate the stability field for water at standard conditions.

The oxidation of water is given by

$$O_2(g) + 4H^{+} + 4e^{-} \rightleftharpoons 2H_2O(l)$$

From Table 6.4,

$$\Delta G^{0}_{H_2O(l)} = -56.69 \text{ kcal}$$

$$\Delta G^{0}_{O_2(g)} = 0$$

$$\Delta G^{0}_{H^{+}} = 0$$

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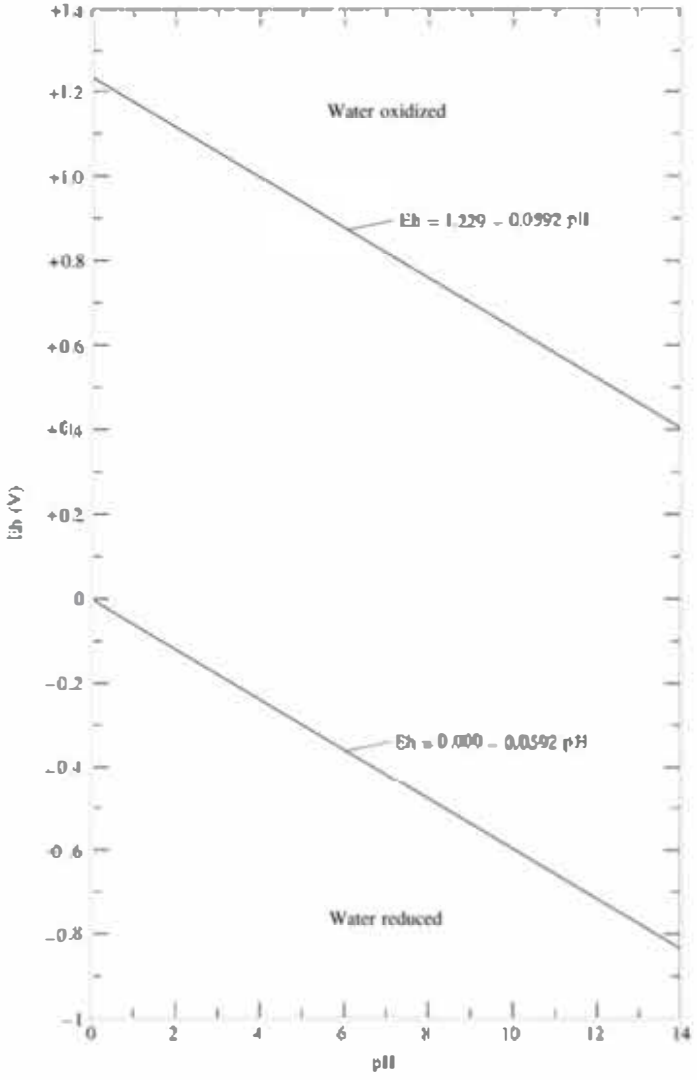
FIGURE 6.2 Eh-pH diagram showing the stability field for water.



From Equation 6.20,

$$\Delta G_R^0 = 2\Delta G^0_{H_2O(l)} - \Delta G^0_{O_2(g)} - 4\Delta G^0_{H^+}$$

$$\Delta G_R^0 = 2(-56.69) - 0 - 4(0) = -113.38\ kcal$$

The value of ΔG_R^0 in kilocalories is converted to a standard potential by use of Equation 6.19:

$$E^0 = \frac{-\Delta G_R^0}{nF} = \frac{-(-113.38)}{4 \cdot 23.06} = 1.229\ V$$

The Nernst equation (Equation 6.24) can be expressed as:

$$Eh = E^0 - \frac{RT}{nF} 2.303 \log \frac{[H_2O]}{[O_2][H^+]^4}$$

R000338

The activity of dissolved gaseous oxygen is expressed as a partial pressure, P_{o2}. At standard conditions it has a value of 1atm. The activity of water is unity. The Nernst equation thus reduces to

$$Eh = 1.229 - \frac{0.00199 \cdot 298}{4 \cdot 23.06} 2.303 \log \left[H^+\right]^{-4}$$

This expression can be reduced to

$$Eh_{(Volts)} = 1.229 - 0.0592pH$$

This equation defines the upper boundary of stability for water, above which oxidation would break apart the water molecule.

The reduction of hydrogen ions to form gaseous hydrogen is

$$2H^+ + 2e^- \rightleftharpoons H_{2(gas)}$$

From Table 6.4,

$$\Delta G^0_{H^+} = 0$$

$$\Delta G^0_{H_2(gas)} = 0$$

The value of ΔG^0_R for the formation of hydrogen gas is obviously zero. Therefore, the value of E^0 is also zero.

From the Nernst equation,

$$Eh = E^0 - \frac{0.00199 \cdot 298}{2 \cdot 23.06} 2.303 \log \frac{P_{H_2}}{\left[H^+\right]^2}$$

The value of P_{H2} is 1 atm and the calculated value of E^0 is 0, hence the preceding expression can be reduced to

$$Eh_{(Volts)} = 0.000 - 0.0592pH$$

This equation forms the lower boundary of the stability field for water. These boundaries are plotted in Figure 6.2.

6.5.4 Calculating Eh-pH Stability Fields

The stability fields within the Eh-pH diagram for various forms of an element can be computed using chemical thermodynamics. Basic sources of thermodynamic data include Bagman et al. (1968; 1969; 1971) and Robie et al. (1978).

Boundaries for an element between dissolved species that have different valence states are computed using the Nernst equation (Equation 6.27, 6.28, or 6.29). If both ions are at the same valence state, then the equation for chemical equilibrium is used. If one is calculating the boundary between a solid species and a dissolved form, the chemical activity of the solid species is 1. For some of the boundaries of solid species, it will be necessary to assume an activity for the dissolved species.

R000339

EXAMPLE PROBLEM

Calculate an Eh-pH diagram for iron in which the solid species are $Fe(OH)_3$ and FeO and the activity of dissolved iron is 56 μg/L(10^{-6} M).

Soluble forms of the ferrous ion and the ferric ion include Fe^{2+}, Fe^{3+}, $FeOH^{2+}$, and $Fe(OH)_2^+$. Transformations between these ions are determined by redox equations:

$$FeOH^{2+} + H^+ + e^- \rightleftharpoons Fe^{2+} + H_2O \quad (6.30)$$

$$Fe(OH)_2^+ + H^+ + e^- \rightleftharpoons Fe^{2+} + 2H_2O \quad (6.31)$$

$$Fe^{3+} + e^- \rightleftharpoons Fe^{2+} \quad (6.32)$$

The free energy and the standard potential for these reactions can be determined from Equations 6.20 and 6.19, respectively.

From Table 6.4 free energies are as follows.

$FeOH^{2+} = -54.83$ kcal/mol

$Fe(OH)_2^+ = -106.7$ kcal/mol

$Fe^{2+} = -18.85$ kcal/mol

$Fe^{3+} = -1.1$ kcal/mol

$H_2O = -56.69$ kcal/mol

$FeO = -60.03$ kcal/mol

$Fe(OH)_3 = -166$ kcal/mol

$Fe(OH)_4^- = -198.4$ kcal/mol

$H^+ = 0$

For Reaction 6.30 ($FeOH^{2+} + H^+ + e^- \rightleftharpoons Fe^{2+} + H_2O$):

$$\Delta G_R^0 = \left[\Delta G_{H_2O}^0 + \Delta G_{Fe^{2+}}^0\right] - \left[\Delta G_{FeOH^{2+}} + \Delta G_{H^+}^0\right]$$

$$\Delta G_R^0 = -56.69 + (-18.85) - (-54.83) - 0$$

$$\Delta G_R^0 = -20.71 \text{ kcal/mol}$$

$$E^0 = \frac{-\Delta G^0_R}{nF} = \frac{-(-20.71)}{1 \cdot 23.06} V$$

$$E^0 = +0.898 V$$

For Reaction 6.31 ($Fe(OH)_2^+ + 2H^+ + e^- \rightleftharpoons Fe^{2+} + 2H_2O$):

$$\Delta G_R^0 = 2\Delta G_{H_2O}^0 + \Delta G_{Fe^{2+}}^0 - \Delta G_{Fe(OH)_2^+}^0 - 2\Delta G_{H^+}^0$$

$$\Delta G_R^0 = 2(-56.69) + (-18.85) - (-106.7) - 2(0)$$

$$\Delta G_R^0 = -25.53 \text{ kcal/mol}$$

$$E^0 \frac{-\Delta G_R^0}{nF} = \frac{-(-25.53)}{1 \cdot 23.06} V$$

$$E^0 = +1.107 V$$

For Reaction 6.32 ($Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$):

$$\Delta G_R^0 = \Delta G_{Fe^{2+}}^0 - \Delta G_{Fe^{3+}}^0$$

$$\Delta G_R^0 = -18.85 - (-1.1)$$

$$\Delta G_R^0 = -17.75$$

$$E^0 = \frac{-\Delta G_R^0}{nF} = \frac{-(-17.75)}{1 \cdot 23.06} V$$

$$E^0 = +0.770V$$

The boundaries between the stability fields are determined from the Nernst equation. At the boundary between two fields, the activities of the iron species on the left of the reaction is equal to the activity of the iron species on the right of the equation—i.e., the two species are at equilibrium.

For Reaction 6.30 ($FeOH^{2+} + H^+ + e^- \rightleftharpoons Fe^{2+} + H_2O$):

$$Eh = E^0 - \frac{0.0592}{n} \log \frac{[Fe^{2+}]}{[FeOH^{2+}]} - 0.0592 \frac{m}{n} pH$$

Since $[FeOH^{2+}] = [Fe^{2+}]$, m (the number of hydrogen ions) = 1, n(the number of electrons)= 1, $E^0 = +0.898$ V, and log 1 = 0:

$$Eh_{(volts)} = 0.898 - 0.0592\ pH \qquad \textbf{(6.33)}$$

For Reaction 6.31 ($Fe(OH)_2^+ + 2H^+ + e^- \rightleftharpoons Fe^{2+} + 2H_2O$):

$$Eh = E^0 - \frac{0.0592}{n} \log \frac{[Fe^{2+}]}{[Fe(OH)_2^+]} - 0.0592 \frac{m}{n} pH$$

Since $[Fe(OH)_2^+] = [Fe^{2+}]$, $m = 2$, $n = 1$, and $E^0 = +1.107$ V:

$$Eh_{(volts)} = 1.107 - 0.1184\ pH \qquad \textbf{(6.34)}$$

For Reaction 6.32 ($Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$):

$$Eh = E^0 - \frac{0.0592}{n} \log \frac{[Fe^{2+}]}{[Fe^{3+}]} - 0.0592 \frac{m}{n} pH$$

This reaction is independent of pH because neither $[H^+]$ nor $[OH^-]$ appears in the reaction. Hence the value of m is 0. Because as $[Fe^{3+}] = [Fe^{2+}]$ and log 1 = 0, Eh is a constant equal to E^0, which is 0.770 V:

$$Eh = 0.770\ V \qquad \textbf{(6.35)}$$

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The boundary between two dissolved species that are at the same valence state can be determined from chemical equilibrium.

For iron there are two boundaries between dissolved ions of ferric iron. These boundaries are represented by these reactions:

$$Fe^{3+} + H_2O \rightleftharpoons FeOH^{2+} + H^+ \quad \textbf{(6.36)}$$

$$FeOH^{2+} + H_2O \rightleftharpoons Fe(OH)_2^{+} + H^+ \quad \textbf{(6.37)}$$

For Reaction 6.36 $\left(Fe^{3+} + H_2O \rightleftharpoons FeOH^{2+} + H^+\right)$, the equilibrium constant can be obtained from the free energy of the reaction. The first step is to find the free energy of the reaction using Equation 6.20.

$$\Delta G_R^0 = \Delta G^0_{FeOH^{2+}} + \Delta G^0_{H+} - \Delta G^0_{Fe^{3+}} - \Delta G^0_{H_2O}$$

$$\Delta G_R^0 = -54.83 + 0 - (-1.1) - (-56.69)$$

$$\Delta G_R^0 = +2.96 \text{ kcal/mol}$$

The next step is to determine the equilibrium constant using Equation 6.22.

$$\log k_{eq} = -\frac{\Delta G_R^0}{1.364} = -\frac{2.96}{1.364} = -2.17$$

$$K_{eq} = 10^{-2.17}$$

From Equation 6.6,

$$K_{eq} = \frac{\left[FeOH^{2+}\right]\left[H^+\right]}{\left[Fe^{3+}\right]\left[H_2O\right]} = 10^{-2.17}$$

Since $[H_2O] = 1$ and at the boundary $[FeOH^{2+}] = [Fe^{3+}]$,

$$[H^+] = 10^{-2.17} \quad \textbf{(6.38)}$$

This means that a vertical line at a pH of 2.17 separates these two stability fields.

For Reaction 6.37 $\left(FeOH^{2+} + H_2O \rightleftharpoons Fe(OH)_2^{+} + H^+\right)$, find the free energy of the reaction:

$$\Delta G_R^0 = \Delta G^0_{Fe(OH)_2^+} + \Delta G^0_{H+} - \Delta G^0_{FeOH^{2+}} - \Delta G^0_{H_2O}$$

$$\Delta G_R^0 = -106.7 + 0 - (-54.83) - (-56.69)$$

$$\Delta G_R^0 = +4.82 \text{ kcal/mol}$$

Next find the value of K_{eq}:

$$\log K_{eq} = \frac{-\Delta G_R^0}{1.364} = \frac{-4.82}{1.364} = -3.53$$

$$K_{eq} = 10^{-3.53}$$

Finally, from Equation 6.6,

$$K_{eq} = \frac{\left[Fe(OH)^{2+}\right]\left[H^+\right]}{\left[FeOH^{2+}\right]\left[H_2O\right]} = 10^{-3.53}$$

Since $[H_2O]$ = land $[Fe(OH)^{2+}] = [FeOH^{2+}]$,

$$[H^-] = 10^{-3.53} \tag{6.39}$$

Lines that delineate the stability field for solids can be obtained by similar reasoning. Remember that the activity of a solid in equilibrium with dissolved species is 1. The location of the boundaries of solid species is a function of the amount of dissolved iron present.

In this situation there are two stable iron precipitates, Fe(OH)3 and FeO. The reactions at the boundaries include

$$Fe(OH)_3 + H^+ \rightleftharpoons Fe(OH)_2^+ + H_2O \tag{6.40}$$

$$Fe(OH)_3 + 3H^+ + e^- \rightleftharpoons Fe^{2+} + 3H_2O \tag{6.41}$$

$$Fe(OH)_4^- + H^+ \rightleftharpoons Fe(OH)_3 + H_2O \tag{6.42}$$

$$Fe(OH)_3 + e^- \rightleftharpoons FeO + H_2O + OH^- \tag{6.43}$$

$$Fe(OH)_4^- + 2H^+ + e^- \rightleftharpoons FeO + 3H_2O \tag{6.44}$$

$$FeO + 2H^+ \rightleftharpoons Fe^{2+} + H_2O \tag{6.45}$$

Reaction 6.40 $Fe(OH)_3 + H^+ \rightleftharpoons Fe(OH)_2^+ + H_2O$ is solved using an equilibrium approach:

$$\Delta G_R^0 = \Delta G^0_{Fe(OH)_2^+} + \Delta G^0_{H_2O} - \Delta G^0_{Fe(OH)_3} - \Delta G^0_{H^+}$$

$$\Delta G_R^0 = -106.7 + (-56.69) - (-166) - 0 = 2.61$$

$$\log K_{eq} = -\frac{\Delta G_R^0}{1.364} = -\frac{2.61}{1.364} = -1.91$$

$$K_{eq} = 10^{-1.91}$$

$$K_{eq} = \frac{\left[Fe(OH)_2^+\right]\left[H_2O\right]}{\left[Fe(OH)_3\right]\left[H^+\right]} = 10^{-1.91}$$

R000343

Since [Fe(OH)3] = land [H2O] = I,

$$\left[H^+\right] = \frac{\left[Fe(OH)_2{}^+\right]}{10^{-1.91}}$$

Reaction 6.41 $Fe(OH)_3 + 3H^+ + e^- \rightleftharpoons Fe^{2+} + 3H_2O$ is solved using the Nernst equation:

$$\Delta G_R^0 = \Delta G_{Fe^{2+}}^0 + 3\Delta G_{H_2O}^0 - \Delta G_{Fe(OH)_3}^0 - 3\Delta G_{H^+}^0$$

$$\Delta G_R^0 = -18.85 + 3(-56.69) - (-166) - 0$$

$$\Delta G_R^0 = -22.95 \text{ kcal/mol}$$

$$E^0 = \frac{-\Delta G_R^0}{nF} = \frac{(-22.95)}{1 \cdot 23.06} = 0.994\text{V}$$

$$Eh = E^0 - \frac{0.0592}{n}\log\frac{\left[Fe^{2+}\right]}{\left[Fe(OH)_3\right]} - 0.0592\frac{m}{n}\text{pH}$$

Since there are three hydrogen ions ($m = 3$) and one electron ($n = 1$) and $[Fe(OH)_3] = I$, then

$$Eh_{(\text{volts})} = 0.994 - 0.0592\ \log\left[Fe^{2+}\right] - 0.178\text{pH} \qquad \textbf{(6.47)}$$

Reaction 6.42 $\left(Fe(OH)_4{}^- + H^+ \rightleftharpoons Fe(OH)_3 + H_2O\right)$ is solved by using an equilibrium approach:

$$\Delta G^0{}_R = \Delta G^0{}_{Fe(OH)_3} + \Delta G^0{}_{H_2O} - \Delta G^0{}_{Fe(OH)_4^-} - \Delta G^0{}_{H^+}$$

$$\Delta G^0{}_R = -166 - 56.69 - (-198.4) - 0$$

$$\Delta G^0{}_R = -24.29$$

$$\log K_{eq} = -\frac{\Delta G^0{}_R}{1.364} = \frac{24.29}{1.364} = 17.8$$

$$K_{eq} = 10^{17.8}$$

$$K_{eq} = \frac{\left[Fe(OH)_3\right]\left[H_2O\right]}{\left[Fe(OH)_4{}^-\right]\left[H^+\right]} = 10^{17.8}$$

Since $[Fe(OH)_3] = 1$ and $[H_2O] = 1$,

$$\left[H^+\right] = \frac{10^{-17.8}}{\left[Fe(OH)_4{}^-\right]} \qquad \textbf{(6.48)}$$

Equation 6.43 $\left(Fe(OH)_3 + e^- \rightleftharpoons FeO + H_2O + OH^-\right)$ is solved using the Nernst equation:

$$\Delta G^0{}_R = \Delta G^0{}_{FeO} + \Delta G^0{}_{H_2O} + \Delta G^0{}_{OH^-} - \Delta G^0{}_{Fe(OH)_3}$$

$$\Delta G^0{}_R = -60.03 + (-56.69) + (-37.59) - (-166)$$

$$\Delta G^0{}_R = +11.69$$

$$E^0 = \frac{-\Delta G^0{}_R}{nF} = \frac{-11.69}{1 \cdot 23.06} = -0.507\ \text{V}$$

$$Eh = E^0 - \frac{0.0592}{n} \log \frac{[FeO][H_2O][OH^-]}{[Fe(OH)_3]}$$

Since $[Fe(OH)_3] = 1$, $[FeO] = 1$, $[H_2O] = 1$, and $n = 1$,

$$Eh = -0.507 - 0.0592 \log[OH^-]$$

Because the diagram uses pH as a variable, $[OH^-]$ must be expressed in terms of pH. By definition, $[OH^-] = 10^{-14}/[H^+]$; therefore, $\log [OH^-] = \log 10^{-14} - \log [H^+]$, so that

$$Eh = -0.5.7 - 0.0592(pH - 14)$$

$$Eh_{(volts)} = 0.322 - 0.0592\ pH \qquad (6.49)$$

Reaction 6.44 $\left(Fe(OH)_4^- + 2H^+ + e^- \rightleftharpoons FeO + 3H_2O\right)$ is solved using the Nernst equation:

$$\Delta G^0{}_R = \Delta G^0{}_{FeO} + 3\Delta G^0{}_{H_2O} - \Delta G^0{}_{Fe(OH)_4^-} - 2\Delta G^0{}_{H^+}$$

$$\Delta G^0{}_R = -60.03 + 3(-56.69) - (-198.4) - 0$$

$$\Delta G^0{}_R = -31.7\ \text{kcal/mol}$$

$$E^0 = \frac{-\Delta G^0{}_R}{nF} = \frac{-(-31.7)}{1 \cdot 23.06} = +1.375$$

$$Eh = E^0 - \frac{0.0592}{n} \log \frac{[FeO][H_2O]^3}{[Fe(OH)_4^-][H^+]^2}$$

Since $[FeO]$ and $[H_2O]$ are 1 and $n = 1$,

$$Eh = +1.375 - 0.0592 \log \frac{1}{[Fe(OH)_4^-][H^+]^2}$$

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This can be expressed in terms of pH as

$$Eh = 1.375 + 0.0592 \log\left[Fe(OH)_4^-\right] + 2(0.0592) \log\left[H^+\right]$$

$$Eh_{(volts)} = 1.375 + 0.0592 \log\left[Fe(OH)_4^-\right] - 0.118pH \qquad (6.50)$$

Reaction 6.45 ($FeO + 2H^+ \rightleftharpoons Fe^{2+} + H_2O$) is solved as an equilibrium reaction:

$$\Delta G^0_R = \Delta G^0_{Fe^{2+}} + \Delta G^0_{H_2O} - \Delta G^0_{FeO} - 2\Delta G^0_{H^+}$$

$$\Delta G^0_R = -18.85 + (-56.69) - (-60.03) - 2(0)$$

$$\Delta G^0_R = -15.51 \text{ kcal/mol}$$

$$\log k_{eq} = \frac{-\Delta G^0_R}{1.364} = 11.36$$

$$k_{eq} = 10^{11.36}$$

$$k_{eq} = \frac{[Fe^{2+}][H_2O]}{[FeO][H^+]^2}$$

Since $[H_2O]$ and $[FeO] = 1$,

$$[H^+]^2 = \frac{[Fe^{2+}]}{10^{11.36}}$$

$$[H^+] = \sqrt{\frac{[Fe^{2+}]}{10^{11.36}}} \qquad (6.51)$$

Several of the equations, including Equations 6.46, 6.47, 6.48, 6.50, and 6.51, depend upon the activity of the dissolved iron.

The following equations, which are independent of dissolved iron activity, have been derived.

Boundary	Equation Number	Equation
$FeOH^{2+} - Fe^{2+}$	6.31	$Eh_{(volts)} = 0.898 - 0.0592pH$
$Fe(OH)_2^+ - Fe^{2+}$	6.32	$Eh_{(volts)} = 1.107 - 0.118pH$
$Fe^{3+} - Fe^{2+}$	6.33	$Eh_{(volts)} = 0.770$
$Fe^{3+} - FeOH^{2+}$	6.38	$pH = 2.17$
$Fe(OH)^{2+} - Fe(OH)_2^+$	6.39	$pH = 3.53$
$Fe(OH)_3 - FeO$	6.49	$Eh_{(volts)} = 0.322 - 0.0592pH$

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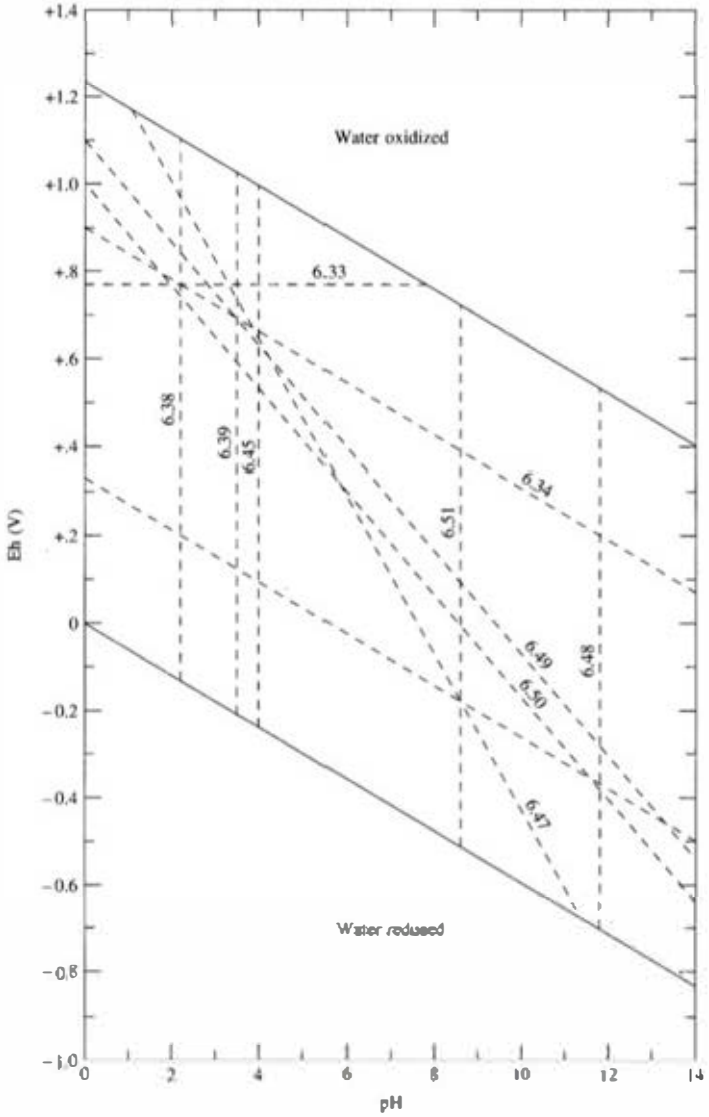
FIGURE 6.3 Equations for an Eh-pH diagram for dissolved iron with dissolved iron activity of 10^{-6} Mol under standard conditions. (Numbers adjacent to dotted lines refer to equations discussed in the text)



The iron Eh-pH diagram of Figure 6.4 is for a system that contains only dissolved iron. If other elements are present, such as sulfur, then additional iron compounds are possible. Figure 6.5 shows an Eh-pH diagram for a system with an iron activity of 56 µg/L (10^{-6} mol), sulfur of 96 mg/L as SO_4^{2-}, and carbon dioxide of 61 mg/L as HCO_3^-. Solids in the shaded area are thermodynamically stable. Under the conditions specified in this diagram, iron carbonate ($FeCO_3$) saturation was not reached and none is recorded as a solid phase.

The area of the region in which iron is precipitated rather than dissolved is a function of the concentration of dissolved iron. The more dissolved iron that is present, the greater the size of the stability field for the precipitates. This is illustrated in Figure 6.6. In this diagram the sulfur is 96 mg/L as SO_4^{2-} and the carbonate is 61 mg/L as HCO_3^-. Dissolved iron ranges from 5.6 µg/L to 56 mg/L.

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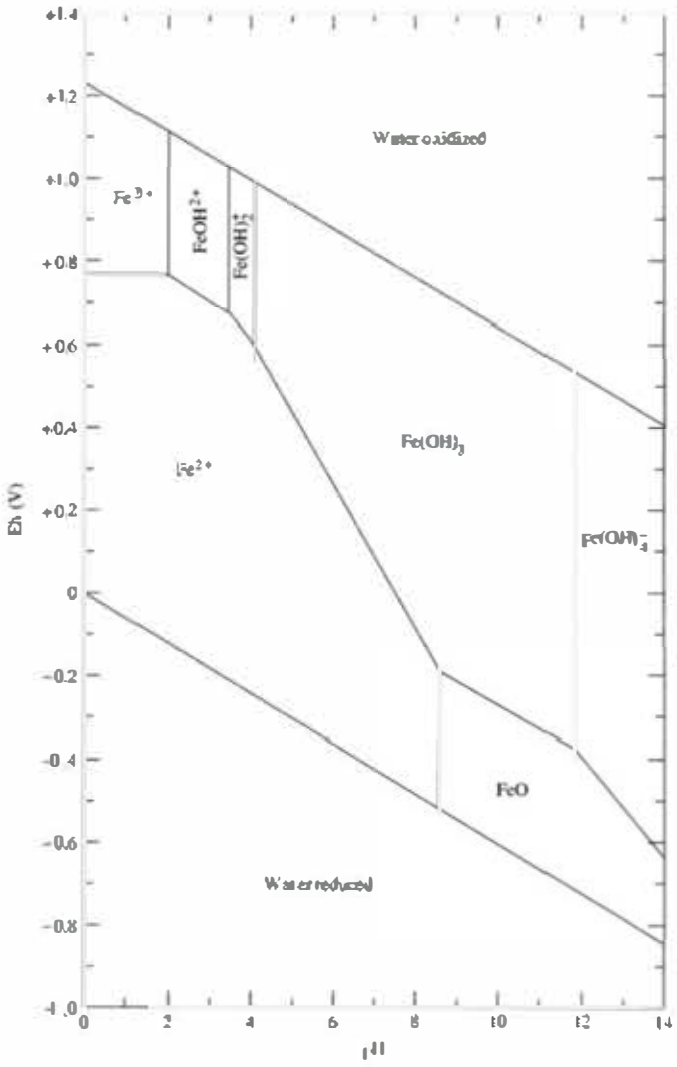
FIGURE 6.4 Final Eh-pH diagram for a dissolved iron system with dissolved iron at 10^{-6} moles under standard conditions.



Eh-pH diagrams have been used in the ground-water literature to explain such phenomena as the solubility of ferric oxyhydroxides (Whittemore and Langmuir 1975), hexavalent chromium (Robertson 1975), manganese (Hem 1985), iron, copper, silver, chromium, manganese, vanadium, molybdenum, and arsenic (Hem 1977), uranium (Langmuir 1978), thorium (Langmuir and Herman 1980), and arsenic (Matisoff et al. 1982).

6.6 Metal Complexes and Facilitated Particle Transport

6.6.1 Hydration of Cations

Although we consider that metallic ions exist in solution as an isolated ion, such as Cu^{2+}, in fact that is not the case. The Cu^{2+} ion is surrounded by polar water atoms that are chemically bound to the ion. Metallic ions, in general, have six water molecules

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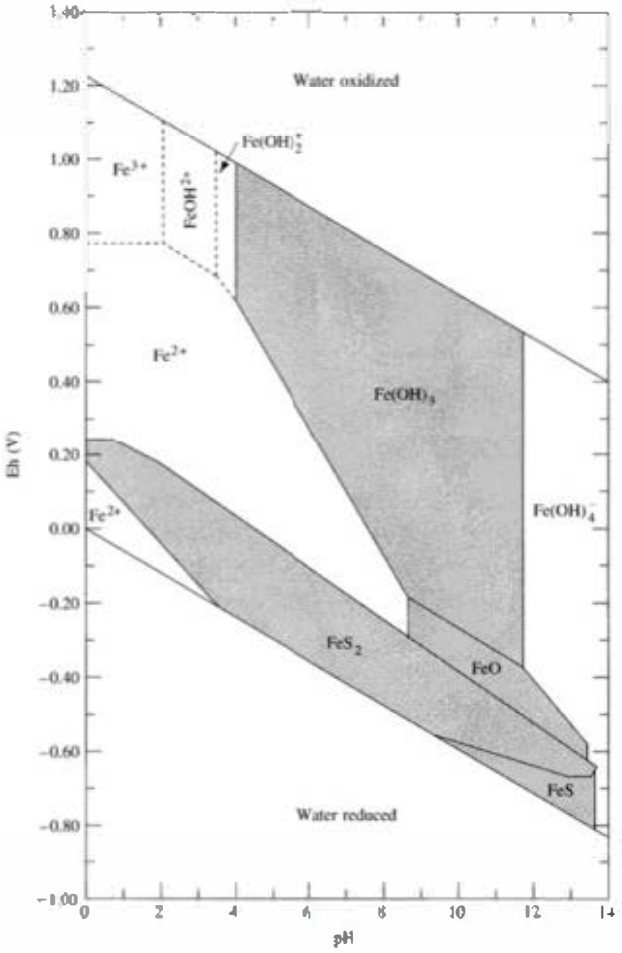
FIGURE 6.5 Eh-pH diagram showing fields of stability for dissolved iron under standard conditions. Activity of dissolved iron is 10^{-6} mol (56 µg/L), of sulfur species is 96 mg/L as SO_4^{2-}, and of carbon dioxide species is 61 mg/L as HCO_3^-.



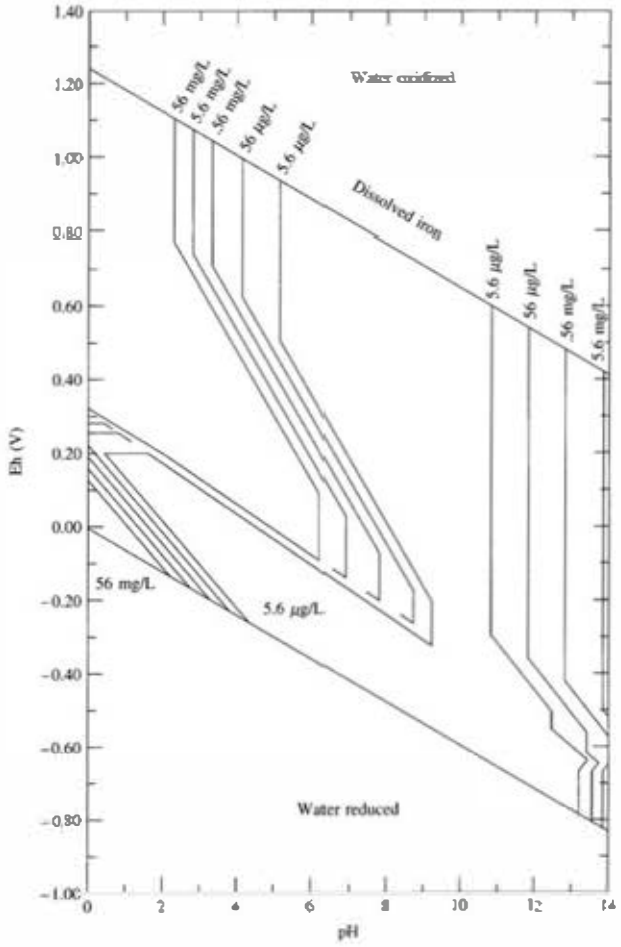
Source: J. D. Hem. 1985. *Study and interpretation of the chemical characteristics of natural waters*. Water Supply Paper 2254, U.S. Geological Survey.

surrounding them. The hydrated cupric ion is $Cu(H_2O)_6^{2+}$. Even outside the shell of chemically bound water molecules, there is a region where the polar water molecules are ordered by the electrostatic charge of the metallic ion. Anions in close association with a metal cation are called ligands; together they form a coordination compound. Water is considered to be a ligand that is bound to the metal ion. If other ligands bind to the metal, they must replace some of the water molecules acting as ligands. The stability of a complex relative to cation or ligand exchange can be described by equilibrium constants for the reaction.

6.6.2 Complexation

The following inorganic anions act as simple ligands in natural waters: OH^-, CO_3^{2-}, SO_4^{2-}, Cl^-, Br^-, F^-, NO_3^-, SiO_3^{2-}, S^{2-}, $S_2O_3^-$, PO_4^{3-}, $P_2O_7^{4-}$, $P_3O_{10}^{5-}$, and CN^-. Ammonia (NH_3) is a polar molecule that can also act as a ligand. Ligands can bond either covalently or electrostatically with a metal to form a complex ion or compound. We have already

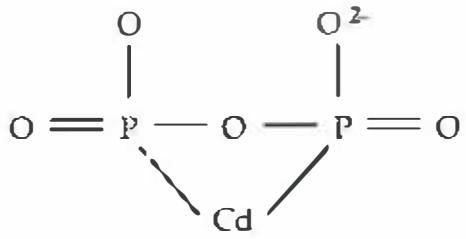
FIGURE 6.6 Equilibrium activity of dissolved iron as a function of Eh and pH under standard conditions, sulfur activity of 96 mg/L as SO_4^{2-} and activity of carbon dioxide of 61 mg/L as HCO_3^-.



Source: J. D. Hem. 1985. *Study and interpretation of the chemical characteristics of natural waters.* Water Supply Paper 2254, U.S. Geological Survey.

looked at the complex forms of the ferric ion and the hydroxyl ion. They form a series of complex ions: $FeOH^{2+}$, $Fe(OH)_2^+$, $Fe(OH)_3$ and $Fe(OH)_4^-$. Complex formation is involved with chemical equilibrium of ionic compounds and oxidation-reduction reactions.

In the case of monovalent ions, there is only one site where the ligand bonds to the metal ion and the ligand is called monodentate (literally, "one tooth"). If the ligand has more than one site that can bond (polydentate), then it forms what is known as a chelating agent. For example, the pyrophosphate ion, $P_2O_7^{4-}$, can bond to a metal ion, such as cadmium, at two locations:



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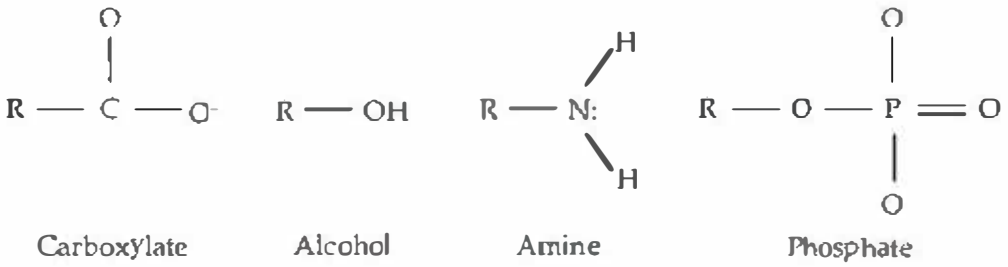
6.6.3 Organic Complexing Agents

Both natural waters and wastewaters contain a number of organic compounds that can act as chelating agents. In general, these organic compounds have a functional group that contains oxygen, nitrogen, phosphorous, or sulfur. If R symbolizes one or more carbon atoms with the appropriate number of hydrogens, then organic complexes can include functional groups such as



There are a number of organic complexing agents that occur in nature. They are associated with humic substances that form from the decomposition of vegetation. These are complex organic molecules with molecular weights ranging upward into the tens of thousands. If a humic substance is extracted with a strong base and then acidified, there are three products. The nonextractable organic material is called humin. Substances called fulvic acids remain in the acidic solution, and other substances called humic acids precipitate from the acidified extract. These represent classes of compounds that contain many different individual organic molecules. Humic and fulvic acids contain many functional groups that can chelate to metals. Metals may be kept in solution by chelation with soluble fulvic acids or they may bind to the insoluble humic substances by cation exchange (Manahan 1984).

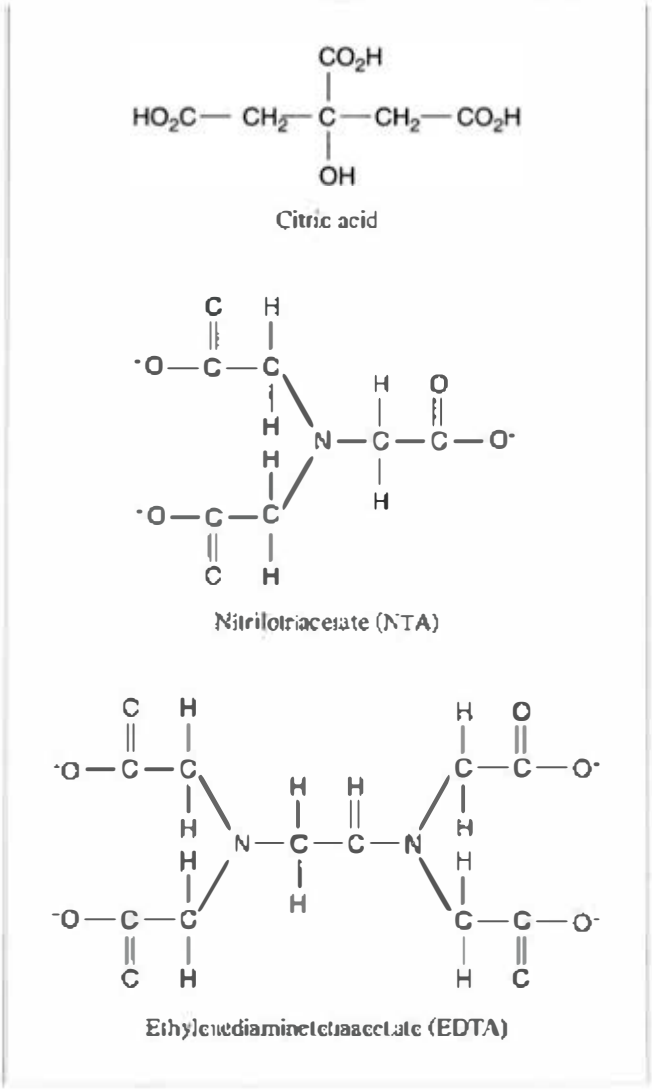
Synthetic organic complexing agents are used in a number of industrial processes. They can be used as cleaning compounds, as constituents of detergent, in metal plating baths, and in water conditioning. These compounds include sodium tripolyphosphate, sodium ethylenediaminetetraacetate (EDTA), citric acid, and sodium nitrilotriacetate (NTA). The structures of some of these compounds are given in Figure 6.7. Synthetic chelating agents may keep metals in solution under conditions where the unchelated metal would precipitate or undergo cation exchange.

EDTA in wastewater can vastly increase the mobility of associated metals in the subsurface. Monitoring wells near radioactive waste disposal trenches at the Oak Ridge (Tennessee) National Laboratory contained significant levels of sodium EDTA, which was used as a cleaning agent. The same wells also contained radioactive ^{60}Co, a metal that is normally not expected to migrate very far due to cation exchange. The ^{60}Co had been chelated by the EDTA and hence had greatly increased mobility in the subsurface (Means et al. 1978).

6.6.4 Facilitated Particle Transport

Many metals and other inorganic compounds have a great sorptive capacity and an affinity for particles suspended in water. Normally in subsurface environments this limits contaminant mobility in that most mobile particles and colloids are filtered out of flowing groundwater in porous media. However, particles suspended in groundwater

FIGURE 6.7 Structure of chelating agents including (a) citric acid, (b) nitrilotriacetate (NTA), and (c) ethylenediaminetetraacetate (EDTA).



can be mobilized in flow through fractured rock or karst rocks where groundwater moves through larger conduits and suspended particles are not filtered by the geologic medium. Contaminants sorbing on these particles, including many metals, essentially can "hitch a ride" on moving grains and colloids and this can increase the effective speed of contaminant movement through aquifers by orders of magnitude. This enhanced mobility is called **facilitated particle transport**.

Facilitated particle transport can pose problems in modeling contaminant movement and dispersion because of accelerated movement, and also impact the representativeness of groundwater sampling protocols. Many standard techniques for measuring metal concentrations in groundwater require samples to be filtered and acidified in the field. In conditions where groundwater contains contaminants sorbed on suspended particles and colloids, some practitioners collect both filtered and unfiltered samples for comparative chemical analysis.

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6.7 Chemistry of Nonmetallic Inorganic Contaminants

6.7.1 Fluoride

Fluoride occurs in water as the F^- ion. In natural waters the amount of fluoride present is generally less than 1.0 mg/L, although concentrations as great as 67 mg/L have been reported (Hem 1985). Fluoride is present in minerals such as fluorite (CaF_2) and apatite ($Ca_5(Cl,F,OH)(PO_4)_3$). Weathering of these minerals may release fluoride. It may be released as a contaminant from industrial processes utilizing hydrofluoric acid. Cryolite (Na_3AlF_6) is used as a flux in the electrolytic production of aluminum. The manufacture of phosphate fertilizer from phosphate-rich rock may also release fluoride. Effluent from a Florida fertilizer plant had fluoride ranging from 2810 to 5150 mg/L (Cross and Ross 1970).

Fluoride can form complexes in water with a number of cations, including aluminum, beryllium, and ferric iron (Hem 1985). Dissolved fluoride can react with calcium to form fluorite. The solubility product for fluorite is $10^{-10.4}$. Precipitation of fluorite can act as a control on the amount of dissolved fluoride in solution if dissolved calcium is present. Table 6.5 shows the equilibrium amount of dissolved fluoride calculated for various activities of calcium. Actual activities of fluoride are likely to be somewhat higher due to the effect of the ionic strength of the solution as well as the effect of any complexes that might form with the fluoride ion.

Fluoride can dissolve into groundwater from anthropogenic sources, but also from volcanic activity and other natural geologic sources through subsurface rock-water interaction. Magmatic fluorine is often in the form of hydrogen fluoride (HF) which is one of the most soluble gases in magmas, exsolving from molten rock only partially, and leaving large amounts of fluoride in cooled volcanic and plutonic rocks. High subsurface temperatures and acidic conditions enhance the dissolution of fluoride from these rocks into groundwater. Portions of the earth's large magmatic provinces, such as the Deccan flood basalts of India, the Siberian traps of central Asia, and the East African Rift Valley are endemic for fluorosis from consumption of high fluoride concentration in groundwater, as are smaller more isolated locales at the base of volcanoes (Brindha and Elango 2011; D'Alessandro 2006).

Corbett and Manner (1984) have reported on the distribution of fluoride in water from both unconsolidated and bedrock aquifers of northeastern Ohio. They found that 239 out of 255 wells had fluoride concentrations less than 1mg/L. However, 14 of

TABLE 6.5 Equilibrium fluoride concentrations as a function of calcium activity.

Calcium		Fluoride	
Activity (mol)	Concentration (mg/L)	Activity (mol)	Concentration (mg/L)
2×10^{-2}	800	4.48×10^{-5}	0.85
10^{-2}	400	6.31×10^{-5}	1.20
5×10^{-3}	200	8.92×10^{-5}	1.70
10^{-3}	40	2.00×10^{-4}	3.79
5×10^{-4}	20	2.82×10^{-4}	5.36
10^{-4}	4	6.31×10^{-4}	11.99

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the wells had fluoride ranging from 1 to 5.9 mg/L. All these high-fluoride wells were associated with a specific bedrock formation. Such information is useful from a public health standpoint because there is a 2.0-mg/L drinking-water criteria for fluoride. Some fluoride is needed to build strong teeth in growing children; however, fluoride in excess of 2.0 mg/L will cause teeth to discolor. Chronic ingestion of high fluoride in drinking water can also produce a serious condition known as skeletal fluorosis, which can damage bones and joints.

6.7.2 Chlorine and Bromine

The halides chlorine and bromine have similar chemistry, although chlorine is far more abundant in nature than bromine. Even though the elements can exist in a number of oxidation states, the chloride and bromide ions (Cl^-, Br^-) are the only ones of significance in natural waters. These halides are widely distributed in rocks and soil, and can be naturally leached into groundwaters. The chloride ion occurs in natural waters in fairly low concentrations, usually less than 100 mg/L, unless the water is brackish or saline. Chloride is used by humans in many applications and can be added to the subsurface via industrial discharges, sewage, animal wastes, and road salting. Chlorine gas is used as a disinfectant for purification of water and is a strong oxidizing agent when dissolved in water. Commercial fertilizers can contain chloride as KCl. Chlorine and bromine are components of halogenated organic compounds used for industrial solvents and pesticides. These compounds have been released to the environment both intentionally through the use of pesticides and accidentally through spills and leaks. Recent increases in shale hydrocarbon development have produced large quantities of post-fracking brine waters (which flow back upwards to the surface after well development), as has brine production from dewatering associated with coal bed methane extraction (also called coal seam gas). These large quantities of brine have increasingly been disposed of through underground injection. Fracking flowback water with Cl^- concentrations as high as 151,000 mg/L have been reported (Haluszczak et al. 2013).

Chloride and bromide ions are not reactive. They don't participate in redox reactions, aren't sorbed onto mineral or organic surfaces, and don't form insoluble precipitates. Chloride is sometimes used as a tracer in groundwater studies because it is conservative. Distinctive ratios of Cl^- and Br^- and other elements in groundwater have been valuable in reconstruction groundwater's movement and origin, including determining mixing ratios of different source waters. These ions are highly mobile in the subsurface and are often eventually transported to closed basins or oceans. Additionally, concentrations of chlorine isotopes in groundwater have effectively been used for groundwater dating techniques, including bomb-pulse chlorine-36 put into atmosphere with nuclear weapons testing and falling with rainfall, infiltrating and percolating into groundwater (Challan 2016). These forensic groundwater analytical techniques aid in the tracking of groundwater pollution (see Chapter 8).

6.7.3 Sulfur

Sulfur is naturally released to the environment by the weathering of minerals containing the element. Rock containing pyrite can be oxidized to release sulfur, with microorganisms acting as a catalyst and mediating the oxidation. This is the source

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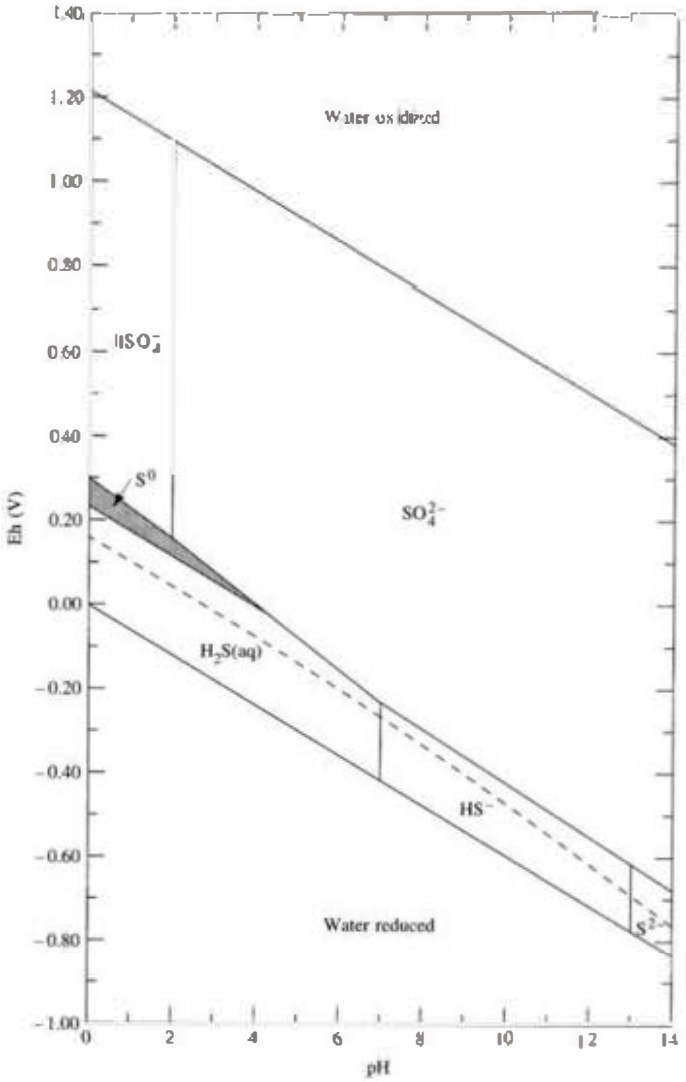
of the acidic water that drains from many areas that have been mined. Sulfuric acid is widely used in industrial processes. Sulfur can be released to the environment by the processing of sulfide ores and by the burning of fossil fuels, all of which contain sulfur to some degree. Sulfur is also a component of many fertilizers and can leach into groundwater systems from agricultural sources.

Sulfur can exist in valence states ranging from S^{-2} to S^{+6}. Figure 6.8 is an Eh-pH diagram showing the stability of the two oxidized forms of sulfur, $HSO4^-$ and SO_4^{2-}, and the three reduced forms, S^{2-}, HS^-, and H_2S (aqueous). The field of stability for elemental sulfur is also shown. The total sulfur activity used in computing the diagram is 10^{-3} mol/L or 96 mg/L as SO_4^{2-}. If a greater total sulfur activity were used, the stability field for elemental sulfur would be larger. Although this is a very useful diagram

FIGURE 6.8 Eh-pH diagram for sulfur species at standard conditions with total dissolved sulfur activity of 96 mg/L.



Source: J. D. Hem. 1985. *Study and interpretation of the chemical characteristics of natural waters*. Water Supply Paper 2254, U.S. Geological Survey.

for understanding the equilibrium conditions for dissolved sulfur, the redox reactions can be slow if microbes are not mediating the reactions. Hence, it may take a long time for the system to reach equilibrium.

Gypsum (calcium sulfate) is quite soluble in water ($K_{eq} = 10^{-4.6}$) and, except for waters with extremely high sulfate, would not be a sink for sulfate. Strontium sulfate is sparingly soluble ($K_{eq} = 10^{-6.5}$), whereas barium sulfate is nearly insoluble ($K_{eq} = 10^{-10.0}$). However, strontium and barium are not found in much abundance in natural waters. Sulfate could act as a sink for strontium and barium. Sulfur isotopes can be used to distinguish pollutant sources in some cases.

6.7.4 Nitrogen

Nitrogen is another element that can occur in both oxidized and reduced forms as well as the elemental state. The common forms of inorganic nitrogen include nitrate, NO_3^-, nitrite, NO_2^-, nitrogen gas, N_2, ammonium, NH_4^+, and cyanide, CN^-. Nitrogen is also a major constituent of organic matter in the form of amino acids. The majority (78%) of the Earth's atmosphere is nitrogen gas. Atmospheric nitrogen can be "fixed", or converted to nitrate, by cyanobacteria in lakes and the ocean and by bacteria living on the roots of plants such as legumes and lichens. Atmospheric nitrogen can also be converted to oxidized and reduced forms via fertilizer production and by heating it to high temperatures in internal combustion engines, power plants, lightning discharges and forest fires. Rainwater contains dissolved nitrate and ammonia. Nitrogen is released to the subsurface from sewage, animal wastes, and fertilizers.

In soil and groundwater, oxidation and reduction of nitrogen species is accomplished by microorganisms. Under oxidizing conditions ammonia is converted to nitrite, which is converted to nitrate. Nitrite is a very reactive ion and is almost immediately converted to nitrate, so that little nitrite is normally found in the environment. Under reducing conditions nitrate is converted primarily to nitrogen gas, a process known as **denitrification**. Organic matter will decay to ammonia under reducing conditions. Septic tank effluent, for example, normally has high ammonia and very little nitrate. If the receiving groundwater is reducing, the nitrogen will stay in the ammonia form. If it is oxidizing, bacteria will convert the ammonia to nitrate (Feth 1966). Nitrate is chemically conservative, can be mobile in the subsurface environment, and understandably, high nitrate concentrations in drinking water are most often associated with privately owned wells. Since the 1940s, health concerns and regulatory standards for nitrogen in groundwater center on infant methemoglobinemia (commonly called the "blue baby" disease). The high gastric pH of infants and their great fluid intake relative to body weight contribute to their internal bacterial reduction of ingested nitrate to nitrite, and the generated nitrite inhibits the function of blood hemoglobin in the transfer of oxygen.

Nitrate contamination of groundwater has been documented in a number of areas (e.g., Hill 1982; Flipse et al. 1984; and Silver and Fielden 1980). Hill studied the distribution of nitrate in groundwater from a shallow unconsolidated sand aquifer. It was found that the groundwater beneath areas of forest or permanent pasture has less than 1.0 mg/L of nitrate as nitrogen. The groundwater beneath heavily fertilized potato fields typically contained in excess of 10 mg/L nitrate as nitrogen. Gray and Morgan-Jones (1980) found that the nitrate content of groundwater in a study area

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increased over the past 40 years and that the use of fertilizers in this catchment area also increased over the same time period.

Nitrogen occurs as two isotopes, ^{14}N and ^{15}N. Of the two, ^{14}N is by far the most abundant in the atmosphere. The relative abundance of ^{15}N—that is, the $^{15}N/^{14}N$ ratio—in nitrate may be used to distinguish nitrate that comes from animal and human waste from nitrate that comes from mineral fertilizers (Flipse et al. 1984).

The $^{15}N/^{14}N$ ratio is usually expressed as a $\delta^{15}N$ value, which is defined as

$$\delta^{15}N(‰) = \frac{\left(^{15}N/^{14}N\right)\text{sample} - \left(^{15}N/^{14}N\right)\text{standard}}{\left(^{15}N/^{14}N\right)\text{standard}} \times 1000$$

where ‰ stands for parts per thousand.

If the $\delta^{15}N$ is positive, then the nitrate of the sample has been enriched in ^{15}N with respect to the standard. For nitrogen, the standard is the atmospheric composition. Nitrate from animal and human waste typically has a $\delta^{15}N$ in excess of +10‰.

Flipse and Bonner (1985) found that mineral fertilizers used on Long Island had $\delta^{15}N$ values that averaged 0.2‰ at one site and −5.9‰ at another. However, the $\delta^{15}N$ of the groundwater beneath the sites that had been fertilized was about +6‰. This increase in $\delta^{15}N$ from the mineral fertilizer was attributed to fractionation that occurred during infiltration of the nitrogen. However, the resulting $\delta^{15}N$ was still clearly lower than that expected from animal and human waste.

6.7.5 Arsenic

Arsenic can occur in valence states of +5, +3, +1, 0 and −3. However, the important states of dissolved arsenic in water are the arsenate $H_nAsO_4^{3-n}$, with a valence state of +5, and the arsenite $H_nAsO_3^{2-n}$, with a valence state of +3. An Eh-pH diagram for arsenic that shows the fields of stability for the arsenates and arsenites is given in Figure 6.9. Dissolved arsenic species can be absorbed by ferric hydroxides. Arsenic (+5) is more strongly sorbed than arsenic (+3). Ferric hydroxides are stable over a wide Eh-pH range, so this fact limits the mobility of arsenic. However, conditions that reduce Fe^{3+} to Fe^{2+} and As^{5+} to As^{3+} increase the mobility of arsenic in the environment, because the precipitated ferric hydroxides become soluble ferrous hydroxides (Matisoff et al. 1982). In an oxidizing environment with a pH above 4.0, we will find colloidal ferric iron hydroxides, which will sorb arsenic and would thus expect to have little arsenic in solution. Under strongly reducing conditions, if both iron and hydrogen sulfide are present, arsenic sulfide coprecipitates with iron sulfide. Mildly reducing conditions that lack hydrogen sulfide present conditions under which one would expect to find the most mobile arsenic, as iron would be in the soluble ferrous state and arsenic would be in the arsenite form (Hounslow 1980).

Arsenic has been released to the environment through the burning of coal and the smelting of ores. In the past it was used in the formulation of insecticides and embalming corpses. Starting at the time of the Civil War in the United States (1860–1865), arsenic was an ingredient in a popular embalming fluid. As much as 3 lb of arsenic could have been used per corpse. The use of arsenic in embalming fluids was

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banned by the federal government in 1910 because its use interfered with the investigation of suspected arsenic poisonings. However, graveyards from the Civil War and the late nineteenth century may be a source of arsenic contamination (Konefes 1990). It has some modern industrial uses. Groundwater has been found to have high (up to 96 μg/L) concentrations from natural sources in northeastern Ohio (Matisoff et al. 1982). Elevated arsenic (up to 5 mg/L) in groundwater in Nova Scotia, Canada, was reportedly due to the weathering of piles of mining waste that contained arsenopyrite (Grantham and Jones 1977). In the western United States high (>50 μg/L) concentrations of arsenic are common in groundwater. These are associated with areas of sedimentary rocks derived from volcanic areas, geothermal systems and gold and uranium mining districts. Irrigation in some areas has liberated arsenic to the extent that concentrations of up to 1 mg/L are found in shallow groundwater beneath irrigated fields (Welch, Lico, and Hughes 1988).

Naturally occurring arsenic in groundwater can also be a huge problem. In what one writer called "one of the largest mass poisonings in history," thousands of tube wells were drilled in shallow aquifers contaminated with naturally-occurring arsenic in Bangladesh and India in the 1980s and 1990s before the problem was recognized (Brahic 2004). As a result, arsenic has posed risk to an estimated 57 million people in Bangladesh (Hossain 2006), and 100,000 are estimated to have been affected by high concentrations in shallow well water in the region (Brahic 2004). Annually, another 270,000 have been estimated to have had cancer related deaths, as long-term exposure to arsenic has been related to cancer of the kidneys, lungs, bladder and skin (Brahic 2004). The problem was unrecognized for many years, in part because a study by the British Geological Survey (BGS) and Britain's National Environment Research Council (NERC) did not adequately test for arsenic in reconnaissance groundwater quality surveys which subsequently served as the basis for drawing up national water policies and the drilling of thousands of wells.

6.7.6 Selenium

Selenium occurs in oxidizing solutions as selenite, SeO_3^{2-}, with a +4 valence and as selenate, SeO_4^{2-}, with a +6 valence. It can be reduced to the insoluble elemental form, Se^0. It may also form a precipitate ferroselenite, $FeSe_2$, under reducing conditions. Selenite may be sorbed onto amorphous ferric hydroxides. Selenium has a number of industrial uses, such as the manufacture of pigments, stainless steel, and rubber compounds. It is contained in phosphate fertilizers. Selenium has been known to concentrate in irrigation return water draining from land that has soil high in selenium, and can be present in waste liquids from metal smelting. It is naturally present in coal, particularly bituminous coal, and can be concentrated approximately 1,250 times in the burning process at coal-fired power plants (coal versus precipitator ash), and can be present in elevated concentrations in waste scrubber water, ash ponds or other liquid wastes which could leach and percolate into the subsurface.

In small concentrations selenium is an essential nutrient, but in large amounts it is harmful to humans, fish, and wildlife (Coefield 2009). High selenium in groundwater-dependent ecosystems can wipe out entire species and cause massive

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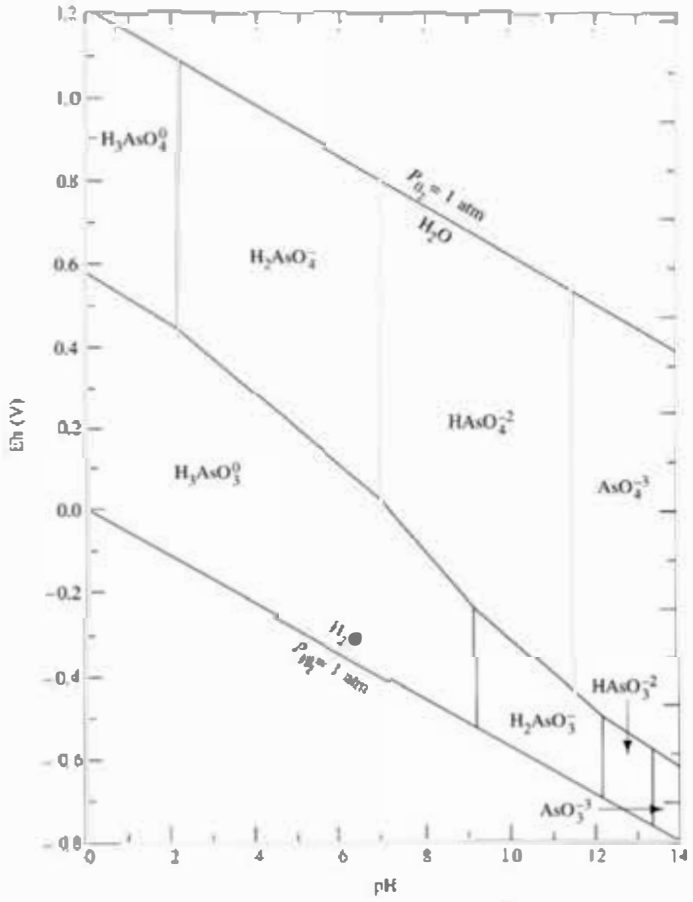
wildlife and fish kills. High selenium has been problematic at many sites and from activities worldwide, including (Lemly 2002):

1. Nickel and silver mining in Torun, Poland.
2. Municipal landfill leachates in Stockholm, Sweden; Minnesota, U.S.A.; and in London, U.K.
3. Irrigation runoff in Chihuahua, Mexico; Utah, U.S.A.; and in Kesterson National Wildlife Refuge, California, U.S.A.
4. Coal combustion waste in Texas, Pennsylvania, Kentucky, North Carolina, U.S.A. and Alberta Canada.
5. Phosphate mining waste in Idaho, U.S.A.
6. Gold mining waste in Buenos Aires, Argentina; Quito, Ecuador; and Yukon, Canada.
7. Metal smelting waste in Ontario, Canada.
8. Oil-refinery waste in Louisiana, U.S.A.

FIGURE 6.9 Eh-pH diagram for arsenic species under standard conditions.



Source: A. H. Welch, M. S. Lico, and J. L. Hughes, 1988. Arsenic in ground water of the western United States. *Groundwater* 26:333–347. Used with permission.

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6.7.7 Phosphorus

Phosphorus can occur in a number of valence states, but in natural water it is really significant only in the +5 state. Dissolved phosphorus in water occurs as phosphoric acid (H_3PO_4) and its dissociation products, the orthophosphate ions: $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}. The proportion of each present in an aqueous solution is a function of pH. Dissolved phosphorus is readily sorbed onto soil and has a very low mobility in groundwater. In alkaline soils it can react with calcium carbonate to form a mineral precipitate, hydroxyapatite.

$$3HPO_4^{2-} + 5CaCO_3 + 2H_2O \rightarrow Ca_5(PO_4)_3(OH) + 5HCO_3^- + OH^-$$

Phosphate is released to the environment from mineral fertilizers, animal wastes, sewage, and detergents.

6.8 Chemistry of Metals

Metals are cations, and most have fairly limited mobility in soil and groundwater because of cation exchange or sorption on the surface of mineral grains. They can also form precipitates of varying solubility under specific Eh-pH conditions. Geologically, metal ores are typicaly in the form of sulfides, oxides, silicates, or "native" metals. Metals are mobile in groundwater if the Eh-pH range is such that soluble ions exist and the soil has a low cation-exchange capacity (Dowdy and Volk 1983). They can also be mobile if they are chelated or if they are attached to a mobile colloid. Conditions that promote mobility include an acidic, sandy soil with low organic and clay content. Discharge of a metal in an acidic solution would keep the metal soluble and promote mobility.

6.8.1 Beryllium

Beryllium occurs only in the +2 valence state. In natural waters we can have Be^{2+}, $Be(OH)^+$, $Be(OH)_2$ and $Be(OH)_3^-$. Beryllium oxide and hydroxide have low solubilities and can act as a control on beryllium concentration. At equilibrium with $Be(OH)_2$, the dissolved form would have an activity of about 100 µg/L at a pH of 6 (Hem 1985). Nonetheless, beryllium can find its way into groundwater from industrial wastewater discharges or from natural weathering and dissolution of rocks, particularly igneous rock containing granites and pegmatites. Beryllium is used for making metal alloys for the aerospace industry, nuclear reactors, and is used in electrical equipment and microwave ovens.

6.8.2 Strontium

Strontium also occurs in the +2 valence state and has a chemistry similar to that of calcium. The solubility product for strontium sulfate, $SrSO_4$, is $10^{-6.4}$. This suggests that there might be an equilibrium control on strontium concentration if sulfate is present in the water. Strontium carbonate, $SrCO_3$, has a solubility product of 10^{-10}. In general, strontium is present in groundwaters in concentrations of less than 1 mg/L.

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However, in tracing groundwater pathways and subsurface movement of potential contaminants, the isotopic ratio of $^{87}Sr/^{86}Sr$ can be a "powerful tool in distinguishing among solute sources," as the ratio can reflect mineral interaction with groundwater, differences in initial water quality, recharge waters of varying evaporative concentrations or pCO_2 concentration, and differences in relative mobilities of different groundwaters (USGS 2015).

6.8.3 Barium

This alkaline earth element also has a valence of +2. Its distribution is controlled by the solubility of barite, $BaSO_4$. Barite has a solubility product of 10^{-10}. If the activity of sulfate is 96 mg/L (10^{-3} *M*), then the activity of barium is 10^{-7} *M*, or 0.014 mg/L. Barium is also found as witherite ($BaCO_3$), and other compounds, but is not found in the environment as a free element because of its high reactivity. Barium sulfate can be an additive to oil-well drilling fluid, medical waste, and because in its ionic form barium is soluble and toxic, it is a component of some rodenticides.

6.8.4 Vanadium

This transition metal has oxidation states of + 3, +4, and +5. In aqueous solutions it forms 10 different oxides and hydroxides. Dissolved iron can react with vanadium to form an insoluble ferrous vanadate, which can act as a control on vanadium in natural water (Hem 1977).

$$FeOH^+ + 2H_2VO_4^- + H^+ \rightleftharpoons Fe(VO_3)_2 + 3H_2O$$

6.8.5 Chromium

Chromium in natural waters occurs in a +3 and a +6 valence state. Stable ionic forms in aqueous systems include Cr^{3+}, $CrOH^{2+}$, $Cr(OH)_2^+$, $Cr_2O_7^{2+}$ and CrO_4^{2-}. Chromous hydroxide, $Cr(OH)_3$ is a possible precipitate under reducing conditions. Figure 6.10 is an Eh-pH diagram for the stability field for chromous hydroxide. Under some conditions chromate might react with ferrous iron to produce a chromous hydroxide precipitate (Robertson 1975).

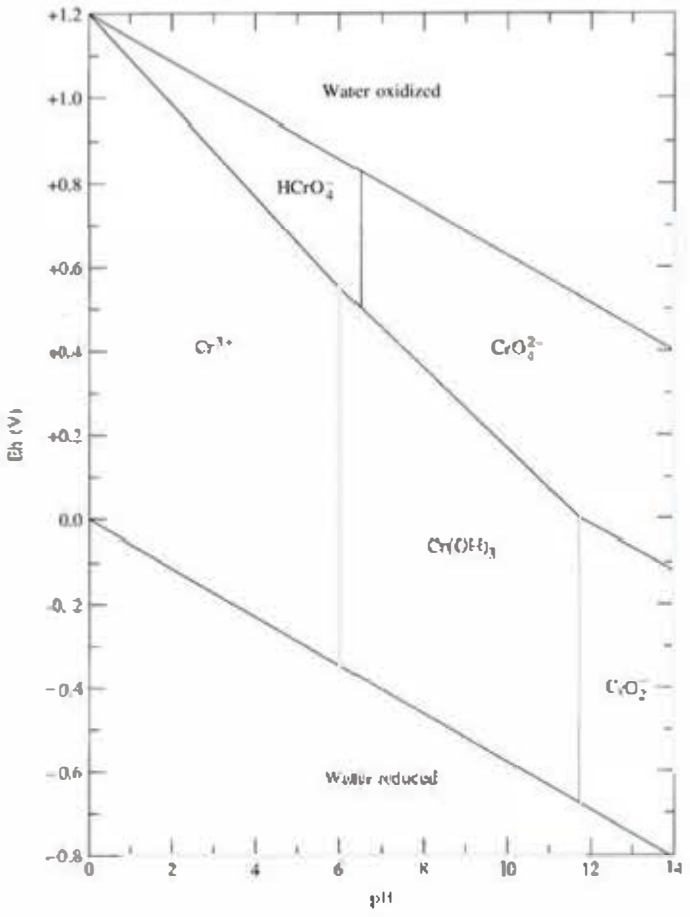
$$CrO_4^{2-} + 3Fe^{2+} + 8H_2O \rightleftharpoons 3Fe(OH)_3 + Cr(OH)_3 + 4H^+$$

In general the hexavalent chromium in groundwater is soluble and mobile and trivalent chromium will be insoluble and immobile. Industrial discharges of hexavalent chromium are common from metalplating industries. This material may be quite mobile in groundwater. A hexavalent chromium spill on Long Island, New York, U.S.A., traveled more than 900 m (≈3000 ft) from a wastedischarge pond to a stream (Perlmutter, Lieber, and Frauenthal 1963). Hexavalent chromium from a natural source has been found in groundwater in Paradise Valley, Arizona, U.S.A. (Robertson 1975), and the Blacksmith Institute reports that groundwater containing 6.2 mg/L Cr (VI) was found in Kanpur, India (the Indian government limit is 0.05 mg/L) from

tannery operations, potentially affecting 30,000 people. Popular attention was focused on groundwater pollution from hexavalent chromium in Hinkley, California, U.S.A., after it was dramatized in the 2000 film *Erin Brockovich*.

Chromium in groundwater is much more mobile in the aqueous Cr^{6+} phase than as Cr^{3+}. In a study of a three dimensional chromium plume in a glaciofluvial aquifer in Connecticut, Nikolaos et al. (1994) tested the sorbed chromium in the soil and the dissolved chromium in the groundwater. The mean soil concentration was 0.675 g/kg while 25 mg/L was dissolved in the groundwater. A mass balance calculation reveled that more than 99% of the mass of chromium was immobilized in the soil. This has important implications for groundwater remediation. The mobile chromium in the groundwater could be removed by pump and treat methods. However, if the geochemical equilibrium is upset and chromium is desorbed from the soil, then it would be very difficult to ever remove all of the chromium by pump and treat. As a part of a remedial investigation at a chromium spill site, one must determine how strongly the chromium is bound to the soil. Methods of extracting the dissolved portion without upsetting the equilibrium that binds the majority of the chromium to the soil must be developed.

FIGURE 6.10 Eh-pH diagram for chromium under standard conditions.



Source: Modified from F. N. Robertson. 1975. Hexavalent chromium in the ground water in Paradise Valley, Arizona. *Groundwater* 13:516–527. Used with permission.

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Case History

Henderson (1994) investigated a chromium spill in the Trinity Sand aquifer near Odessa, Texas. He found that the mobile Cr^{6+} was being reduced to Cr^{3+} by ferrous iron (Fe^{2+}) and organic carbon. The trivalent chromium is then sorbed onto the soil surfaces which are coated with solid iron oxyhydroxides. The soil contained up to 5 g/kg and 95 to 99 percent was in the trivalent state. Prior to the initiation of the study, the chromium plating operation had ceased operations, so that the source of hexavalent chromium ended. Over the course of the study, the plume of groundwater contaminated with Cr^{6+} stopped growing, and even began to shrink (Figure 6.11). The cause of this degradation is the reduction of the Cr^{6+} to Cr^{3+} which forms chromium hydroxide ($CrOH_3$) and its subsequent sorption onto the soil.

The calculated half life of the chromium was 2.5 years. The reduction in dissolved hexavalent chromium mass in the aquifer is illustrated in Figure 6.12. The shaded area represents observed conditions at four different sampling events. The curved line is a first order reduction with the 2.5 year half life.

With the transformation of dissolved to solid chromium as a function of time, the groundwater in the aquifer is undergoing natural remediation. Computer modeling of the plume resulted in a diminution of the dissolved Cr^{6+} below a 100 µg/L drinking water standard by no later than the year 2006 (Figure 6.13). Operation and maintenance at the site were still ongoing in 2017.

6.8.6 Cobalt

Cobalt occurs with valence states of +2 and +3. In the Eh and pH range of natural waters, only the +2 valence state is stable. It is thought that cobalt can coprecipitate or be absorbed by manganese and iron oxides. Cobalt carbonate has a solubility product of 10^{-10}. At a pH of 8.0 with 100 mg/L of carbonate, the equilibrium solubility of cobalt is 6 µg/L (Hem, 1985). The solubility product of cobalt sulfide is very low, $10^{-21.3}$. Virtually no cobalt would be in solution in a reducing environment. Radioactive cobalt is a waste product of certain defense activities (Means, Crerar, and Duguid 1978). Cobalt occurs in nature as smaltite ($CoAs_2$), and cobaltite (CoAsS). In the United States, stable cobalt has been identified at 426 of the 1,636 current or former National Priorities List (NPL) sites, whereas radioactive cobalt has been found at 13 sites (ATSDR 2015).

6.8.7 Nickel

This metal occurs in aqueous solutions in the +2 valence state. Nickel ores include a variety of minerals, consisting of nickel, antimony, sulfur, and arsenic: NiSb, $NiAs_2$, NiAsS, and NiSbS. Nickel carbonate is more soluble than cobalt carbonate ($K_{sp} = 10^{-6.9}$), whereas the sulfide has a similar solubility ($K_{sp} = 10^{-19.4}$). Nickel is widely used in industry.

6.8.8 Molybdenum

Molybdenum occurs as the ore mineral molybdenite, MoS_2. The most common oxidation states are +4 and +6. Under oxidizing conditions the Mo^{6+} state dominates. Below pH 1.8 one finds H_2MoO_4 (aqueous). Between pH 1.8 and pH 5.3, $HMoO_4^-$ occurs, whereas above pH 5.3 the molybdate ion, MoO_4^{2-}, is stable. If ferrous iron is present, ferrous molybdate ($FeMoO_4$) presents a possible solubility control, since this has a solubility product of $10^{-10.45}$ at a pH range of 5.3 to 8.5 (Hem 1977). Molybdenum may also sorb

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onto amorphous ferric hydroxide (Kaback and Runnels 1980). The solubility product of calcium molybdate, $CaMoO_4$, is $10^{-8.7}$ (Hem 1985). Molybdenum is used as an alloy in steel and as an additive to lubricants. Waste sources include mining and smelting of ore.

6.8.9 Copper

Copper occurs in either a +1 or a +2 valence state. Dissolved copper species in water include Cu^{2+}, $HCuO_2^-$, CuO_2^{2-}, and Cu+. Cupric copper and ferrous iron can undergo an oxidation-reduction:

$$2Cu^{2+} + 2Fe^{2+} + 7H_2O \rightleftharpoons Cu_2O + 2Fe(OH)_3 + 8H^+$$

Both cupric and cuprous sulfide have very low solubility products. Copper concentrations can be very high in acid mine drainage from metal mines, up to several hundred milligrams per liter. Copper can be leached from copper water-supply pipes and fixtures, especially by waters that have a pH of less than 7 (Hem 1985).

6.8.10 Silver

Silver, a rare element, is widely used in industry. It occurs in the +1 valence state. Silver chloride, AgCl, has a solubility product of $10^{-9.7}$, which limits the solubility of silver in waters with chloride ion. Silver can also be naturally reduced to the metallic state by ferrous iron:

$$Ag^+ + Fe^{2+} + 3H_2O \rightleftharpoons Fe(OH)_3 + Ag + 3H^+$$

Silver sulfide has a low solubility. Thus, in water with chloride, iron, and sulfur present, stable solid forms of silver occur over the entire Eh-pH field (Hem 1977). As a result, there is very little soluble silver in natural waters.

6.8.11 Zinc

Zinc is a fairly common metal and is extensively used in metallurgy and as a pigment, zinc oxide, which is often worn on the noses of lifeguards and other people in the sun. It occurs in the +2 valence state. Zinc carbonate has a rather low equilibrium constant, 10^{-10}, which would limit the solubility at pH ranges where the carbonate ion predominates. In a pH range of 8 to 11 and with 610 mg/L of HCO_3^-, there should be less than 100 µg/L of dissolved zinc (Hem 1985).

6.8.12 Cadmium

Cadmium has a very low maximum contaminant level (MCL) in drinking water, 4 µg/L, due to its toxicity. It exists in aqueous solution in the +2 valence state. Cadmium carbonate has a very low solubility product, $10^{-13.7}$. Although this could serve as a control on solubility under some conditions, cadmium can be mobile in the environment. On Long Island, New York, a metal-plating waste containing cadmium and chromium traveled about 3000 ft in a shallow aquifer (Perlmutter, Lieber, and Frauenthal 1963). Cadmium has been implicated in an outbreak of a disease in Japan resulting in a softening of the bones of the victims that resulted in extreme bone pain.

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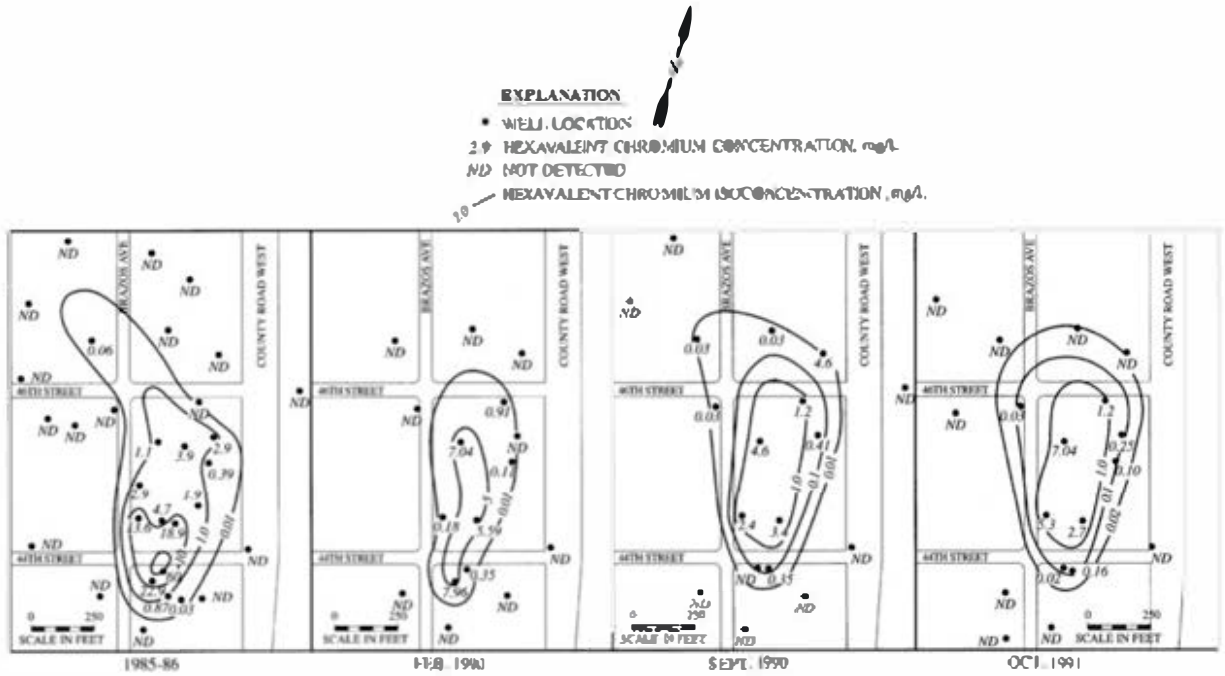
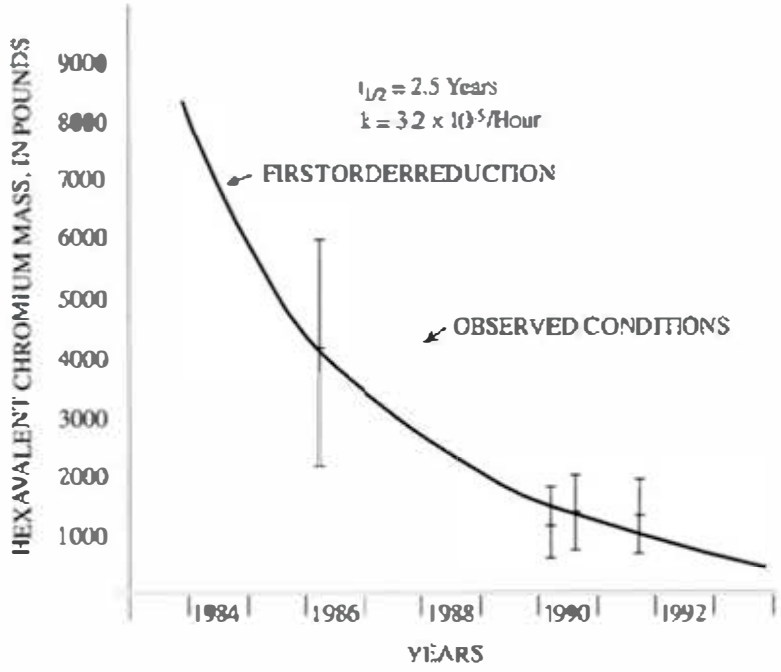
FIGURE 6.11 Shrinkage of the maximum extent of an observed plume of Cr^{6+} with time.



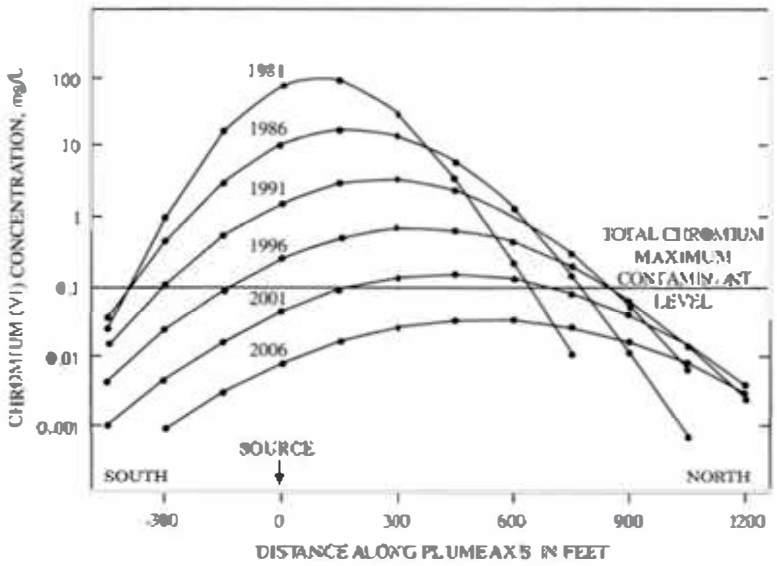
Source: T. Henderson. 1994. Geochemical reduction of hexavalent chromium in the Trinity Sand aquifer. *Groundwater* 32:477-486. Used with permission.

FIGURE 6.12 Reduction of the dissolved mass of Cr^{6+} with time.



Source: T. Henderson. 1994. Geochemical reduction of hexavalent chromium in the Trinity Sand aquifer. *Groundwater* 32:477–486. Used with permission.

FIGURE 6.13 Result of fate and transport modeling of concentration of Cr^{6+} along the axis of the plume.



Source: T. Henderson. 1994. Geochemical reduction of hexavalent chromium in the Trinity Sand aquifer. *Groundwater* 32:477–486. Used with permission.

The cadmium was traced to rice and soybeans grown in soil contaminated by airborne cadmium that came from a nearby lead-and zinc-smelting operation (Emmerson 1970).

6.8.13 Mercury

Mercury has the lowest MCL for any inorganic chemical, 2 μg/L. It is considered to be very toxic. It has been known to concentrate in the food chain, especially in fish. Several outbreaks of mercury poisoning have been confirmed in Japan. Local discharges of mercury from industrial processes into surface-water bodies resulted in high mercury levels in fish. Inhabitants of fishing villages ate fish up to three times a day. Mortality of those affected was about 40%, and the poisoning was passed to unborn babies by apparently healthy mothers (Waldbott 1973). Mercury occurs as a metal and in the valence states +1 and +2. Most of the inorganic mercury compounds have a low solubility. The solubility product of Hg_2Cl_2 is $10^{-17.9}$, and for HgS it is about 10^{-50}. Under most natural conditions there is little soluble inorganic mercury. However, methane-generating bacteria can convert metallic mercury to organic forms such as methyl mercury, $HgCH_3^+$. The monomethyl mercury ion is soluble in water. Bacteria can also produce dimethyl mercury, $Hg(CH_3)_2$, which is volatile. Other organic forms of mercury, such as ethylmercuric chloride (C_2H_5HgCl), are manufactured and used as fungicides.

6.8.14 Lead

Lead occurs in aqueous solution as Pb^{2+} and in various hydroxides. Various lead compounds have solubility products that indicate that under the right Eh-pH conditions, lead solubility would be limited in natural waters: $PbCl_2$, $K_{sp} = 10^{-4.8}$; PbF_2, $K_{sp} = 10^{-7.5}$; $PbSO_4$, $K_{sp} = 10^{-7.8}$; $PbCO_3$, $K_{sp} = 10^{-13.1}$ and PbS, $K_{sp} = 10^{-27.5}$. Lead and the other metals are cations

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that can be expected to undergo cation and exchange with clays. Hence, the mobility of lead in groundwater is limited. Lead is present in nature as a trace element. In two different studies soils in uncontaminated areas were reported to contain 17 μg of lead per gram of soil (μg Pb/g) (Nriagu 1972) and 29 μg Pb/g (Ure and Berrow 1972). However, there are a number of anthropogenic sources of lead, including mining and smelting, paint, use of sewage sludge as a soil conditioner, lead arsenate pesticides, and leaded gasoline. Urban areas especially have much higher levels of lead in the soil due primarily to paint flaking from buildings and burning of leaded gasoline (Davis 1990). A study of lead in soils near highways in the Minneapolis St. Paul, USA, area revealed concentrations ranging from 128 to 700 μg Pb/g (Singer and Hanson 1969). A study in California, U.S.A. found that lead in soil decreased with distance from a freeway which ran through a rural area, with 118 μg Pb/g found 15 meters from the expressway and 85 μg Pb/g as much as 362 meters away (Page et al. 1971). Lead additives were used as anti-knock compounds in gasoline, but are now restricted or banned in many parts of the world.

Elevated lead is also found in soil around lead smelters. Davies (1990) estimates that in the immediate area of a well established lead smelter (1 to 3 km away), lead in soil is likely to be on the order of 1500 μg Pb/g. In a study conducted in southeastern Missouri, USA, the investigators were able to distinguish lead from automobile exhaust from lead from smelter activities on the basis of the ratio of stable lead isotopes, $^{206}Pb/^{204}Pb$ (Rabinowitz and Wetherill 1972). In that study they found lead in soil near smelters averaging 2600 μg Pb/g and near highways averaging 270 μg Pb/g.

In general urban soils have highet lead content than rural soils. In a major study of metals in urban soils in Great Britain a total of 4,126 lawns were tested, with a geometric mean lead content of 266 μg Pb/g and a range of thirteen to 14,100 μg Pb/g (Culbard et al. 1988). In London a total of 578 samples had a geometric mean lead content of 654 μg Pb/g.

Soluble lead is absorbed by soils, and its mobility is limited. The two most important factors in determining the amount of lead that will be sorbed by soil are the pH and the cation exchange capacity (CEC) of the soil (Zimdahl and Skogerbe 1977). This relationship can be described by an equation, with the amount of lead sorbed per gram of soil represented by N^*:

$$N^*_{(mol/gm)} = 2.81 \times 10^{-6} CEC_{(meq/100g)} + 1.07 \times 10^{-5} pH - 4.93 \times 10^{-5}$$

The above equation shows that with a pH greater than 4.61 the amount of lead sorbed by the soil increases and that below a pH of 4.61, it decreases. The cation exchange capacity of a soil is dependent upon the amount and type of clay in the soil and the amount of soil organic matter. Lead absorption is due to precipitation of the carbonate, fixation on organic matter, or sorption by hydrous oxides of iron and magnesium. Griffin and Shimp (1976) demonstrated that the sorption capacity of a clay for lead at a pH of 5.0 was much greater than at a pH of 4.0.

Because of the high affinity of soil for lead, the metal tends to accumulate in the upper few centimeters of soil. In a study of heavy metal mobility in soils near a zinc smelter, lead was found to be concentrated in the upper 10 cm of the soil (Scokart et al. 1983). This was due to the extremely low mobility of lead in soil. The reason that urban soils have such high lead levels is twofold. First, there are more

sources of lead. But more important is the fact that the lead in the soil is so immobile that it continues to accumulate. In a study of trace metals in virgin agricultural soil profiles in Canada, Wright and others (1955) found lead to be more concentrated in the upper part of the soil profile. The lead was assumed to come from the weathering process and was concentrated in the zone where leaching was the most prevalent. This is further evidence for the very low mobility of lead in the environment.

There is one potential pathway for lead migration. If lead is sorbed onto colloidal-sized metal hydroxides, and the hydroxide moves through an aquifer as a colloidal particle, then the lead would also move. This would show up as lead in total metals analysis, which is run on an unfiltered sample. The colloidal particles, which may impart turbidity to the sample, would be digested and any sorbed lead liberated in the analysis. Colloidal-sized lead particles could also migrate with groundwater and be detected with the total lead analysis.

6.8.15 Rare Earth Elements

Rare earth elements (REEs) are increasingly important materials for modern technologies and can be found in groundwater. Although REE concentrations in groundwater can be low, they are used in investigations as tracers to indicate water movement and source, and importantly have associated radioactive pollutants in REE mining waste. There are 17 REEs, but the name "rare" is misleading as some (e.g., cerium) can be relatively abundant in the earth's crust. REE mining activity is rapidly expanding as are the economic uses of REEs. For example, REEs are used in cellular phones, laptop computer hard drives, automobile airbags and ABS brakes, medical magnetic resonance imaging (MRI), hybrid car batteries, wind turbine generators, plasma color televisions, satellite components, and communications equipment, to name a few applications. REEs have been shown to be useful in tracking and tracing groundwater (Johannessonn et al. 1997; Kreamer et al. 1996; Johannessonn 2006), and radioactive elements of uranium and thorium are commonly found in slurry tailing from REE mining.

6.9 Radioactive Isotopes

6.9.1 Introduction

Certain isotopes of elements undergo spontaneous decay, resulting in the release of energy and energetic particles and consequent formation of different isotopes. Some of these radioactive isotopes are naturally occurring and others are created by the bombardment of the Earth by cosmic radiation. Humans have created nuclear isotopes through the detonation of nuclear weapons and the construction of nuclear reactors. Table 6.6 lists the sources of environmentally important isotopes.

Radionuclides emit ionizing radiation—alpha particles, beta particles, and gamma rays—when they decay. An alpha particle is a helium nucleus with atomic mass 4 and atomic number 2. A beta particle is either a negative electron or a positron (positive electron). Gamma radiation consists of electromagnetic radiation similar to X-rays but more energetic (i.e., it has a shorter wave length). Gamma radiation is more destructive to tissue than X-rays. The primary effect of these particles is to produce ions, hence the name ionizing radiation. Alpha particles do not penetrate very far into matter due

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TABLE 6.6 Sources of environmentally important radioactive isotopes.

Source	Radionuclides
Naturally occurring	^{40}K, ^{222}Rn, ^{226}Ra, $^{230,232}Th$, $^{235,238}U$
Cosmic irradiation	^{3}H, ^{7}Be, ^{14}C, ^{22}Na
Nuclear weapons tests	^{3}H, ^{90}Sr, ^{137}Cs, $^{239,240}Pu$
Mining waste—uranium, phosphate, coal	^{222}Rn ^{226}Ra, $^{230,232}Th$, $^{235,238}U$
Industrial wastes—e.g., nuclear power plants, weapons manufacturing, research and medical waste	$^{59,63}Ni$, ^{60}Co, ^{90}Sr, $^{93,99}Zr$, ^{99}Tc, ^{107}Pd, ^{129}I, ^{137}Cs, ^{144}Ce, ^{151}Sm, $^{152,154}Eu$, ^{237}Np, $^{239,240,242}Pu$, $^{241,243}Am$

Source: G.W.Gee, D.Rai, and R.J.Serne. 1983. Mobility of radionuclides in soil. In D.W.Nelson et al. (ed.) *Chemical Mobility and Reactivity in Soil Systems*, 203. (Madison, WI: Soil Science Society of America Spec. Publ. 11, 1983).

to their large size, but they produce a lot of ions along their short path. Beta particles penetrate to a greater depth but produce fewer ions per unit path length.

Radionuclide concentrations can be reported in terms of their mass per volume concentration (e.g., milligrams per liter). However, they are more frequently reported in terms of a standard unit of radioactivity, the **curie** (Ci). A curie is 3.7×10^{10} disintegrations per second. In water we use the **picocurie** (pCi), which is 1×10^{-12} Ci, or 3.7×10^{-2} disintegrations per second. In the SI system the unit of radioactivity is the **becquerel** (Bq), which is 1disintegration per second.

Radiation doses are measured in terms of rads, which are a measure of the absorption by the body of ionizing radiation of any type. A rad is equivalent to 100 ergs of energy from ionizing radiation absorbed per gram of soft tissue. In the SI system the unit of dose is a gray (Gy), which is equal to 100 rads.

The effect of ionizing radiation depends upon the type of particle and the body tissue with which it interacts. Therefore, the absolute measurement of dose must be converted to a dose equivalent. The unit of dose equivalent is the rem. Rads are converted to rems by multiplying by a factor that depends upon the type of ionizing radiation and its biological effect. For example, with gamma radiation the factor is 1 and a rad is equal to a rem. In the SI system the unit of dose equivalent is the seivert (Sv), and it is equal to a gray times the dose factor. A seivert is 100 rem.

6.9.2 Adsorption of Cationic Radionuclides

The cationic radionuclides may be subjected to ion exchange and other processes that sorb the radionuclide onto mineral or organic surfaces in the soil. The following transition metals and lanthanides have large distribution coefficients and hence low mobilities in waters that are in the neutral range: ^{60}Co, ^{59}Ni, ^{63}Ni, ^{65}Zn, ^{93}Zr, ^{107}Pd, ^{110}Ag, ^{144}Ce, ^{147}Pm, ^{151}Sm, ^{152}Eu, and ^{154}Eu. Many of them do not desorb significantly. The degree of sorption is strongly related to the pH of the solution. Insoluble metal hydroxides may also be formed. Technetium (Tc) solubility depends strongly upon the Eh of the solution, because under oxidizing conditions it forms the soluble pertechnetate ion (TcO_4^-) (Gee, Rai, and Serne 1983).

^{90}Sr, ^{137}CS, and ^{226}Ra undergo cation exchange in a fashion similar to other exchangeable cations, such as Ca^{2+} and Mg^{2+}. Thorium and lead also have high distribution coefficients and limited mobility in neutral to alkaline soil. Lead is sorbed on

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hydrous oxides of iron, aluminum, and most likely manganese. Thorium hydroxides are of very limited solubility (Gee, Rai, and Serne 1983).

6.9.3 Uranium

Uranium occurs primarily as ^{238}U, with ^{235}U being much more rare. One of the disintegration products of ^{238}U is ^{226}Ra. This decay series ends with ^{206}Pb, a stable isotope. ^{238}U can also degrade to ^{234}U. The $^{234}U/^{238}U$ ratio is useful in tracking and dating groundwater (see Chapter 8). ^{238}U has a very long half-life, 4.5×10^9 years, which indicates that it is not very radioactive. The ^{235}U isotope can decay to form ^{223}Ra.

The chemistry of dissolved uranium is somewhat complex (Giridher and Langmuir 1991; Langmuir 1978). It has three valence states, +4, +5, and +6. Uranium can undergo oxidation-reduction reactions such as oxidation from the +4 to the +6 state:

$$U^{4+} + 2H_2O \rightleftharpoons UO_2^{2+} + 4H^+ + 2e^-$$

In a system with just uranium and water, stable species include (1) +4 valence: U^{4+} UOH^{3+}, and (2) +6 valence: UO_2^{2+} UO_2H^+ $(UO2)_3(OH)_5^+$ and $(UO2)_3(OH)_7^-$. The stability fields for this ions and precipitates are shown in Figure 6.14 for an aqueous solution with a total uranium activity of 10^{-6} mol/L The U(6+) species has a tendency to from a complexes with a wide variety of inorganic anions, including carbonate, hydroxide, phosphate, fluoride, and sulfate. This can be illustrated with an Eh-pH diagram of the same 10^{-6} mol/L solution of U but in contact with carbon dioxide at a partial pressure of 10^{-2} atm. This is represented by Figure 6.15. In Figure 6.14 the UO_2^{2+} formed a series of complexes with OH^-, starting with UO_2OH^+, at a pH above about 5.2. With carbon present, as in Figure 6.15, UO_2^{2+} can form a series of carbonate complexes that replace the hydroxyl complexes.

The soluble complexes of oxidized uranium depend upon the pH of the water. Most natural water contains fluoride, phosphorus, carbon dioxide, and sulfur. Figure 6.16 shows the distribution of uranyl complexes for a groundwater under standard conditions with $P_{CO2} = 10^{-2.5}$ atm, $F^- = 0.3$ mg/L, $Cl^- = 10$ mg/L, $so_4^{2-} = 100$ mg/L, and $P0_4^- = 0.1$mg/L. In different pH ranges the most prevalent stable species include

$$UO_2^{2+}, UO_2(HPO_4)_2^{2-}, UO_2(CO_3)_2^{2-}, \text{and } UO_2(CO_3)_3^{4-}.$$

If reduced species of iron or sulfur are present, they could reduce U(6+) to U(4+) and precipitate the nearly insoluble mineral uranite, UO_2 This reduction could occur by oxidation of HS^- to SO_4^{2-}:

$$4UO_2(CO_3)_3^{4-} + HS^- + 15H^+ \rightleftharpoons 4UO_2(s) + SO_4^{2-} + 12CO_2(g) + 8H_2O$$

The same reduction could be accomplished by oxidation of ferrous iron to ferric hydroxide:

$$UO_2(CO_2)_3^{4-} + 2Fe^{2+} + 3H_2O \rightleftharpoons UO_2(s) + 2Fe(OH)_3 + 3CO_2$$

Because sulfur and iron are common in groundwater systems, under reducing conditions one could expect the formation of uranite, which would remove uranium from solution. Figures 6.14 and 6.15 show the stability field for uranite ($U0_2$). In the

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has a very low solubility. The primary thorium ore is monazite, which contains oxides of thorium, phosphorus, and the rare earths yttrium, lanthanum, and cerium.

The mobility of thorium is greatly enhanced if ligands are present to form complexes. Figure 6.20 shows the inorganic thorium complexes that form as a function of the pH of the solution. The solution contains 0.3 mg/L F^-, 10 mg/L Cl^-, 100 mg/L SO_4^{2-} and 0.1mg/L PO_4^{2-}. It can be seen from this figure that the most abundant aqueous species in order of increasing pH are $Th(SO_4)_2^0$, ThF_2^{2+} $Th(HPO_4)_2^0$, $Th(HPO_4)_3^{2-}$ and $Th(OH)_4^0$ However, the mobility of thorium complexes formed by organic ligands such as EDTA and citric acid are much greater than those formed by inorganic ligands (Langmuir and Herman 1980).

Adsorption of dissolved thorium increases with increasing pH above pH 2. The sorption of thorium onto clays, oxides and soil organic matter is nearly total by a pH of 6.5. Strongly complexing organic ligands such as EDTA can retard sorption or even promote desorption (Langmuir and Herman 1980). Thorium in natural waters and soil should be nearly immobile due to the low solubility of the minerals and the strong tendency for dissolved forms tobe sorbed only by clays, mineral oxides, and soil organic matter.

6.9.5 Radium

Radium occurs naturally in four isotopes: ^{223}Ra, 226Ra and ^{228}Ra. ^{232}Th decays into both ^{228}Ra and ^{226}Ra, whereas ^{235}U decays to ^{223}Ra and ^{238}U disintegrates to ^{235Th}, which in turn decays to ^{226}Ra. One isotope, ^{226}Ra, has a much longer half-life than any of the others, 1599 years. Because of their short half-lives, the radium isotopes are strongly radioactive (Hem 1985).

Knowledge of the aqueous chemistry of radium is summarized in IAEA (2014). It is reportedly similar in chemical behavior to barium (Hem 1985) and calcium (Kathren 1984). It is more soluble than uranium or thorium and can be bioconcentrated by plants (Brazil nuts have an especially high radium content). Radium can be strongly exchanged in the cation exchange series. According to Kathren (1984), the cation exchange sequence for soils is

$$Sr^{2+} < Ra^{2+} < Ca^{2+} < Mg^{2+} < Cs^{2+} < Rb^{2+} < K^+ < NH_4^+ < Na^+ < Li^+$$

^{228}Ra has a much shorter half-life, (5.8 yr) than ^{226}Ra. However, its parent, ^{232}Th, is more abundant in nature than ^{238}U, the parent of ^{226}Ra. As a result, both isotopes are found in groundwater. The U.S. EPA has proposed MCLs of 20 pCi/L for both ^{226}Ra and ^{228}Ra (Federal Register, July 18, 1991). Wells with high radium levels in groundwater have been discovered to be concentrated in two areas of the United States: the Piedmont and coastal plain of the Middle Atlantic states and the upper Northwestern states of Minnesota, Iowa, Illinois, Missouri, and Wisconsin (Hess et al. 1985). Table 6.7 summarizes the distribution of ^{226}Ra and ^{228}Ra in the Atlantic coastal plain and Piedmont region.

The radium content of groundwater is a function of the rock type of the aquifer. Igneous rocks, such as granites, contain the highest proportion of uranium and thorium, the parent isotopes of radium. Granitic rock aquifers and sands and sandstones derived from the weathering of granites have the potential to have high radium. Phosphate rock is also very high in uranium. Radium is not only a problem that is naturally occurring,

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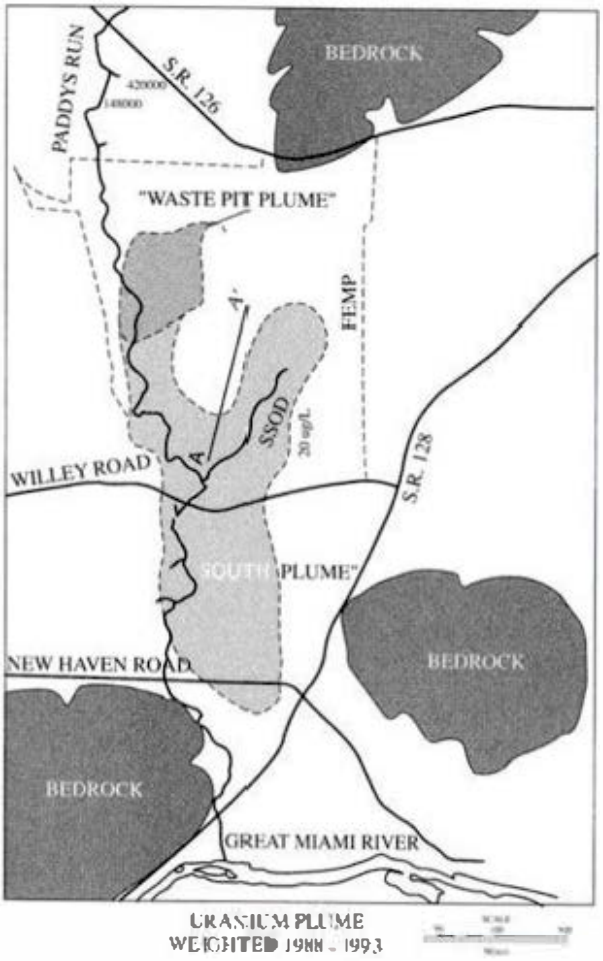
FIGURE 6.17 Composite plume of total dissolved uranium >0.20 µg/L for the period 1988 to 1993.



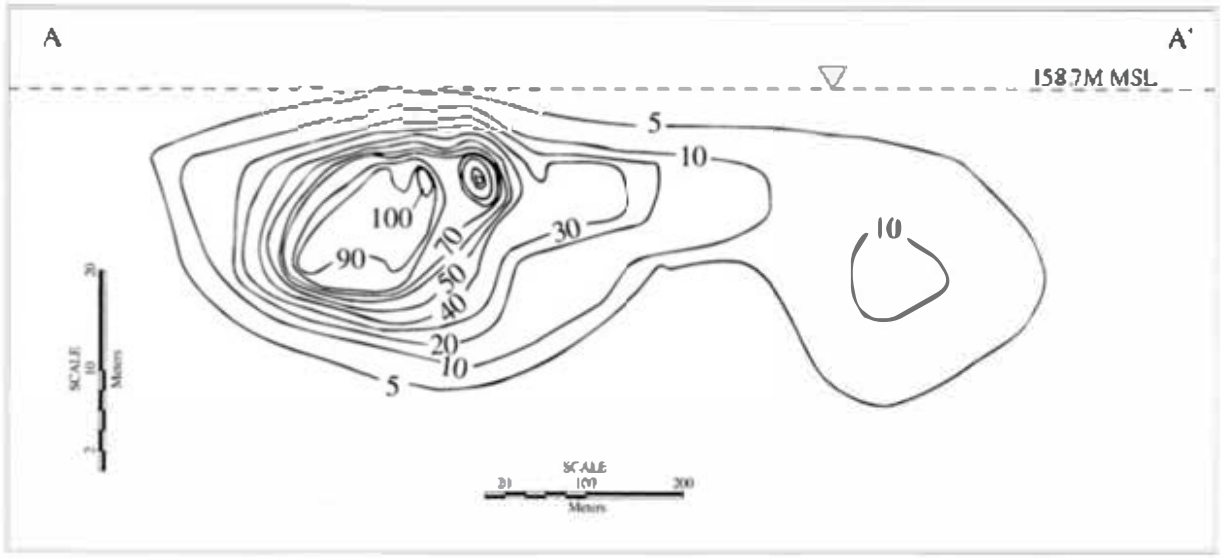
Source: W.C. Sidle and P.Y. Lee. 1996. Uranium contamination in the Great Miami Aquifer at the Fernald Environmental Management Project, Fernald Ohio. *Groundwater* 34:876–882. Used with permission.

Table 6.7 Distribution of 226Ra and 228Ra by aquifer type in the Atlantic coastal plain and Piedmont provinces.

		Ra−228 (pCi/L)		Ra−226 (pCi/L)	
Aquifer Type	Number of Samples	Geometric Mean	Range	Geometric Mean	Range
Igneous (acidic)	42	1.39	0.0–22.6	1.8	0.0–15.9
Metamorphic	75	0.33	0.0–3.9	0.37	0.0–7.4
Sand	143	1.05	0.0–17.6	1.36	0.0–25.9
Arkose	92	2.16	0.0–13.5	2.19	0.0–23.0
Quartzose	50	0.27	0.0–17.6	0.55	0.0–25.9
Limestone	16	0.06	0.0–0.2	0.12	0.0–0.3

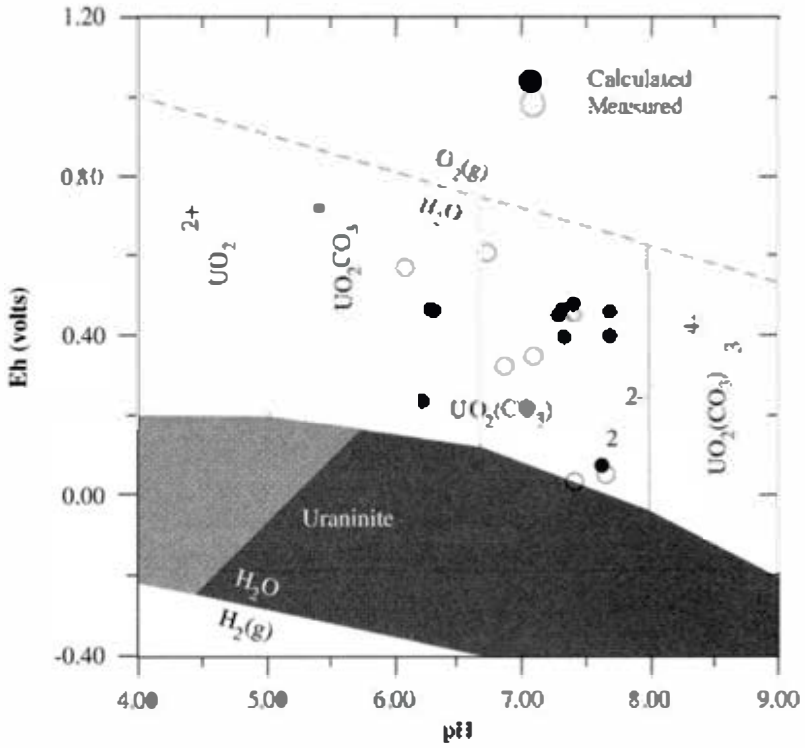
Source: C.T. Hess, J. Michel, T.R. Horton, H.M. Prichard, and W.A. Coniglio, "The occurrence of radioactivity in public water supplies in the United States," *Health Physics* 48 (1985):553–86.

FIGURE 6.18 Longitudinal profile of total dissolved uranium along line A – A' from Figure 6.17.



Source: W.C. Sidle and P.Y. Lee. 1996. Uranium contamination in the Great Miami Aquifer at the Fernald Environmental Management Project, Fernald Ohio. *Groundwater* 34:876-882. Used with permission.

Figure 6.19 Measured and calculated redox potential for the UO_2^{2+}/U^{4+} pair plotted on the $\Sigma U = 10^{-6}$ stability field.



Source: W.C. Sidle and P.Y. Lee. 1996. Uranium contamination in the Great Miami Aquifer at the Fernald Environmental Management Project, Fernald Ohio. *Groundwater* 34:876-882. Used with permission.

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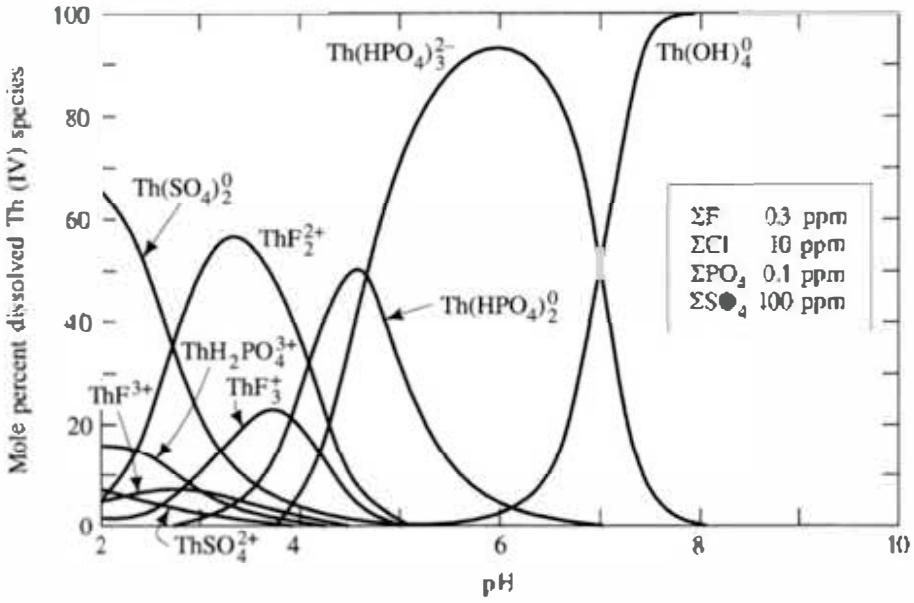
Figure 6.20 Distribution of thorium complexes as a function of pH under standard conditions for an aqueous solution containing 0.3 mg/L F^-, 10 mg/L Cl^-, 100 mg/L SO_4^{2-}, and 0.1 mg/L PO_4^{3-}.



Source: D. Langmuir and J.S. Herman. 1980. The mobility of thorium in natural waters at low temperatures. *Geochemica et Cosmochimica Acta* 44:1753–1766. Used with permission.

but there are localized areas of radium contamination from industrial operations. These are associated with uranium mill tailings as well as facilities where radioluminescent paints were prepared and used. For example, from World War I up until 1968 wrist watches with radium dials that glowed in the dark were sold in the United States.

6.9.6 Radon

There are several isotopes of radon, but ^{222}Rn is the only one that is important environmentally. The other isotopes have half-lives of less than 1 min. The half-life of ^{222}Rn is 3.8 days. ^{222}Rn is produced by the decay of ^{226}Ra, so that it is associated with rocks that are high in uranium. Radon can be associated with water that is low in dissolved ^{226}Ra, because it comes primarily from the decay of the radium in the rock. Radon is a noble gas and does not undergo any chemical reactions, nor is it sorbed onto mineral matter. Radon is lost from water by diffusion into the atmosphere and by radioactive decay through a series of short-lived daughter products to ^{210}Pb, which has a half-life of 21.8 yr.

The EPA has proposed an MCL standard of 300 pCi/L for radon in drinking water (Federal Register, November 2, 1999). However, there is also a health concern for excessive radon accumulation in homes. Radon can enter homes through emanations from the soil as well as by diffusion from tap water with a high radon content.

Owners of private water systems are most at risk from radon in drinking water. Public water-supply systems normally have storage facilities to supply water during fires. The residence time for the water in these facilities allows the radon to both diffuse and decay. Private water systems rely upon wells and usually only have a very small storage facility used to maintain pressure.

8

Site Characterization—Groundwater and Soil Monitoring

8.1 Introduction

Characterization of a potentially contaminated site involves field and laboratory analysis of subsurface properties, with a goal of building a conceptual model of contaminant source strength and configuration, and pollutant movement and transformation with time and space. This, in turn, is done to optimize monitoring strategies, and develop advantageous and cost effective remedial solutions.

The process of characterization begins with identifying the goals of characterization and remediation, and these goals can widely vary. Site characterization approaches will be quite different if the overall goal is to identify parties responsible for pollution, versus a goal of protecting public health, versus a goal of maintaining a vibrant groundwater dependent ecosystem. Further, a site can have several prioritized goals and not just one. Objectives are often linked, for example, one objective might be to minimize costs by requiring a thorough (and perhaps costly) site characterization in order to reduce potentially higher remediation costs by strategically targeting pollutants. There are many different site characterization methodologies including phased or progressive approaches and adaptive management techniques. At a site where very little is known about the nature and extent of subsurface contamination, often a first sampling step is collection and analysis for a broad range of potential contaminants, to be narrowed and focused based on the findings of those early surveys.

It must be emphasized that each site is unique and should not be addressed in a "one size fits all" or "we did it this way at the last site" boilerplate approach. Some of the seemingly smallest changes in geologic heterogeneities at different sites can radically alter subsurface fluid flow, and if unrecognized can cause inappropriate assumptions to be made and incorrect approaches to be followed. Likewise, site-specific physical, human-made features that protrude into or affect the subsurface (e.g., building footings, buried pipeline trenches backed-filled with gravel or other non-native material, groundwater pumping, surface irrigation or paving, application of chemicals at the ground surface, chronic and slow leaks versus massive leaks) all can alter how pollutants change their distribution, phase, form, and potential threat. An underlying note of caution is that the data that monitoring provides is not always representative of the complete hydrogeological picture

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or demonstrates contaminant distribution. Not accounting for these unique properties at each site, or blindly assuming that selected monitoring data is broadly representative of actual field conditions, can cost huge sums in misspent money, useless monitoring, ineffective remediation, lost time, and misstated risks (Nielsen 2005).

There are some general perspectives and overall guiding principles regarding monitoring and site characterization that are helpful. They include the following:

1. Resources spent on proper and thorough site characterization typically save many times their investment in reduced remedial costs.
2. Incautious monitoring installation and practices can make the original environmental problem worse by allowing cross-contamination and short-circuiting of contaminant migration.
3. It is standard to have well-defined goals for characterization and remediation before embarking on site activities.
4. It is very helpful to calculate a good mass balance of contaminants early on, including an estimate (or range of estimates) in source mass, amount retained in vadose zone, amount reaching the water table, mass dissolving into water, mass volatilizing into the gaseous phase, amount sorbing onto soils, mass transforming and/or chemically or biologically degrading, and other sources and sinks of contaminant mass.
5. Typically assessment should begin with noninvasive methods (methods that do not appreciably disturb the subsurface at a site) in order to optimize subsequent invasive methods (such as monitoring well installation).
6. Employing an "outside-in" approach where possible is advantageous to reduce equipment contamination or to prevent contaminant spreading, (e.g., drilling monitoring wells first in areas suspected of low contamination rather than "hot spots," or the practice of sampling wells deemed to be cleanest with low contamination first to reduce the possibility of cross contamination).
7. Phased approaches have benefits in allowing adjustment in monitoring strategies as more information is learned.
8. Consider early/interim remedial action as monitoring and monitoring plans are progressing (beyond just typical emergency response actions to immediate threats). Actions which are taken as monitoring plans are being completed can include: providing early source isolation, plume containment, and extraction of nonaqueous phase liquids to reduce their propensity to migrate.

There are a selection of noninvasive, or minimally invasive techniques available for initial groundwater surveys at potentially contaminated sites, and these procedures are often followed by groundwater and soil sampling. For groundwater sampling, the more invasive methods of installing monitoring wells and collecting groundwater samples have been developed with the specific intention of obtaining a representative sample of water from an aquifer (FDEP 2008; Hughes and Aarons 2014; Aller et al. 1991; NUDLC 2012; Arnold et al. 2009). These monitoring well methods minimize the potential for the introduction of contaminants into the ground through the process of installing a monitoring well. Wells and sampling devices can be constructed of materials that have a minimum tendency to leach materials into and sorb compounds from the water sample. Groundwater samples can be collected in such a manner that

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dissolved gases are not lost or exchanged with the atmospheric gases. Soil samples can also be collected for classification and chemical analysis.

Various methods of collecting samples of soil water are also available, as are procedures for determining the location and nature of subsurface contamination. Soil gas sampling can be done to give an indication of areas where volatile organic compounds are contained in the soil or groundwater. Many other forensic approaches help with the determination of groundwater and contaminant travel times, source location and timing, contaminant transformations and phase changes, geological formations and structures, and potential risk.

Proper site characterization can transform understanding and advance the development of effective remedial strategies. Australian guidance defines the "sound science" associated with contaminated site characterization and development of robust site conceptual models as being based on "organized investigations and observations conducted by qualified personnel using documented methods and leading to verifiable results and conclusions" (NSW 2010).

8.2 Noninvasive Measures

At the beginning of a site characterization program, noninvasive methods are employed to understand the sire without excessive perturbation of the subsurface. Although monitoring wells are usually an essential part of characterizing groundwater contamination, their installation can trigger vertical migration of pollutants, depending on the method of installation. A site characterization process typically begins with definition of objectives and a review of site specifics and history. Records of facility operations and inventories are investigated, contaminant handling practices at the site are looked into, drains and drywells are located, surface features and drainage patterns are reviewed, buried pipelines are identified, past and present employees may be interviewed, pertinent climatic data checked, existing local wells pinpointed along with associated groundwater quality data, and applicable law and regulations reviewed. As part of this process, facility records and manifests are analyzed to understand the possible mass of contaminants handled historically at the site. Agency and utility files, and regional geologic and hydrogeologic information are evaluated. An integral part of these undertakings is an initial site water balance and contaminant mass balance. Most of these undertakings are office related and not carried out directly on-site.

Air photo interpretation, surface geophysics, and quick soil and surface water survey and screening techniques are minimally invasive field techniques. Soil gas surveys are particularly useful for volatile compounds, and there are other noninvasive and informative practices useful in initial site assessment.

8.2.1 Interpretation of Aerial Photography and Remote Sensing

A review of site surface features, both present-day and historical, are easily accessible with the advent of widely available air photo libraries, such as National Aeronautics and Space Administration (NASA) World Wind and Google Earth. Many things pertinent to site characterization can be observed from visible aerial photography. This includes past and present site structures, roads and access points, possible soil staining

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or discoloration, the proximity of nearby creeks and streams, local wetlands and reservoirs and how these change with time, vegetative changes, urbanization, local erosion, industrial surface impoundments, and evaporation ponds. In tectonically active terrain, faults can sometimes be identified by observable surface lineaments. (Faults can be crucial to groundwater flow and contaminant movement in fractured terrain). Because of the replacement of film with digital imagery, the record of aerial photography has come to have a previously unrealized permanence. It should be noted that aerial photography displays a degree of radial distortion and without correction measurements of distance and topography are not accurate. Even so, aerial observation can provide better spatial resolution and geometric fidelity than many ground-based approaches.

The electromagnetic spectrum beyond visible light can also be quite helpful, as aerial photography provides broader spectral sensitivity than the human eye. Spectral bands or individual wavelengths can help identify many site activities. For example, near-infrared radiation (reflectance) can identify plant health, and thermal infrared (emitted spectra) can show heat sources on a property. Radar scanning can identify topographic expressions of subtle features like faults and folds often better than conventional satellite images. These radar techniques include Side-Looking Airborne Radar (SLAR) and LIDAR (a combination of the word "light" and "radar") that can identify ground uplift or subsidence, and define geomorphologic features. There are also airborne geophysical techniques that are noninvasive and help define the geological surroundings of a site. Although traditionally used for geologic resource and mineral assessment, aeromagnetic, radiometric, and gravity surveys can add important information to an understanding of field geological influences on contaminant travel.

8.2.2 The Use of Surface Geophysical Techniques for Site Characterization

Noninvasive surface geophysical techniques can advance site characterization in many ways, although some techniques are expensive, and natural and human-made surface features can interfere with their efficacy. American Standard Testing Methods' ASTM D6429-(2011)e1 is a standard guide for selection of surface geophysical methods, and Olhoeft (1992) provides a Geophysical Advisor Expert System to facilitate field decisions on appropriate geophysical methods.

Electromagnetic Surveys (EM) One surface geophysical method is an electromagnetic survey that measures the magnetic susceptibility of earth materials and their variation. An electromagnetic (EM) induction sensor can detect subsurface electrical conductivity dissimilarities, and therefore is good for locating lateral changes or discontinuities in soil or rock, and fluid filled fracture zones. These heterogeneities can be extremely important in subsurface contaminant movement, particularly for non-aqueous phase liquids (NAPLs). EM techniques can directly detect: burial trenches or pits containing drums or bulk wastes, electrically conductive plumes (particularly useful in coastal saltwater intrusion and saline landfill plumes), plume movement using time-series measurements, and utility pipes/cables (which may transport contaminants through their trench backfill and/or interfere with other geophysical techniques). Electrical conductivity variation can also be an indicator of NAPL presence.

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Airborne electromagnetic surveys can explore large swaths of land, helping to delineate factors directly pertinent to contaminant hydrogeology such as large faults, paleochannels and shear zones with appreciable groundwater and/or clay gouge, and dissimilarities in the electrical conductivity of groundwater bodies. Helicopter transient electromagnetic surveys (TEM) can examine subsurface properties down to 200m depth, and have been used to identify contaminated landfill sites, model pollution and coastal hydrogeology, and optimize management of mining tailings facilities (Silvestri et al. 2009; Pellerin et al. 2010; Kirkegard et al. 2011; Christensen and Halkjaer 2014).

Direct Current Resistivity and Induced Polarization Another geophysical technique is a direct current resistivity survey that employs a constant electrical source using electrodes placed in the ground. The attenuation of voltage from between these electrodes (electrical resistance) allows calculation of depths to water tables or water-bearing horizons, freshwater/ saltwater interfaces, depth to bedrock, and stratigraphy at a site. Like EM techniques, direct current resistivity can identify electrically anomalous plumes and burial sites for bulk wastes and drums. Fencelines, pipelines, and other surface interferences can alter DC resistivity results. A related technique is induced polarization which measures the transient electrical response. This technique has been applied to locating subsurface NAPLs and tracking active or passive remediation, particularly for surfactants that might be injected for soil flushing cleanups (Personna et al. 2013; Magill 2009).

Time Domain Reflectometry Time Domain Reflectometry or TDR measures the relationship between the velocity that an electromagnetic wave moves through and between metal rods which are pushed into the ground, and the dielectric constant of the soil through which the wave propagates. This method has been used to estimate soil water content for many years, but many other applications for contaminated soil have been developed. For example, Olchawa and Kumor (2008) have used a soil's dielectric permittivity measured with TDR to measure the content of diesel oil in soil.

Magnetometry Magnetometry measures nonuniformities in the earth's magnetic field typically caused by buried tanks and drums made of ferrous material (iron and steel) and underground pipelines and utilities. Because many industrial sites have the potential to contain leaking tanks or pipes, these surveys can help locate problem areas. Even in the absence of leaking tanks and pipes, backfill surrounding underground tanks and pipes can be a conduit for some future pollutant flow and can be identified as a potential preferred pathway for fluid migration. Also, locating buried utility features is a critical step before drilling monitoring boreholes.

Seismic Surveys Reflective and refractive seismic techniques require an energy source such as a force striking the ground which generates low-amplitude waves through the earth to surface geophones that record the arrival of these waves. The time delay of wave arrival provides information that can help calculate subsurface stratigraphy, depths to both water table and bedrock, physical and elastic properties of subsurface formations, and lateral soil/rock discontinuities. Because pollution sources can either be pooled up above, or deflected by, subsurface layers, their identification is important in developing an accurate site conceptual model.

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Ground Penetrating Radar (GPR) Ground penetrating radar (GPR) in optimal circumstances also can identify depth to water table and bedrock, stratigraphy, metallic and nonmetalic buried objects, and underground tunnels and cavities. It has limitations in clayey soils because of a lack of radar penetration.

8.2.3 Rapid Noninvasive Field Surveys and Screening

If a thousand soil samples are sent to the laboratory for contaminant analysis, and only one comes back as registering detectable concentration, time and money has been wasted in site characterization. There are rapid field methods for determining the extent of soil, water, and major well contamination that can help focus and direct characterization efforts and save resources. For example, surface water sampling and analysis surveys are normally simple and quick because of easy access, and are often a first measure taken at a site suspected of contamination. Certain surface waters, such as springs, gaining reaches of streams, and wetlands, often directly reflect changes in adjacent groundwater.

Unaided Methods Some survey methods are unaided, such as when soil staining is directly visible, or inferred from directly observable problems like noxious odors, stressed or dead vegetation, and impaired or dead animals. Test pits, holes for building footings, and trenches can be an easy way to observe large cross-sections of the shallow subsurface. Pits, holes, and trenches are often available at urban and industrial sites where buildings are being put in, old underground tanks are being exhumed, or underground pipelines and utilities are being established. These open holes and trenches can provide opportunities for visible identification of contamination because of large continuous exposure of the subsurface. Direct sampling of soil and any ponded water is simple with a limited risk of vertical contaminant migration. Test pits and trenches can delineate shallow stratigraphy, waste disposal areas, grossly contaminated sites, buried pipelines and underground storage tanks. Importantly, some of these site features potentially contain health hazards (e.g., toxic gases or potential trench wall collapse), and safety measures need to always be considered in these investigations.

Colorimetric Screening Techniques Classes of contaminants, like NAPLs, can be inexpensively and immediately detected by direct visual sightings in soil and water, but can be difficult when a NAPL or another pollutant of interest is clear or colorless, at low saturation, or distributed heterogeneously. NAPLs which cannot be visually detected can be quickly discovered by a number of other simple techniques. Many NAPLs like crude oil, coal tar, creosote, and other petroleum products naturally fluoresce when exposed to ultraviolet (UV) light. The inexpensive methodology of putting a soil sample in a transparent plastic bag and placing it under a "black" (UV) light is a cost effective way to screen soils for many sorts of NAPL contamination. Also for NAPLs there are hydrophobic dyes which, when put in transparent containers with soils and shaken, give indicator colors in the presence of NAPLs. In water, hydrophobic filters or hydrophobic materials can be used to detect NAPL, or centrifugation can more clearly separate a nonaqueous phase from water. A syringe needle can also be used to extract suspected globules in a surface water or groundwater sample, and the globule can be placed in a water column to observe whether it mixes, sinks, or floats. In wells, NAPL presence can be observed in a number of ways. A simple quick

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method is dropping and retrieving a weighted string into a well and observing whether oil phases adhere to it. The weighted string should not be reused in another well to avoid cross-contamination. Hydrocarbon detection pastes (and water detection pastes for fuel storage tanks) can additionally help differentiate oils and water.

Immunological Surveys Another rapid field screening technique for water and soils are immunological surveys where polyclonal antibodies are mixed with soils and elicit a colorimetric response in the presence of certain pollutants. Polycyclic aromatic hydrocarbons (PAHs) have been shown to be detectable with about 5% false negatives and 5% false positives in one immunological survey (Knopp et al. 2000).

8.3 Minimally Invasive Soil Monitoring

Monitoring techniques which have minor perturbation of field site geologic materials include soil vapor monitoring, soil water sampling, and phyroscreening. Although some of these techniques penetrate the subsurface, the disturbance is minor and at shallow depths.

8.3.1 Soil Vapor Monitoring—Introduction

Soil-gas monitoring can be valuable for several reasons. Volatile organic liquids in the subsurface can partition into a vapor phase in the vadose zone and therefore be identified with soil gas measurement. A volatile organic liquid source may be pure oil phase product either adhering to a mineral surface or forming a nonaqueous phase layer on top of the capillary zone. It may also be dissolved in soil water or groundwater. The major benefit of soil gas screening is that it can locate zones of contamination. Identified locations of undissolved product present in the vadose zone can be recognized as a potentially persistent reservoir for ongoing contamination of groundwater, and infiltrating precipitation could dissolve the product in these zones and carry it down to the water table in the aqueous phase. Soil-gas monitoring can also be used to help determine the location of spills and leaks, and the horizontal extent of a layer of a volatile, nonaqueous phase liquid, such as gasoline, floating on the water table. Vapors from the gasoline can partition into the vadose zone, so that if they are detected by soil-gas monitoring in an area where product spills or leaks are not likely, this is an indication that the product may be migrating into the area. Additionally, soil-gas monitoring has been used as a screening method to evaluate the extent of a plume of groundwater contaminated with volatile organic compounds. The soil gas above the plume may contain volatile organics if the plume is at the water table.

Contaminant vapors themselves can be problematic. They can intrude into buildings and homes, sometimes with adverse health and safety implications (USEPA 2002). The restoration of a site may involve soil remediation if organic compounds are detected in the vadose zone. Soil vapor monitoring has been incorporated into guidelines for site investigation for some countries, for example Denmark (Algreen et al. 2015a). Under many conditions soil gas monitoring can be done much more quickly and inexpensively than installing groundwater monitoring wells. Soil gas monitoring is a noninvasive technique with little subsurface disturbance which can be used to optimize follow-on invasive methods such as well installation (ITRC 2007).

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The boring is then unsealed; the vapor monitor is removed and sealed in a container for shipping to the lab, where it is analyzed (Kerfoot and Meyer 1986; NSW 2010).

Soil gas monitoring to find groundwater contamination plumes works best in areas where the vadose zone is comprised of dry, coarse-grained soils. The depth to water cannot be too deep, but at least 4.6 m (15 ft) is preferable. If the water table is too shallow, the concentration gradients are very steep, and a slight difference in depth of measurement may give a great difference in measured values (Marrin 1988). It is not possible to find an exact correlation between the soil gas concentration and contaminant concentration in the underlying groundwater. At best an order-of-magnitude correlation is possible (Thompson and Marrin 1987). Soil gas measurements are affected not only by the soil gas but also by the sampling technique and the soil-air permeability. After a rainfall, soil pores may be physically occluded by infiltrating rainwater and sampling may be impossible, particularly in finer soils. If there are several volatile organic compounds in the groundwater, they will partition into the vadose zone according to their individual Henry's law constants (Chapter 3). The organic compound with the greatest concentration in the soil gas may be the compound with the greatesr Henry's law constant and not the one with the greatest concentration in the groundwater. Although care must be taken when interpreting the results of a soil gas survey, these surveys are valuable screening techniques and have significant qualitative value.

Samples of indoor air in buildings are important in identifying risks from explosive or toxic vapors, but at some sites they also show a general correlation between intrusive indoor air vapor concentrations and underlying groundwater volatile organic compound (VOC) plumes. These indoor air concentrations can vary greatly seasonally or with varying barometric pressure, but still can provide useful information which mirrors groundwater concentrations. Indoor air sampling uses a vacuum-filled ampule in which a valve is released and air is drawn in. Valve release can either be rapid for a single-time sample, or can have a slow timed release that collects an integrated sample with time.

8.3.3 Soil Water Sampling—Introduction

Contamination moving from the surface toward the water table passes through the vadose zone. Monitoring of soil-water quality in the vadose zone beneath hazardous-waste land-treatment systems is required under Subtitle C of the Resource Conservation and Recovery Act in the United States. States may also require vadose-zone monitoring beneath other types of hazardous-waste facilities.

In order to determine the chemical composition and quality of soil moisture in the vadose zone, a sample must be collected. Because the soil water in the vadose zone is under tension, it cannot flow into a well under gravity the way that groundwater flows into a well. Soil water must be collected with a suction lysimeter (Wilson 1990).

8.3.4 Suction Lysimeters

A **suction lysimeter** is a porous cup located on the end of a hollow tube. The tube can be PVC or even stainless steel. The porous cup can be ceramic, nylon, PFTE, or fritted stainless steel. Tubing connects the suction lysimeter with the surface.

A suction is applied to the hollow tube and held for a period of time. If the suction is greater (more negative) than the soil-moisture tension in the soil, a potential gradient

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will develop from the soil to the potous cup. Soil-water will flow into the porous cup, from which it can then be directed through the tubing to the surface for collection. The flow of soil moisture can be slow, and it may be necessary to hold the vacuum overnight to supply a sufficient volume.

A vacuum lysimeter simply has a porous tip on the end of a hollow tube with a stopper that extends to the surface. The vacuum is applied to the lysimeter by means of a hand-vacuum pump attached to a small tube that extends down to the porous tip, and a sample is drawn to the surface when vacuum is applied (Figure 8.1). The practical depth of this type of sampler is about 1.8 m (6 ft) due to the awkwardness and cost of installing long tubes (Wilson 1990).

A pressure-vacuum lysimeter has a hollow tube that is about 5.08 cm (2 in.) in diameter and 0.3 m (1 ft) long. Two tubes run from the lysimeter to the surface (Figure 8.2). One of the tubes, the discharge line, extends to the bottom of the lysimeter and the other tube, the pressure-vacuum line, ends near the top. A vacuum is applied to the pressure vacuum line with a vacuum pump while the discharge line is shut off with a pinch clamp. The pressure-vacuum line is then sealed with a pinch clamp and the lysimeter is allowed to sit overnight so that the sample can be drawn into the cup. The pinch clamps are then removed. A hand-pressure pump is then attached to the pressure-vacuum line, and when pressure is applied, the water is forced up the discharge line to the surface. (A single pressure-vacuum hand pump can be used for this operation.) The maximum practical operational depth for the pressure vacuum pump is about 15 m (50 ft). At depths

FIGURE 8.1 Operation of a vacuum lysimeter.

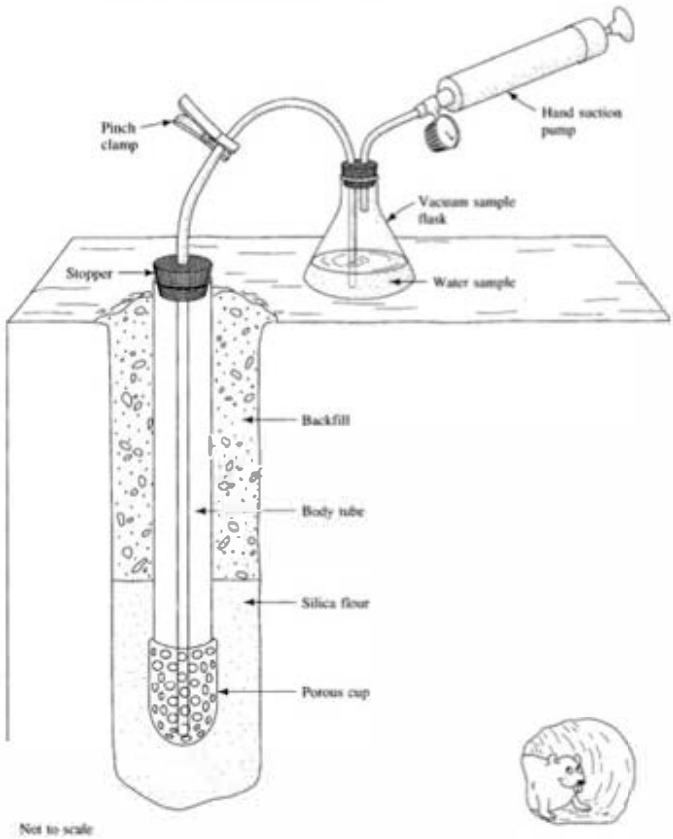
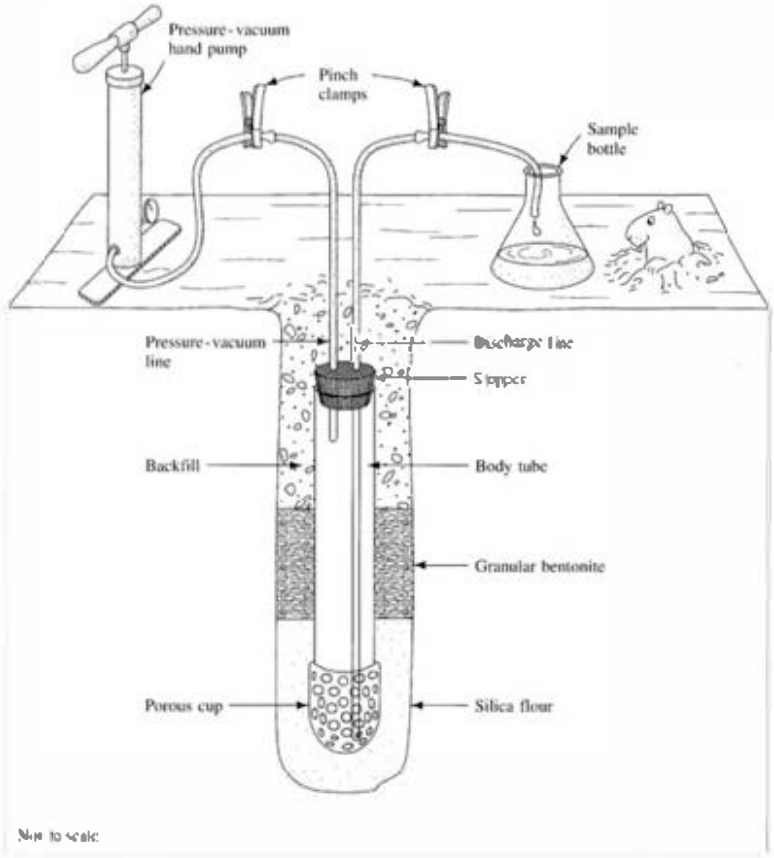


FIGURE 8.2 Operation of a pressure-vacuum lysimeter.



greater than this, the pressure needed to force the sample to the surface tends to drive it back out of the porous cup. This can be avoided by using a lysimeter with a check valve and an internal reservoir (Figure 8.3). When the vacuum is applied the water is drawn into the reservoir. When the pressure is then applied, the check valve prevents backflow into the porous cup and the sample must go to the surface.

8.3.5 Installation of Suction Lysimeters

In order for suction lysimeters to work properly, they must be carefully installed (Wilson 1991). Prior to use, new porous ceramic cups should be leached with a 10% hydrochloric acid solution for 24 hours to remove dust from manufacturing. They should then be thoroughly rinsed by passing distilled water through them. The lysimeter is then pressure tested before being installed by submerging it in water and applying a pressure of 207 kpa (30 lb/in.^{2}) to test for leaks. No leaks should appear at any fittings, and air should bubble evenly through the porous cup.

The suction lysimeter is installed in an augered hole that has a greater diameter than the hollow tube. If the suction lysimeter is placed at a shallow depth, less than about 3 m (10 ft), then the access hole can typically be made by a hand auger. If it is greater than that depth, then a hollow-stem auger-drilling rig is needed to auger a hole.

The porous tip must be well bedded in slurry made of 200-mesh silica flour or native soil material that has been dried and screened to remove the fraction larger

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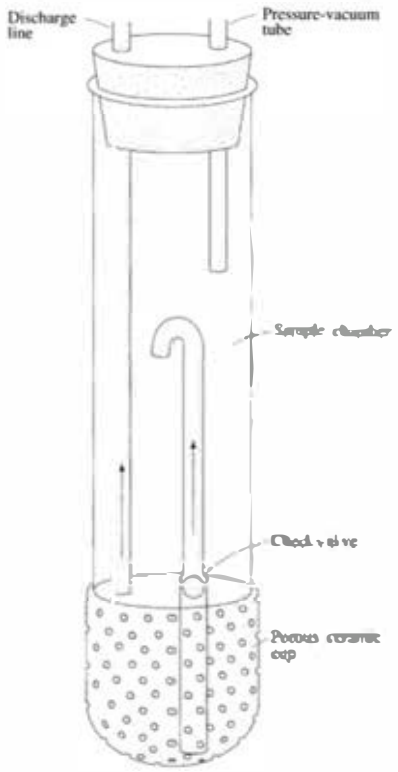
FIGURE 8.3 Design of a pressure-vacuum lysimeter with a sample chamber and a check valve.



than coarse sand. There needs to be good hydraulic contact with the porous cup, the bedding material, and the native soil. Prior to installation the porous tip should be well hydrated by soaking in distilled water.

If a hollow-stem auger is being used, the augers should first be pulled back about 0.61 m (2 ft) to expose the native soil. A slurry made from silica flour and distilled water (0.45 kg (1 lb) of 200-mesh silica flour and 150 mL of distilled water) is put into the hole with a tremmie pipe to fill the hole with about 15.25 cm (6 in.) of slurry. The suction lysimeter is then lowered into the hole and centered. The tremmie pipe is then used carefully to place the slurry around the lysimeter up to an elevation of about 0.3 m (1 ft) above the top of the lysimeter. The unit should be held in place until the water drains from the slurry. The unit is then tested to see if it will hold a vacuum of 60 Kpa (0.6 bars). If it does, the augers are pulled back another 0.91 m (3 ft); then about 0.3 m (1 ft) of sieved native soil and 0.61 m (2 ft) of bentonite granules are added. The tremmie pipe is used to add distilled water to the bentonite to hydrate it. Finally, the augers are pulled and the borehole is backfilled with native soils that are tamped down to ensure compaction. Since a lot of distilled water was added to the soil during installation, the lysimeter needs to be purged until consistent water quality is obtained.

8.3.6 Phyto-screening

Phytoscreening is based on the ability of plants to translocate contaminants from their root zone to plant tissues above ground. Because the root zones of plants can be relatively large and their capture areas in the soil ill-defined, the method is somewhat

qualitative, but potentially useful, particularly in locales with shallow groundwater contamination at large sites. Trees can draw water from groundwater, the capillary fringe, and/or pore water in the vadose zone, and therefore phyto-screening can supplement and enhance soil gas screening techniques (Algreen et al. 2015a). Often tree coring or plant tissue harvesting is used as a collection and detection method for determining the location of subsurface pollutants. Coring and use of plant tissues has been used, with certain limitations, to locate chlorinated solvents (Vroblesky, Nietch, and Morris 1999; Orchard et al. 2000; Vroblesky et al. 2004; Sorek et al. 2008; Larsen et al. 2008; Limmer et al. 2011), BTEX compounds (Algreen et al. 2015b; Wilson et al. 2013) and heavy metals (Stefanov et al. 2012; Algreen et al. 2012; 2014).

8.4 Invasive Methods - Monitoring Well Design

8.4.1 General Information

Monitoring wells are installed for a number of different purposes. During the installation of a monitoring well, a soil boring may be made or rock-core samples may be collected to determine the basic geology of the site. Prior to the design of a well, it is necessary to determine what its use will be. Some purposes of monitoring wells include:

- Measuring the elevation of the water table.
- Measuring a potentiometric water level within an aquifer, or at several depths in an aquifer.
- Collecting water samples for chemical analysis.
- Collecting samples of a nonaqueous phase liquid that are less dense than water.
- Collecting samples of a nonaqueous phase liquid that are more dense than water.
- Testing the permeability of an aquifer or aquiclude at discrete depths.
- Providing access for geophysical instruments.
- Collecting a sample of soil gas.

The use for which the well is intended will dictate the design. For example, if a well is to be used for the collection of water samples, the casing must be large enough to accommodate the watersampling device. However, the diameter should not be much larger than the minimum size, because prior to the sampling of a well, stagnant water must be removed from the casing; the larger the diameter of the casing, the greater the volume of water that must be pumped and properly disposed. Some slightly more expensive characterization techniques can be well worth it for understanding a site. For example, high-resolution multilevel wells can produce orders of magnitude more data and understanding than single-screened wells. Figure 8.4 is a generalized schematic of a typical monitoring well. The following factors should be specified in the design of a monitoring well:

- Type of casing material.
- Diameter of the casing.
- If there will be a well screen, multiple screens, or an open borehole.
- If there is an open borehole, how deep the surface casing should be set. Cross connections between separate aquifers should be avoided.
- Length of casing.
- Depth of the well.
- Number of target sampling depths and screened intervals necessary in each well.
- Setting and length of the well screen(s).

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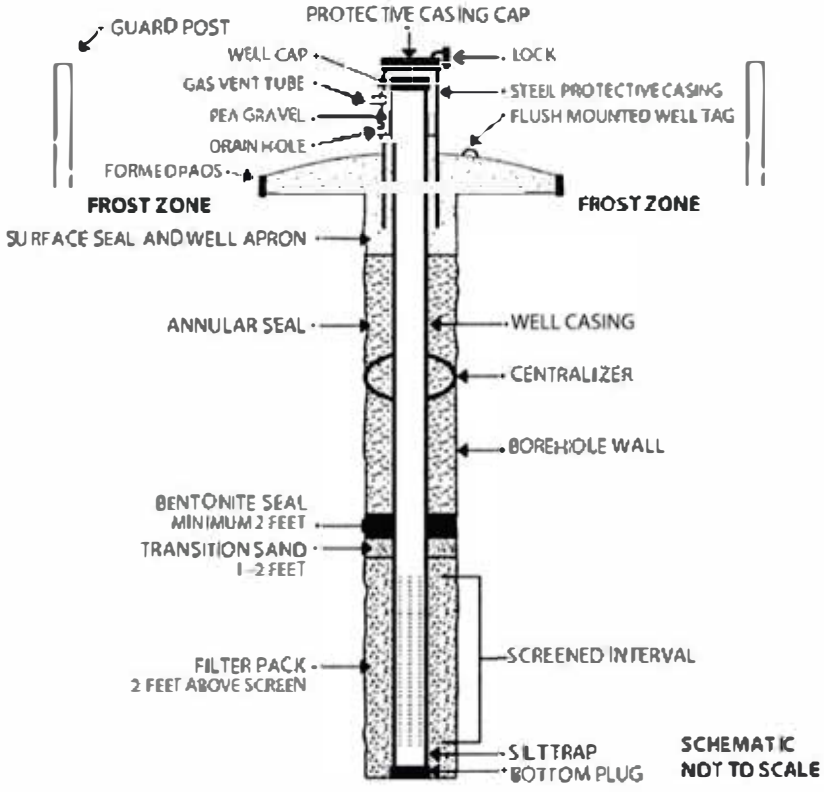
- Diameter of well screen(s).
- Type of material for well screen(s).
- Slot opening of well screen.
- If an artificial filter pack (gravel pack) is necessary.
- Gradation of filter pack (gravel pack) material.
- Method of installation of well and screen.
- Material used to seal annular space between casing and borehole wall.
- Protective casing or well vault.

Monitoring network design is determined not only by intended well uses, but physical factors in the locale. Sire specific influences of geography, practical consideration of surface conditions, and subsurface variability determine network monitoring design (Arnold et al. 2009). Geographical factors include natural and human-made topographic anomalies; natural and engineered surface drainage routes; areas of potential recharge and discharge such as wetlands; factors which influence the overall water balance such as weather and climatic variability; and anthropogenic features such as buildings, pavement, and pipelines. The practicalities of sire accessibility and compatibility of monitoring wells with facility operations is often an important factor in well placement. Subsurface conditions also help dictate well network design. In general, more monitoring wells with closer intervals between wells, and multilevel sampling ability are required if there is complicated geology (e.g., discontinuous structures, tight folds, closely spaced

Figure 8.4 Typical monitoring well.



Source: E. Hughes and G. Aarons, 2014, *Well Design and Construction for Monitoring Groundwater at Contaminated Sites*, The California Environmental Protection Agency.

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fractures, faults, solution channels), heterogeneous conditions (e.g., variable hydraulic conductivity, variable lithology), steep or variable hydraulic gradients, low dispersivity potential, high flow velocities, or if the aquifer is located near a recharge zone. Depths to water tables, confining layers, and bedrock surfaces are key in decisions about screen intervals and drilling depths. Lastly, the number and placement of wells often is based on prior application of noninvasive methods. These can include indirect methods (such as surface geophysics, soil gas where applicable, airborne remote sensing) or direct observation (such as existing wells, soil borings, test pits, and observation of local outcrops).

Common problems with groundwater monitoring systems include instances where wells are placed by regulatory mandate; where there is incomplete site data; when initial ideas on site (and regional) geology, hydrogeology, and water balance are not correct; and when incorrect assumptions are made regarding waste constituent migration. Difficulties also arise with improperly constructed wells, when they are not properly identified, or in cases when wells are not properly surveyed for location and elevation.

8.4.2 Monitoring Well Casing

All monitoring wells have a casing, whether they have a screen or terminate in an open borehole in bedrock. The casing is a piece of solid pipe that leads from the ground surface to the well screen or open borehole and is intended to keep both soil and water from entering the well other than through the screen or open borehole. Casing also prevents water from flowing from one aquifer horizon to another, provided the annular space outside the casing is properly sealed.

The diameter of the casing for a monitoring well is determined by the use for which the monitoring well is planned. If the only purpose of the monitoring well is to measure water levels, then a 2.54 cm (1 in.) inside-diameter casing is all that is needed. An electric probe to measure water level or a pressure transducer will fit inside the 2.54 cm (1 in.) casing. Figure 8.5 shows an electric probe being lowered into a 5.08 cm (2 in.) casing.

If a well is to be used to collect a groundwater sample, the diameter of the well needs to be such that standard well-sampling equipment can fit inside. The common standard for well-sampling equipment is a nominal 5.08 cm (2 in.) diameter. This can accommodate a wide variety of pumps that can withdraw water at rates of 0.03 to 0.13 or 0.19 L/s (0.5 to 2 or 3 gal./min). Specially designed borehole geophysical equipment can also fit inside a 5.08 cm diameter casing.

For some applications, monitoring wells may be intended for several functions such as measuring water levels, collecting water samples, pumping to remove contaminated water and perhaps floating nonaqueous phase liquids, and as a part of a vapor-extraction system. These wells sometimes have diameters larger than 5.08 cm (2 in.) to accommodate pumping equipment with a higher-flow capacity. The actual equipment to be used determines the casing diameter.

Casing diameter can also be influenced by the depth of the well. The deeper the well, the stronger the casing and screen must be to resist the lateral pressure at the final depth and the crushing force of the weight of the length of casing. Larger diameter casing can be made with thicker walls to have greater strength. It is easier to have a straight well with stronger casing. Straight wells are important in accommodating bailers and pumps.

The outside diameter of casing is standard; however, the inside diameter is a function of the wall thickness. Table 8.1 lists the wall thickness and inside diameter for

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FIGURE 8.5 Electric probe used to measure water levels in monitoring wells.

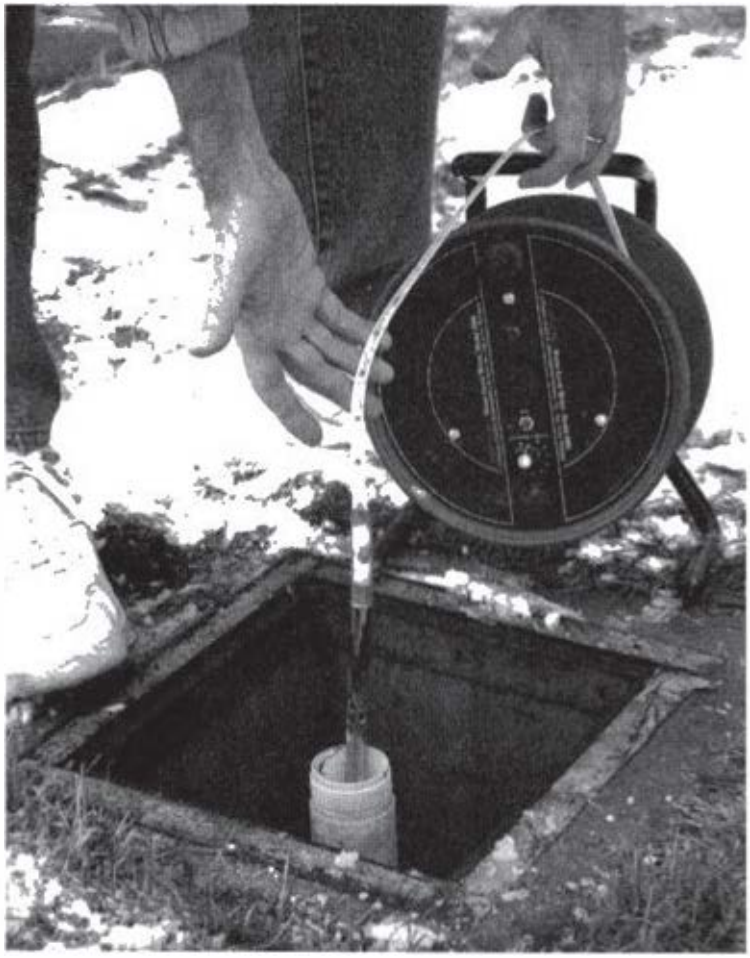

Photo credit: Jim Labre.

TABLE 8.1 Dimensions of inside and outside diameters of well casings.

		Schedule 5		Schedule 10		Schedule 40		Schedule 80	
Pipe Size	Outside Diameter	Wall Thickness	Inside Diameter	Wall Thickness	Inside Diameter	Wall Thickness	Inside Diameter	Wall Thickness	Inside Diameter
Nominal 2"	2.375"	0.065"	2.245"	0.109"	2.157"	0.154"	2.067"	0.218"	1.939"
Nominal 3"	3.500"	0.083"	3.334"	0.120"	3.260"	0.216"	3.068"	0.300"	2.900"
Nominal 4"	4.500"	0.083"	4.334"	0.120"	4.260"	0.237"	4.026"	0.337"	3.826"
Nominal 5"	5.563"	0.109"	5.345"	0.134"	5.295"	0.258"	5.047"	0.375"	4.813"
Nominal 6"	6.625"	0.109"	6.407"	0.134"	6.357"	0.280"	6.065"	0.432"	5.761"

various schedules of casing. The sizes are listed in English units (inches) as many casings and screens were produced for decades in countries not yet on the metric system. Table 8.2 lists recommendations for selection of casing and screen material. Heavier-schedule casing is stronger because it has a thicker wall. The strength of a casing also depends upon the material from which it is constructed. A schedule 5 casing

TABLE 8.2 Recommendations for selection of casing and screen material.

	Do Not Use:	Use:
1	PTFE if well depth exceeds 225-375 feet (68.6-114 meters)	PVC, ABS, SS
2	PVC or ABS if well depth exceeds 1200–2000 feet (366-610 meters)	SS
3	SS if pH < 7.0	PVC, ABS or PTFE
4	SS if D.O. > 2 ppm	PVC, ABS or PTFE
5	SS if H_2S > 1 ppm	PVC, ABS or PTFE
6	SS if TDS > 1000 ppm	PVC, ABS or PTFE
7	SS if CO_2 > 50 ppm	PVC, ABS or PTFE
8	SS if Cl^- > 500 ppm	PVC, ABS or PTFE
9	PVC if a neat PVC solvent/softening agent* is present or if the aqueous concentration of the PVC solvent/softening agent exceeds 0.25 times its solubility in water	SS, PTFE
10	Solvent-bonded joints for PVC casings	Threaded PVC casings
11	Welding stainless joints	Threaded SS casings
12	Any PVC well casing that is not NSF-ASTM approved—D-1785 and F-480	NSF-ASTM approved PVC well casings—D-1785 and F-480
13	Any stainless steel casing that is not ASTM approved—A312	ASTM approved SS 304 and SS 316 casings—A312
14	Any ABS well casing that is not ASTM approved	ASTM approved ABS casings—F-480

*Known PVC solvents/softening agents include:
Tetrahydrofuran, cyclohexane, methyl ethyl ketone, methyl isobutyl ketone, methylene chloride, trichloromethane, 1,1-dichloroethane, 1,1,1-trichloroethane, trichloroethylene, benzene, toluene, acetone, and tetrachloroethylene.

ABS Acrylonitrile butadiene styrene
D.O. Dissolved oxygen
ppm parts per million
PTFE Polytetrafluoroethylene
PVC Polyvinyl chloride
SS Stainless steel
TDS Total dissolved solids

Source: E. Hughes and G. Aarons. 2014. *Well Design and Construction for Monitoring Groundwater at Contaminated Sites.* The California Environmental Protection Agency.)

made of stainless steel is stronger than a schedule 40 casing made of polyvinyl chloride (PVC), yet leaves a greater inside diameter.

There are a number of materials used to make well casings and screens. These materials vary in chemical inertness, strength, durability, ease of handling, and cost. One must always consider the intended use of the monitoring well before selecting a material. What is the chemistry of the groundwater and associated contaminants?

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Will any compounds present in the groundwater react with any of the possible casing materials? How deep will the well be? What are the strength requirements? Is the well intended for a short-term monitoring project or will it remain in service for many years?

Well casings are available in a variety of materials: fluoropolymers, such as PTFE, or polytetrafluoroethylene (Teflon® is the brand name of one manufacturer of PTFE), mild steel, galvanized steel, stainless steel, polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), fluorinated ethylene propylene (FEP), fiberglass-reinforced epoxy (FRE), polypropylene, and fiberglass-reinforced plastic (FRP). The ideal casing material is inexpensive, strong, not subjected to degradation in the environment, and will not affect water-quality samples by either leaching chemicals into or sorbing them from the groundwater (Ranney and Parker 1997). Mild or galvanized steel is often used for water-supply well casings but is not as frequently found in monitoring wells because it may react with the groundwater to leach metals from the casing (Barcelona et al. 1983). Polypropylene, FEP, and ABS are not widely available. Most monitoring wells are made of stainless steel or PVC, with PTFE being less common. PVC casing is the least expensive. Relative casing costs for other materials, compared with PVC, are mild steel = 1.1, polypropylene = 2.1, type 304 stainless steel = 6.9, type 316 stainless steel = 11.2, and PTFE = 20.7. Type 316 stainless steel is more resistant to corrosion than type 304 under reducing conditions (Aller et al. 1991).

Stainless steel has the greatest strength, followed by mild steel. Both are also resistant to heat, but they are heavier than the plastics and are, therefore, more difficult to install. The lower strength of the plastics is compensated for by using a heavier-schedule casing than necessary with steel. Most monitoring wells are shallow enough that schedule 40 or 80 PVC has sufficient strength. PTFE is more brittle and has less wear resistance than PVC or polypropylene and is hence less durable. PTFE also has a low tensile strength and high weight per unit length, which limits its use to shallow depths. Even there, PTFE casing tends to bow under its weight when installed in monitoring wells and may not be straight and plumb. Although its nonstick properties are good in frying pans, the neat cement grout used to seal the annular space between the casing and the borehole may not bond to the PTFE casing (Nielsen 1988). Table 8.3 gives comparative strengths of casing materials.

Groundwater monitoring wells can come into contact with pure organic compounds (LNAPLs and DNAPLs) as well as highly acidic and highly basic conditions. Ranney and Patker (1997) tested six different materials that are used or could be used as monitoring well casings in order to test their resistance to pure (neat) organic chemicals and acids and bases. (Stainless steel and galvanized steel are known to be unaffected by organic compounds but susceptible to corrosion by acids and bases.) They found that PTFE and FEP were unaffected by any of the 28 different organic chemicals in which they were immersed. The other four materials—PVC, ABS, FRE, and FRP—were affected to some degree by some, or in the case of ABS, all of the 28 chemicals. This study suggests that if contact with neat organic compounds is possible, PTFE, FEP, or stainless steel casings should be considered, although some PTFE materials are slightly porous, and are deformable and "ductile" under loading.

In the selection of casing material for groundwater monitoring wells, we must consider the potential chemical reactions between the casing material and the groundwater. Ideally, casing material should neither leach matter into water nor sorb

TABLE 8.3 Comparative strengths of casing materials. Note: 1 lb = 0.454 kg and 1 lb/in^2 = 0.07 kg/cm^2.

Material	Casing Tensile Strength (lb)		Casing Collapse Strength (lb/in^2)	
	2-inch diameter nominal	4-inch diameter nominal	2-inch diameter nominal	4-inch diameter nominal
Polyvinyl chloride (PVC)	7,500	22,000	307	158
PVC casing joint[b]	2,800	6,050	300	150
Stainless steel (SS)[c]	37,760	92,000	896	315
SS casing joint[b]	15,900	81,750	No data	No data
Polytetrafluoroethylene (PTFE)	3,800	No data	No data	No data
PTFE casing joints[b]	540	1,890	No data	No data
Epoxy fiberglass	22,600	56,500	330	250
Epoxy casing joints[d]	14,000	30,000	230	150
Acrylonitrile butadiene styrene (ABS)	8,830	22,000	No data	No data
ABS casing joints[d]	3,360	5,600	No data	No data

a Information provided by E.I. du Pont de Nemours & Company, Wilmington, DE.

b All joints are flush-threaded.

c Stainless steel casing materials are Schedule 5 with Schedule 40 joints; other casing materials (PVC, PTFE, epoxy, ABS) are Schedule 40.

d Joints are not flush-threaded, but are a special type that is thicker than Schedule 40.

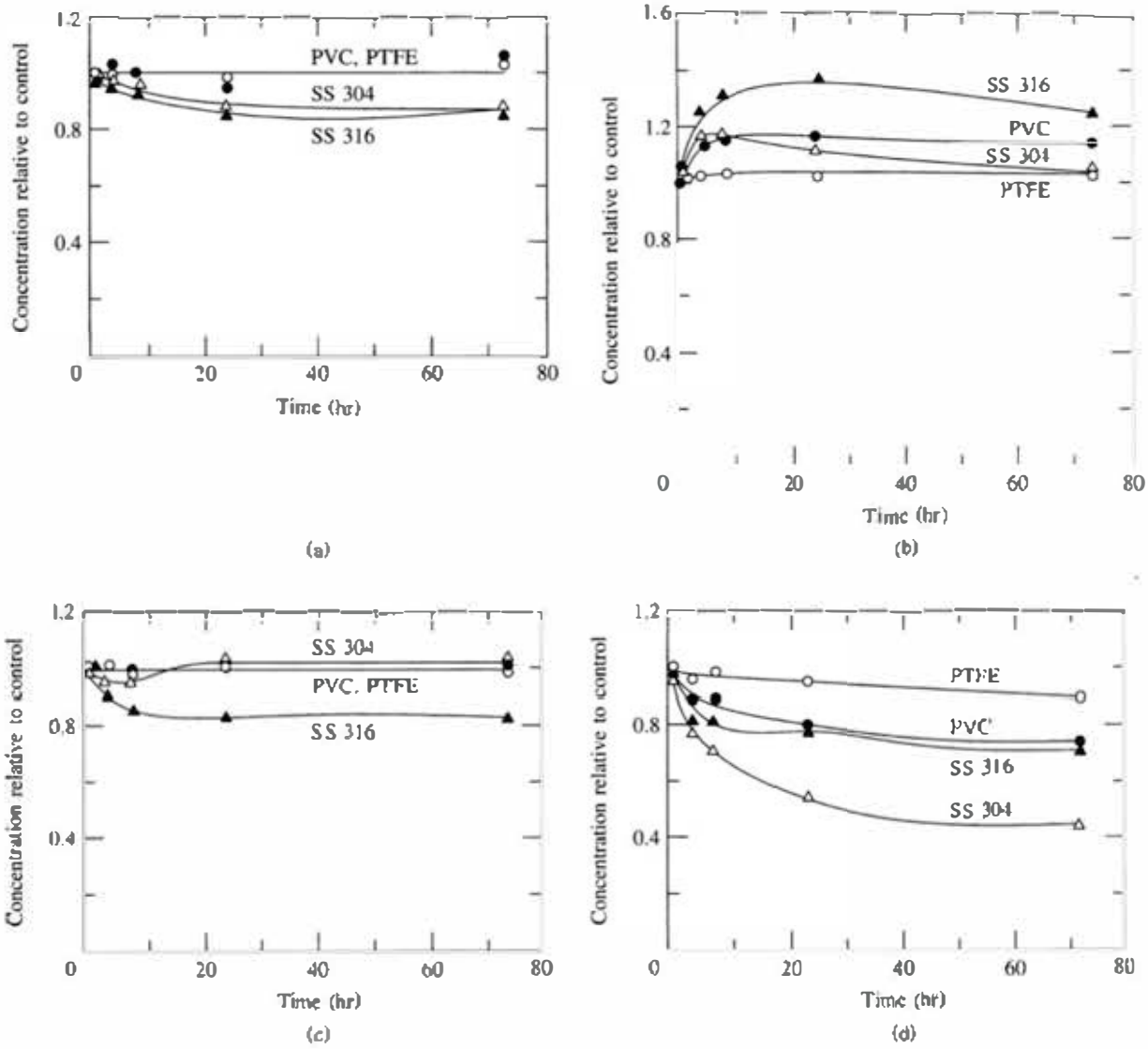
Source: E. Hughes and G. Aarons, 2014. *Well Design and Construction for Monitoring Groundwater at Contaminated Sites.* The California Environmental Protection Agency)

chemicals from water. Table 8.4 shows general recommendations for casing/ screen material selection.

Reynolds and Gillham (1985) studied the sorption from aqueous solution of five halogenated organic compounds by several polymer materials. The organic compounds used were 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, hexachloroethane, perchloroethene, and bromoform. The materials tested were PVC, PTFE, nylon, polypropylene, polyethylene, and latex rubber. Nylon, polypropylene, polyethylene, and latex rubber rapidly absorbed all five compounds. PVC absorbed all the compounds but 1, 1, 1-trichloroethane, although the rate of absorption was low. PTFE absorbed all the compounds but bromoform; although the rate of adsorption of three of the four remaining compounds was low; PTFE absorbed 50% of the perchloroethylene in 8 hours.

Parker, Hewitt, and Jenkins (1990) evaluated the suitability of PVC, PTFE, stainless steel type 304 (SS 304), and stainless steel type 316 (SS 316) as casing material for monitoring metals in groundwater. They evaluated the interaction of four trace elements that are of concern in groundwater studies: arsenic, cadmium, chromium, and lead. The metals were tested at concentrations of 50 and 100 µg/L dissolved in groundwater. Figure 8.6 shows the results of this study. If the concentration relative to

FIGURE 8.6 Sorption and leaching of a. arsenic, b. cadmium, c. chromium, and d. lead by well casings made from PVC, PTFE, type 304 stainless steel, and type 316 stainless steel.

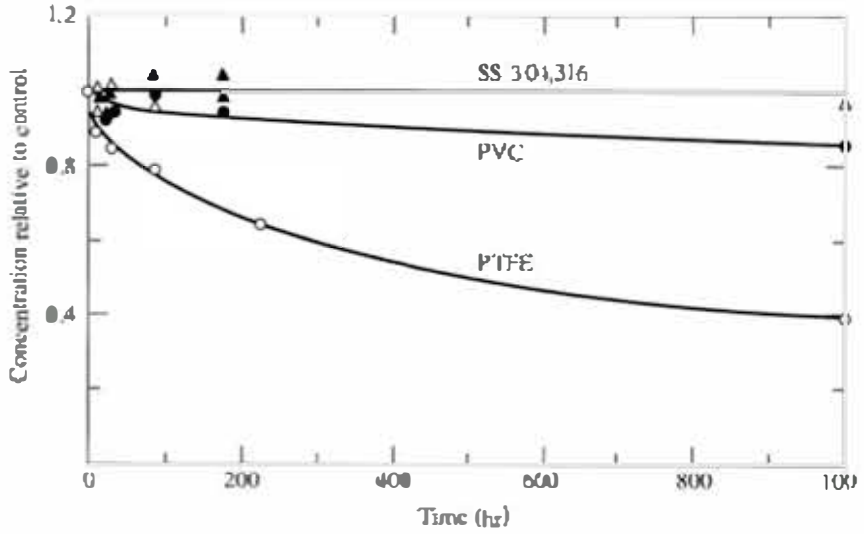


Source: L. V. Parker, A. D. Hewitt, and T. F. Jenkins, 1990. Influence of casing materials on trace-level chemicals in ground water. *Groundwater Monitoring & Remediation* 10:146–156. Used with permission.

for well casing should be used, and in the United States it should carry the designation *NSF wc*, which indicates that the casing conforms to National Sanitation Foundation Standard 14 for potable water supply (National Sanitation Foundation 1988).

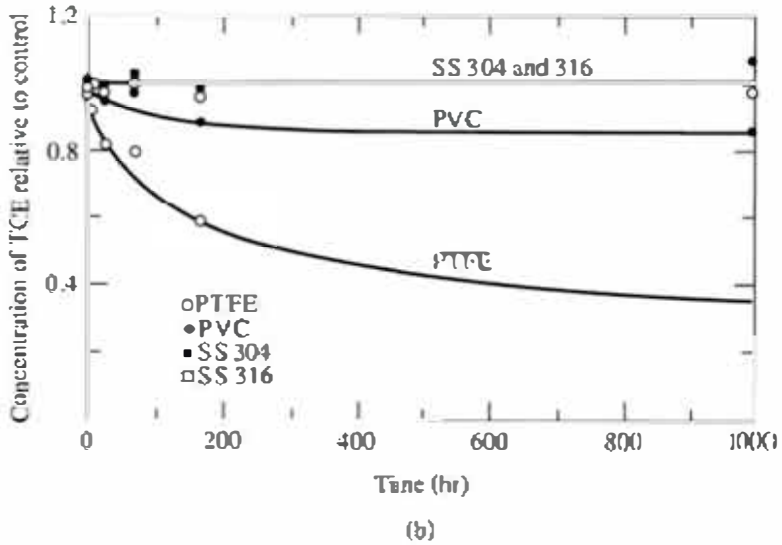
However, PVC should be avoided if organic compounds are present in the ground as nonaqueous phase liquids. Likewise, PVC casing should also never be joined with solvent-glued joints. These solvents include compounds such as methylethylketone and tetrahydrofuran and they may leach into groundwater samples. Threaded joints that are machined directly onto the PVC are the preferred method of joining casing sections and casing to screen. Joints should be flush on the inside of the casing to prevent equipment being lowered into the casing from hanging up in a projecting joint inside

FIGURE 8.7a Sorption of trichloroethylene in the part per million range from groundwater by PVC, PTFE, type 304, and type 316 stainless steel well casings.



Source: L. V. Parker, A. D. Hewitt, and T. F. Jenkins. 1990. Influence of casing materials on trace-level chemicals in ground water. *Groundwater Monitoring & Remediation* 10:146–156. Used with permission.

FIGURE 8.7b Sorption of trichloroethylene in the part per billion range from by PVC, PTFE, type 304, and type 316 stainless steel well casings.



Source: L. V. Parker and T. A. Ranney. 1994. Effect of concentration on sorption of dissolved organics by PVC, PTFE and stainless steel well casings. *Groundwater Monitoring & Remediation* 14:139–149. Used with permission.

the well, or bridging and stoppage of grout or filter pack material in the annular space outside the well.

There are groundwater contaminants other than either metals or dissolved nonpolar organic compounds. Many chemicals associated with agriculture are strongly

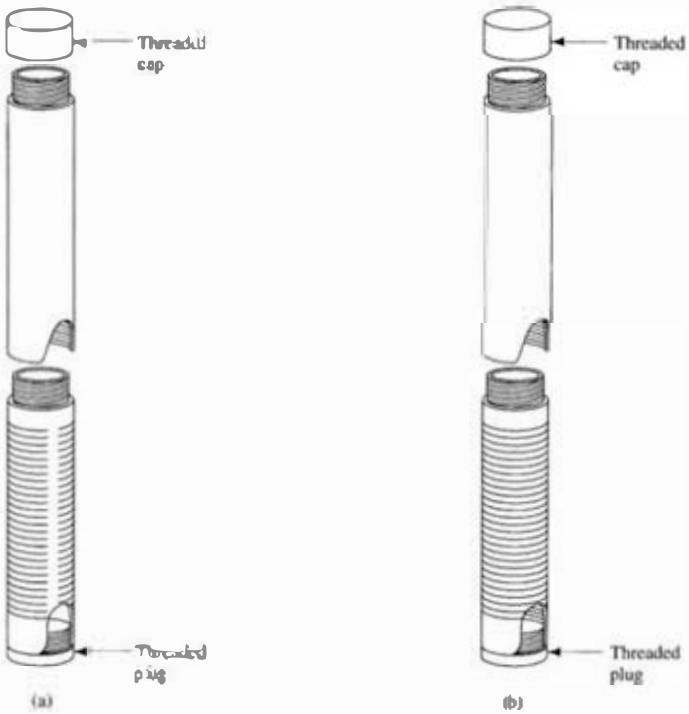
polar or ionic. Papiernik, Widmer and Spalding (1996) studied the impact of using various materials to sample agricultural contaminants, including nitrate-N, atrazine, diethylatrazine, diisopropylatrazine, cyanazine, alachlor, metolachlor and butachlor. They found that other than butachlor (which is not in common use in the United States) there was no significant difference in absorption of the target by either polytetrafluoroethylene (PTFE), rigid PVC, flexible PVC, stainless steel, high density polyethylene (HDPE), or low density polyethylene (LDPE). For any of the chemicals tested, other than butachlor, any of the materials could be used. The least expensive would be HDPE, LDPE, and rigid PVC.

8.4.3 Monitoring Well Screens

If the monitoring well terminates in an unconsolidated formation, a screen is necessary to allow the water to enter while keeping the sediment out. In most monitoring well applications, the well screen is the same diameter as the casing to which it is attached by a threaded coupling. Likewise, the well screen is normally made of the same material as the casing. The considerations that go into deciding the material to use for the casing also apply to the screen. In many cases multilevel sampling will provide crucial information and multiple, isolated screened intervals are necessary.

The screen or screens will have openings to permit the water to enter. Manufactured well screen should always be used rather than handcut slots or drilled holes in plastic pipe. The two common screens for monitoring wells are slotted pipe, which is available in PVC and PTFE, and continuous wire wrap, which is available in stainless steel. Figure 8.8 illustrates these two screen types.

FIGURE 8.8 Slotted (a) and continuous wire-wrapped (b) monitoring well screens.



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The width of the slot or wire-wrap opening is precisely controlled during the manufacture of the screen; the screen is available in a variety of opening sizes, generally ranging from 0.02 to 0635 cm (0.008 to 0.250 in.) A screen with an opening of 0.010 in. (0.0254 cm) is referred to as a 10-slot screen. Many manufacturers carry only a limited number of slot sizes in stock—for example, 10- and 20-slot. Since the casing and screen are typically ordered in advance of the well construction, the hydrogeologist usually has settled on a standard design prior to going on the job. Decisions on slot sizes are important in that too large a slot size without proper filter pack can allow sediment to enter the well during pumping. Conversely, a small slot size can inhibit nonaqueous phase liquids (NAPLs) from entering a well. NAPL must have enough thickness and fluid pressure to supplant water in small slots, overcoming capillary pressure. If well screen slots have small opening sizes, NAPL outside the well in a thin pool may not be able to enter through the screens.

8.4.4 Naturally Developed and Filter-Packed Wells

The casing and screen may be placed in the borehole and the native sediment allowed to cave around the screen. This is called a **naturally developed well** and is often used in sandy sediment with very limited amounts of silt and clay present, but is most realistic for wells with single screens. At least 90% of the sediment should be retained on a 10-slot screen before a naturally developed well is considered (Aller et al. 1991). When water is withdrawn from such a well, it may initially be cloudy due to suspended silt and clay, but the water should eventually clear as the fines near the screen are removed by a process called "well development." In a naturally developed well the slot size is selected to allow some of the fine sediment to enter the well during development; this leaves only the coarser sediment outside the screen.

In designing a water well, it is very important that the well be hydraulically effective—i.e., there should be a minimal loss of energy as the water flows into the well. As mentioned, the selection of the slot opening for naturally developed water wells is very important and is based on a grain-size distribution curve of the sediment opposite the well screen. Monitoring wells are designed to retain much more of the natural formation than water wells because they are much more difficult to develop (Driscoll 1986). Monitoring wells are not usually designed with the precision necessary for a water-supply well. The well should be hydraulically efficient as well as being as clear of silt and clay as possible. If preliminary investigations indicate that the aquifer to be monitored has reasonably coarse sand or gravel and few fines, a standard slot size may be preselected for all the monitoring wells. Ten-slot screen is frequently used under these conditions.

If the formation is cohesive—that is, has a high clay content—or if it is sandy with a high silt content, it will be necessary to use an **artificial filter pack**. Filter packs have also been referred to as "sand packs" or "gravel packs." Filter-pack material is typically medium to coarse sand that is predominately silica with no carbonates. It is mined and graded to have a specific grain-size distribution. Manufactured filter-pack material comes washed and bagged and is far preferable to native sand as artificial filter pack. The filter-pack material is placed in the borehole opposite the well screen. Its purpose is to stabilize the natural formation and keep it out of the screen. This will reduce the amount of silt and clay that enters the well when it is developed. There are also

dual-screen well intake systems (pre-packs) that have a small diameter screen within a larger, second larger diameter screen, and the space in between is filled with filter pack material. Dual screen intakes are sometimes used when there is a propensity for fine-grained material to enter the well. A major disadvantage of these systems is that the two screens can compound the inhibition of NAPLs to enter a well.

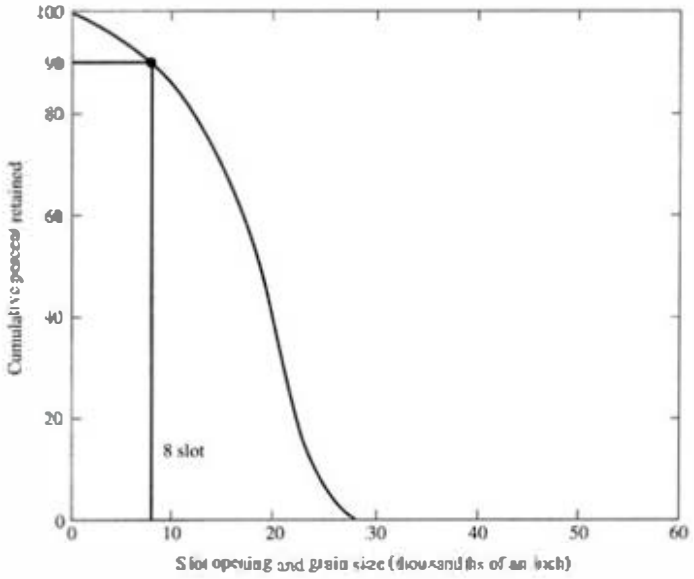
The grain size of the filter-pack material is based on the nature of the formation opposite the screen. If the formation is fine sand, then the grain-size distribution is determined. The filter pack material should have an average grain size that is twice the average grain size of the formation and have a uniformity coefficient (ratio of 40% retained size to 90% retained size) between 2 and 3 (Driscoll 1986). The screen-slot opening is then selected to retain 90% of the filter pack. The minimum practical slot size for monitoring well screens is 0.02 cm (0.008 in.) Figure 8.9 shows a grain-size distribution curve for a filter-pack material designed for an eight-slot screen. If the monitoring well is in silt or clay, all one can do is install an 8 slot screen and appropriate filter pack.

The filter-pack material should be approximately 5 to 7.5 cm (2 to 3 in.) thick. This means that a 5 cm (2 in.) diameter well screen should be installed in a borehole about 10 to 15 cm (6 to 8 in.) in diameter. The filter-pack material is normally extended 0.61 or 0.91 m (2 or 3 ft) above the top of the well screen to allow for settlement of the material during development.

8.4.5 Annular Seal

The annular space in the borehole above the filter pack must be sealed to prevent the movement of surface water downward to the filter pack. It may also be sealed to prevent vertical movement of groundwater from one zone to another or to isolate a discrete sampling zone. The seal should be made of a material that has a low permeability, bonds well to the natural formation and the casing, and expands after it has been

FIGURE 8.9 Grain-size distribution curve used to select an eight-slot screen for a monitoring well.



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emplaced to ensure a tight seal. It should set up within a day or so and be durable and permanent.

Materials typically used for an annular seal are bentonite pellets, granular bentonite slurry, neat cement grout, bentonite-sand slurry, and neat cement grout with a powdered bentonite additive.

Neat cement grout is a mixture of 42.5 kg (94 lb) of type I Portland cement with about 19 to 23 L (5 to 6 gal.) of water. Granular bentonite slurry is a mixture of 13.6 kg (30 lb) of untreated bentonite powder mixed with 56.7 kg (125) lb of untreated bentonite granules with 378.5 L (100 gal) of water. Bentonitecement grout is a mixture of 2.3 kg (5 lb) of untreated powdered bentonite with 42.5 kg (94 lb) of type I Portland cement and 32 L (8.5 gal.) of water. Bentonite-sand slurry is a mixture of 25 kg (55 lb) of untreated powdered bentonite with 378.5 L (100 gal.) of water and 10 to 25% sand by volume to make a slurry that weighs 9.6 kg/L (11 lb/gal.) All water used to make these slurries should be from a source that is fresh and known to be uncontaminated and free from floating oil.

Bentonite is a clay containing at least 85% sodium montmorillonite; it will swell to several times its original volume when thoroughly hydrated. This hydration takes place below the water table. However, bentonite has a high cation-exchange capacity and can affect the chemistry of water that comes into contact with it. Portland cement is used to make cement grout. When Portland cement cures, it is highly alkaline and can affect the pH of groundwater that comes into contact with it. Neat cement grout will shtink by at least 17% when it cures. The addition of bentonite to make a bentonite-cement grout significantly reduces the shrinkage problem. If neat cement grout or bentonite cement grout is used, the casing material should be either stainless steel or schedule 80 PVC due to the heat generated as the cement cures.

The materials available for an annular seal are not ideal. Although they can be used to make an impermeable seal, there is a chance they might affect groundwater quality in their immediate vicinity. This problem is mitigated if 0.61 m (2 ft) of fine sand is placed in the annular space above the filter-pack material or native sand opposite the screen. This keeps the annular seal material from coming into contact with the water entering the well screen.

Many hydrogeologists place a 0.61 m or 0.91 m (2 or 3 ft) layer of bentonite pellets above the fine sand if the pellets will be below the water table. The pellets will swell and keep the grout material from entering the filter-pack material. Clay pellets should not be used in the vadose zone due to lack of hydration and lack of swelling; a clay slurry should be used instead. If the top of the 0.61 m (2 ft) fine-sand seal is above the water table, then 0.61 m (2 ft) of granular bentonite may be placed prior to the addition of the annular seal.

8.4.6 Protective Casing

In order to provide physical protection for the investment in a costly monitoring well, as well as to protect from vandalism by individuals accidentally or intentionally putting foreign fluids and objects into a monitoring well, a locking protective steel casing or well vault is needed.

A protective casing extends several feet above the ground surface. It extends above the top of the monitoring well and has an inside diameter sufficiently large so that the

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hydrogeologist can reach inside and unscrew a cap from the monitoring well. It is set into a surface cement seal. For monitoring wells installed in freezing climates, a drain hole at the bottom of the surface casing is desirable to prevent accumulation of moisture that could freeze in the annular space between the protective casing and the monitoring well. (One of the authors has seen a stainless-steel monitoring well casing pinched shut by water that accumulated in a protective casing without a drain hole and then froze!)

In some applications, it is not practical to have a monitoring well that extends above ground—for example, in the driveway at a gas station. There are small well vaults available that can be used for protection for monitoring wells. However, they should be in places that are not going to flood; otherwise floodwaters could enter the aquifer via the monitoring well. If a well vault is used in a gas station or similar location, it should be clearly marked and should be distinctive from the fillers for underground storage tanks so that an inattentive person does not try to fill it with gasoline! A locking well cap without a vent hole should also be used.

8.4.7 Screen Length and Setting

The hydrogeologist must decide on the length of the screen and the depth to which it will be set, based on the objectives of the monitoring program. Objectives could include monitoring the position of the water table, measuring the potentiometric head at some depth in the aquifer, collecting representative water samples from various depths in the aquifer, and detecting both light and dense nonaqueous phase liquids. Moreover, monitoring might be intended to detect the migration of groundwater containing contaminants into an aquifer or evaluating the effectiveness of removing contaminants from an aquifer. All might require different approaches.

To monitor the position of the water table or to detect the presence of LNAPLs, the screen must be set so that it intersects the water table. The screen must be long enough to intersect the water table over the range of annual fluctuation. In addition, the screen must be long enough so that when the water table is at its greatest depth below the land surface, there is enough of the screen remaining below the water table to contain sufficient water for a water sample. A water-table monitoring well will also be able to detect the presence of light nonaqueous phase liquids. In most applications the minimum length of the screen for a water table–monitoring well is 3 m (10 ft) with about 1.5 m (5 ft) above and 1.5 m (5 ft) below the water table. If the water table has more than 1.5 m (5 ft) of annual fluctuation, a longer well screen is needed. However, some governmental guidance specifies a maximum screen length of 3 m (10 ft) or less. Figure 8.10 shows examples of incorrect (a and b) and correct (c) placement of a multipurpose monitoring well intended to measure the position of the water table, detect floating nonaqueous phase liquids, and collect water samples from the upper part of the aquifer.

If the purpose of a monitoring well is to measure the potentiometric pressure at some depth in the aquifer, then the well is called a piezometer. A piezometer should have a relatively short screen length, 0.6 to 1.5 m (2 to 5 ft), so that the pressure that is recorded is representative of only a small vertical section of the aquifer. A piezometer can also be used to collect groundwater samples that are representative of a small vertical section of the aquifer.

Monitoring wells utilized to collect groundwater samples should be designed with respect to a specific groundwater monitoring goal. The concentration of groundwater

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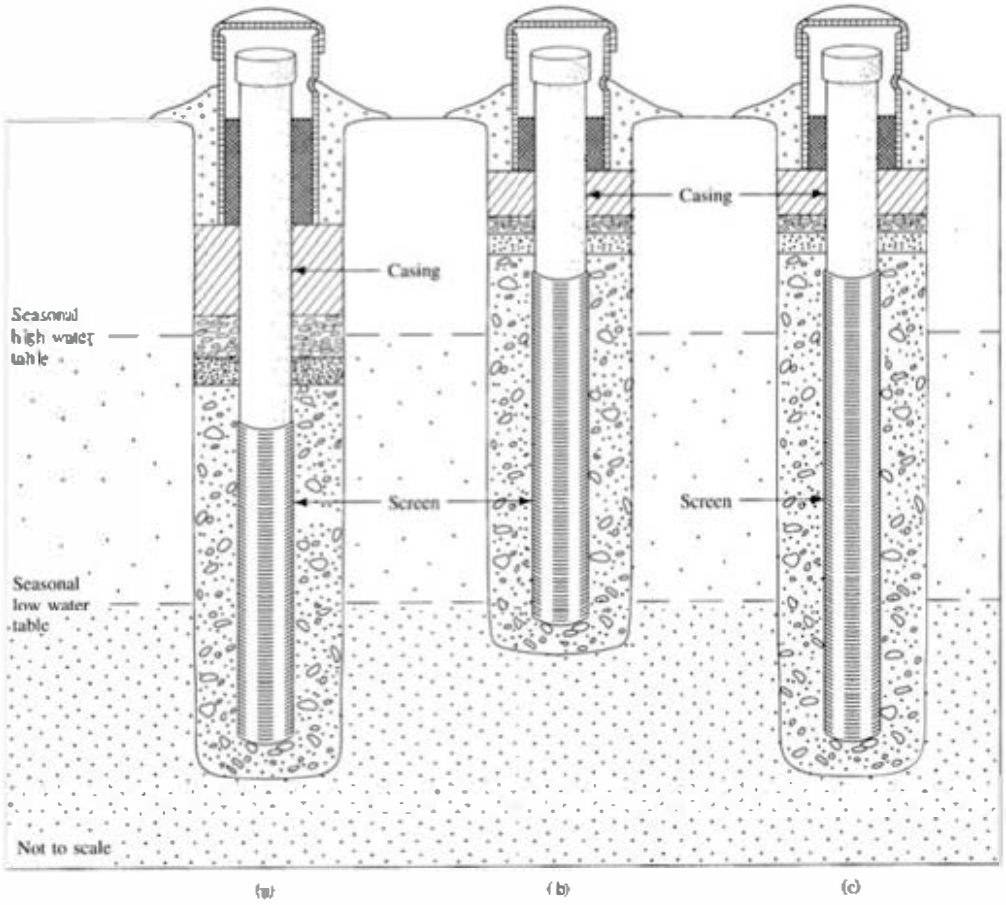
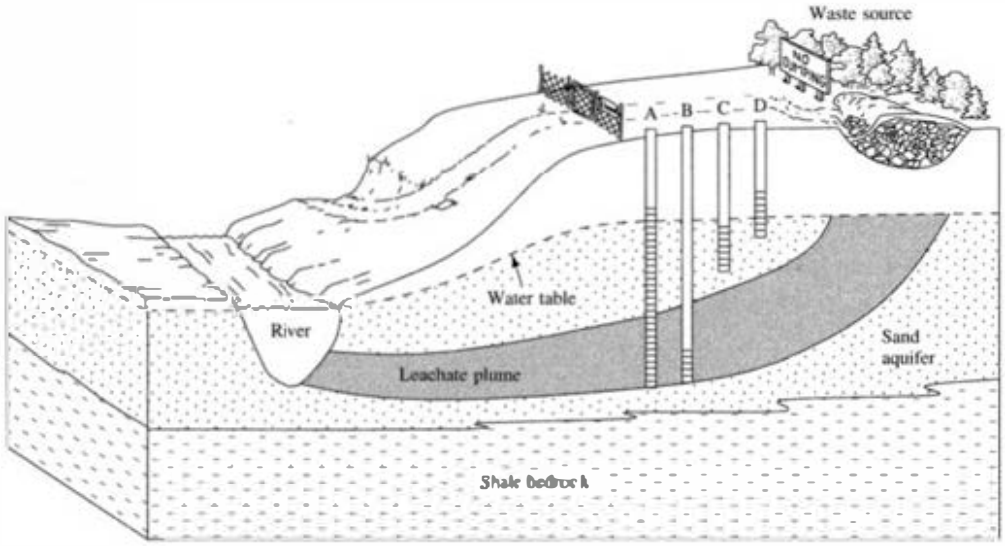
FIGURE 8.10 (a) Incorrect placement of water table–monitoring well screen. Seasonally high water table is above the top of the screen and floating, light nonaqueous phase liquids would be above the screen and not detected. (b) Incorrect placement of water table–monitoring well screen. Seasonally low water table is so far down in well that there is not enough water in well to collect a sample for chemical analysis. (The water table elevation could still be determined) (c) Correct length and placement of water table–monitoring well screen.



contaminants can vary vertically. If a monitoring well has a long well screen, it has a greater probability of intersecting a plume of contamination. However, a water sample taken from such a well may draw water from both contaminated and uncontaminated parts of the aquifer, resulting in a reported concentration that is less than that of the groundwater in the plume. This is illustrated in Figure 8.11.

The collection of such unrepresentative water samples may have serious implications for the implementation of groundwater regulations. While monitoring groundwater in order to find the actual concentration of contaminants in a plume, it may be necessary to use several monitoring wells or piezometers screened at different depths at the same location (well cluster). Alternatively, several nested wells or piezometers can be placed in a single large borehole, each well with a screened interval and surrounding filter pack at a different depth, and with impermeable grout placed in the borehole between the screened intervals of the individual wells. These clustering and nested techniques can be expensive, not only due to the initial cost of the wells but also due to the costs of multiple chemical analyses for each round of sampling. However, such

FIGURE 8.11 Effect of monitoring well-screen length on water-quality sampling. Monitoring well A is fully screened through the thickness of the aquifer. It intersects the plume of leachate but the reported concentration will be less than the actual concentration as water is withdrawn from both contaminated and uncontaminated parts of the aquifer. Piezometer B is also screened to intersect the plume of leachate. The reported concentration will be representative of the leachate. Piezometer C and water-table monitoring well D don't intersect the plume, indicating that it is deep in the aquifer.



a configuration will yield the greatest amount of information about the hydraulic head as well as the water quality, and is typically a recommended regulatory approach for groundwater monitoring. Additionally, there are multilevel monitoring wells that allow discrete vertical sampling in a single borehole, along with measurement of other hydrogeologic properties such as hydraulic conductivity and fluid pressure (head). Multilevel sampling will be discussed further in Section 8.4.9.

If a monitoring well is intended to serve as a warning that a plume of contamination is escaping from a potential source, then it should be screened in the most permeable parts of the aquifer initially to intercept rapid excursions, with the understanding that measured concentrations may be diluted and not representative of the most contaminated parts of an aquifer. Groundwater, and contaminants that it may be carrying, not only preferentially travel through the most permeable material but travel faster there as well. Hence, the leading edge of a plume of contamination will follow the most permeable pathway.

If the plume of contaminated water is following a zone or direction of high hydraulic conductivity, it may flow in a direction that is not parallel to grad h. This may mean that the location of the plume is not exactly down-gradient from the source. (Likewise, as has been discussed in earlier chapters, nonaqueous phase liquids can pool up and deflect off low permeability geologic layers in down-dip directions totally inconsistent with the directions of groundwater flow).

On the other hand, long term monitoring can have different priorities. If an aquifer is contaminated and a monitoring well has been installed to monitor the progress of a remediation effort, the well should not be screened in the most permeable part of the aquifer. Many contaminants can become trapped in low permeability regions, and

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can become sequestered for long periods of time. The eventual slow release of these trapped pollutants can cause a classically observed "rebound" in aqueous concentrations long after the high permeability zones appear to have been clean. In pump and treat systems, the water will preferentially travel through and flush out the more permeable zones. A well screened in a permeable zone may indicate that the aquifer is rapidly being cleaned, but in fact less permeable zones located nearby may still have high concentrations of contaminants that have yet to be removed. Therefore in contaminant investigations, monitoring low permeability zones is also typically carried out.

In general, the concentration of a solute obtained from a monitoring well will be less than the maximum concentration present in the aquifer. The well screen provides a vertically averaged value of the solute in the aquifer over the length of the screen. If the contaminant plume is thinner than the length of the screen, then the vertically averaged concentration of the solute that is obtained from a monitoring well will be less than the solute concentration in the plume as the monitoring well will be drawing in some uncontaminated water and diluting the contaminated water. Chiang, Raven, and Dawson (1995) found that if a monitoring well is purged continuously for 24 hours prior to sampling, it will draw in uncontaminated water from the aquifer below the well screen, and the concentration of solute in the well could be as much as an order of magnitude lower than the vertically averaged solute concentration in the aquifer.

8.4.8 Summary of Monitoring Design for Single Screened Wells

Figure 8.12 illustrates a comparison of the final design of a water-table observation well and a piezometer illustrating the design elements discussed in this section for single well screen designs.

8.4.9 Multiple-level Wells and Multilevel Devices for Groundwater Monitoring

Because many field studies have suggested that most contaminant plumes exhibit significant concentration changes over small vertical distances (Smith et al. 1987; Dumble et al. 2006; Biswas et al. 2014; USDOE 2015), multilevel monitoring wells (particularly high resolution techniques) often produce orders of magnitude more information and more accurate results than single, long-screened wells. Natural hydraulic gradients within long-screened wells can create vertical flow and cross-contamination within the well, and make definition of the vertical distribution of dissolved contaminants impossible (Reilly et al. 1989; Church and Granato 1996; Elci et al. 2001; Neilsen 2005; McMillan 2014). This message has not gotten through to all municipalities, industries, and regulators, however. The U.S. Nuclear Regulatory Commission (NRC), in its 2003 NUREG 1569 Guidance (pages 5-42 and 5-43) for in situ uranium leaching operations correctly states:

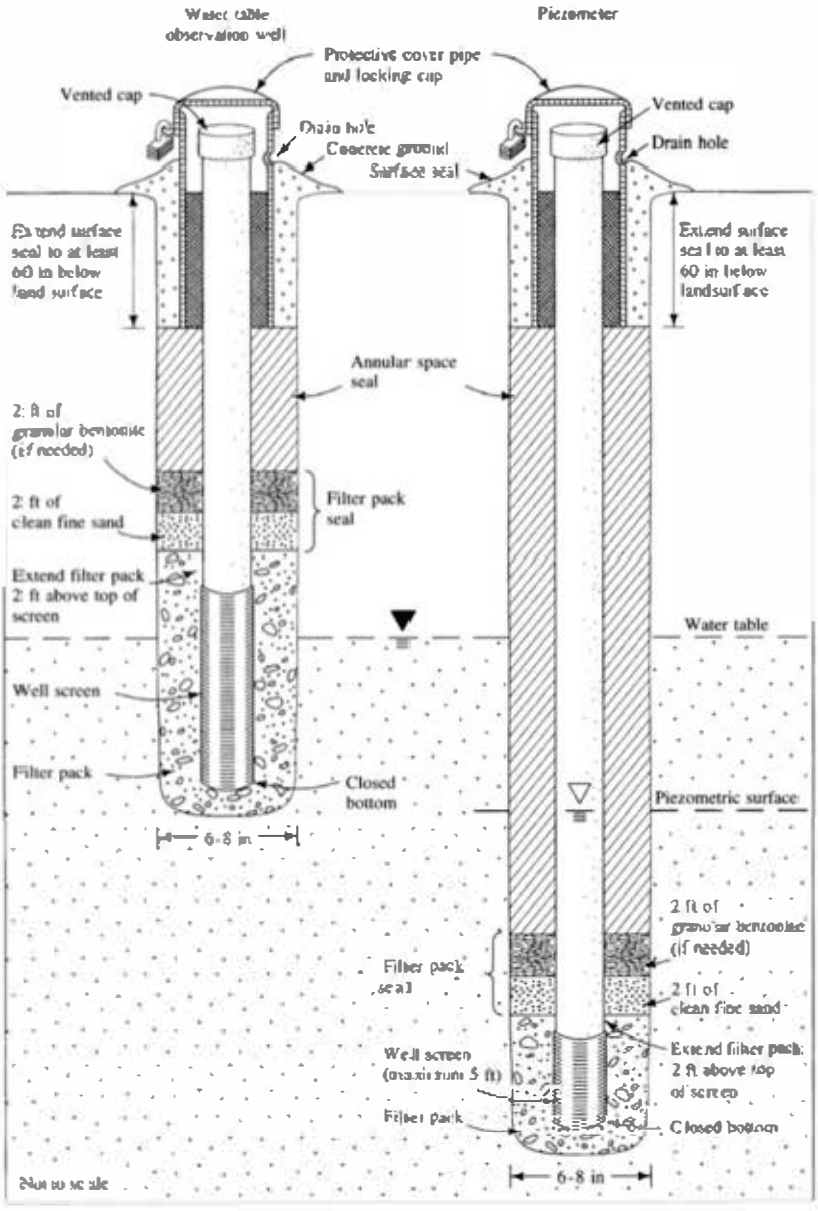
> *"Fully screened monitor wells sample the entire thickness of the aquifer. Therefore, excursions could not pass above or below the well screens. However, the concentration of the indicator parameters might be diluted and therefore may not provide timely warning that an excursion is occurring.*

But then the NRC Guidance continues:

"Partially screened monitor wells only sample the zone of extraction within an aquifer. These wells might miss some excursions, but would suffer less from dilution effects than fully screened wells. For most situations the staff favors fully screened monitor wells."

In this document the U.S. Nuclear Regulatory Commission misrepresents multilevel sampling and does not recognize that high resolution multilevel monitoring: (I) is less likely to "miss" contaminant excursions than wells screened the entire aquifer

FIGURE 8.12 Construction details of a water-table observation well and piezometer.

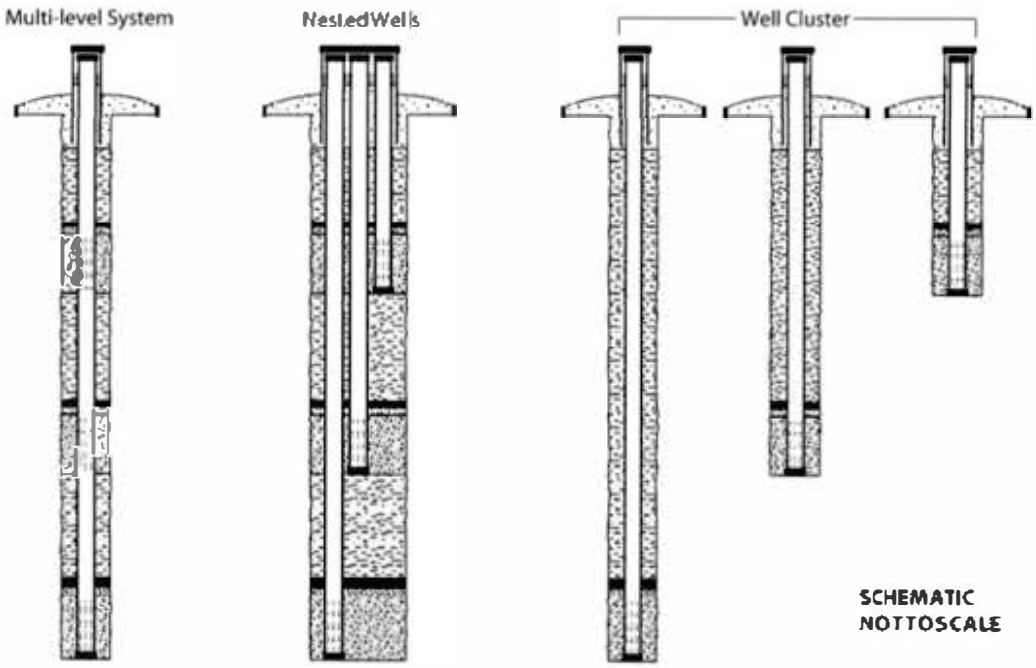


Source: Wisconsin Department of Natural Resources.

length, (2) has more possibility of accurately intercepting and quantifying excursions without bias, (3) reduces the possibility of contaminants migrating vertically within a monitoring well, (4) is many times more useful in post-mining remediation and site stabilization (both in directing cost-effective cleanup efforts and documenting their success), and (5) is much more protective of public health and ecological well-being.

Nested and Clustered Wells As mentioned in Section 8.4.7, to reduce dilution effects of long-screened wells and to preserve vertical sampling integrity, usually monitoring wells are installed in nested or clustered configurations (also called "multiple completions"), or with other types of multilevel sampling devices in a single borehole. Figure 8.13 illustrates multilevel sampling systems, nested wells, and well clusters. For nested wells, there is typically a single large borehole with several piezometers or wells placed in the same hole with screened intervals at different depths below the water table and with grout separating each different sampling depth. There has been some concern with the integrity of grout sealants in nested wells, and some criticism has been leveled at using these nested configurations. This is because of the difficulty in achieving effective and impermeable grout layers. These problems can be significant where the grout layers are thin because of many vertically close-spaced screen and grout intervals, or where there are many casing riser pipes in the nested well requiring grout to be placed effectively between the many pipes without void spaces developing. Clustered well groupings, on the other hand, sample different depths at the same locality by having several, closely spaced monitoring wells or piezometers with each in its own individual borehole. These individual wells typically can be placed within 1.5 m

FIGURE 8.13 Multilevel sampling systems, nested wells, and well clusters with above ground completion.



Source: E. Hughes and G. Aarons 2014. *Well Design and Construction for Monitoring Groundwater at Contaminated Sites*. The California Environmental Protection Agency.

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(5 ft) of each other. Under these circumstances it is possible to obtain an excellent seal to prevent vertical movement of water along the casing.

In nested wells, two or more monitoring wells or piezometers are placed in a large-diameter borehole with grout seal between screened intervals at different depths. For example, this could be done in an unconsolidated formation by (1) driving a 25.4 or 30.5 cm (10 or 12 in.) diameter casing with a cable tool rig to the depth of the bottom piezometer, (2) installing the deepest piezometer, (3) pulling back the casing and installing the filter pack and seal for the deepest piezometer, (4) pulling back the casing and grouting up to the level of the next piezometer, (5) allowing the grout to harden, (6) installing the next piezometer, (7) pulling back the casing and installing the filter pack and seal for the second piezometer, and (8) pulling back the casing and grouting up to the level of the third piezometer, etc.

Simple Manufactured Multilevel Samplers It is possible to install inexpensive multilevel sampling devices in a sandy aquifer. One early manufactured model of such a device consists of a rigid PVC tube, inside of which are multiple tubes of flexible tubing. Each tube leads from the surface and ends at a different depth. Each has a port into which a groundwater sample can be drawn. Sampling ports can be closely spaced vertically, so that very detailed vertical sampling can be accomplished. Water is withdrawn from the tubing by applying suction, so the water table had to be less than 7.6 m (25 ft) below the surface in these simple early multilevel sampling wells. These rudimentary methods include a variation by fastening a bundle of flexible tubes, each of a different length, to the outside of a rigid PVC pipe that acts as a spine. Several types of simple manufactured multilevel samplers have been developed (Pickens et al. 1978; Cherry and Johnson 1982; Ronen et al. 1986).

Barker et al. (1987) evaluated the bias in samples that can be introduced by the use of multilevel piezometers constructed out of flexible tubing. Leaching of plastics from the plastic tubing is one problem. Another problem is the sorbing of organics by the tubing. Both these problems can be minimized by using Teflon® tubing and thoroughly purging the tube priot to sampling, although Teflon® is porous and can have some minimal memory effect. Many types of flexible tubing can actually transmit organics from groundwater through the tubing wall to the sample water in the tubing. This is especially ttue for polyethylene tubing. Samples drawn from below an organic plume may indicate contamination, when in fact the organics are being transmitted across the plastic tubing from adjacent contaminated groundwater. This can apparently occur even with Teflon® tubing. For this reason, multilevel piezometers, designed so that the flexible tubing is exposed to groundwater, may not be appropriate for monitoring plumes of organic contaminants. If the flexible tubing is contained within a casing, such as in Figure 8.14, this should not be an issue because the tubing doesn't come into contact with the groundwater.

A simple multilevel sampler can be installed by using a hollow-stem auger. The device is constructed at the surface and lowered to tbe desired depth through the augers. It is not possible to develop the sampling ports, so this device is best suited for clean, sandy sediment. No filter pack or grout is used in this very simple construction. The augers are withdrawn and the native sand is allowed to slump around it. One disadvantage of this device is that it is usually not possible to measure water levels with it.

generally expensive, these multilevel wells have advantages of allowing fewer wells and subsurface disturbance at each site, collection of fluid samples without repeated purging, prevention of vertical flow within the borehole, less possibility of cross contamination with discrete depth sampling, and options for automated sampling at any number of multiple depths in a single well.

Flexible Liner Systems Another type of multilevel sampling practice employs the flexible liner system (developed by FLUTe™) and represents a significant advancement over a simple multilevel system. Similar to the simple system above, it has a series of internal tubes inside a liner which allow sampling and pressure measurement at selected intervals down hole in uncased wells. In hard rock consolidated systems, downbole television logging in uncased boreholes can identify exact locations of fractures (and other depths of interest) and tubing can be customized to sample those depths. In this system, a flexible polyurethane–coated, nylon fabric liner is emplaced with eversion (turning inside out) from a shipping reel. The liner is pressurized (pneumatically or hydraulically), inflated, and extends downward from internal pressure head. The liner deploys from the ground surface downward, creating a sealing pressure that prevents vertical flow outside the liner, and has tubing (usually made of polyvinylidene fluoride—PVDF) inside the liner from ground surface to vertically displaced subsurface ports. The system is versatile in that the inflating liner can be placed in boreholes that change direction due to directional drilling, and can move in varying diameter boreholes, such as narrow, shallow surface casing to wider uncased sections below, or narrowing or telescoping boreholes. Interestingly, this system can be modified to measure discrete depths of nonaqueous phase liquids (NAPLs) by use of a hydrophobic "ribbon" sampler. In this application, a porous, continuous, hydrophobic sleeve, that is impregnated with a powdered oil dye (Sudan IV), is deployed concurrently on the outside of the flexible liner. The hydrophobic material readily "wicks" NAPLs and when retrieved identifies depths of NAPL contamination. The hydrophobic sleeve is replaceable for additional deployments on the same flexible liner (Riha et al. 2000; USEPA 2004).

Packer Systems A type of multilevel sampler optimal in bedrock boreholes involves straddle packers, which when inflated isolate a section of a borehole for hydrological testing and sampling. In this design (Figure 8.15) packers are located above and below each sampling port; when they are inflated, they seal off that part of the borehole and are particularly effective in segregating individual fractures or groups of fractures for analysis in uncased boreholes. Packers can also be used within well casing in less consolidated material. Packers can be permanently installed, or they can be removed and reused if desired. Though designs vary, the inside of a typical single packer is a perforated pipe forming the inner packer body, covered with a porous plastic sleeve and an expansion sleeve. External to that is a gum rubber inner sheath, often enveloped in woven Kevlar® and encased in a durable gum rubber outer sheath, with the assembly secured on either end with stainless steel clamps. One type is the Solinist® Waterloo System with includes multi-purge manifold well heads and dedicated sampling pumping and transducers.

Interesting specialized variants of packer systems have been constructed for specialized applications. Packers have been used in small, bedrock boreholes in conjunction with seals created by injecting grout into a flexible cylindrical impervious fabric liner. These liners have a diameter slightly larger than the borehole, ensure that the

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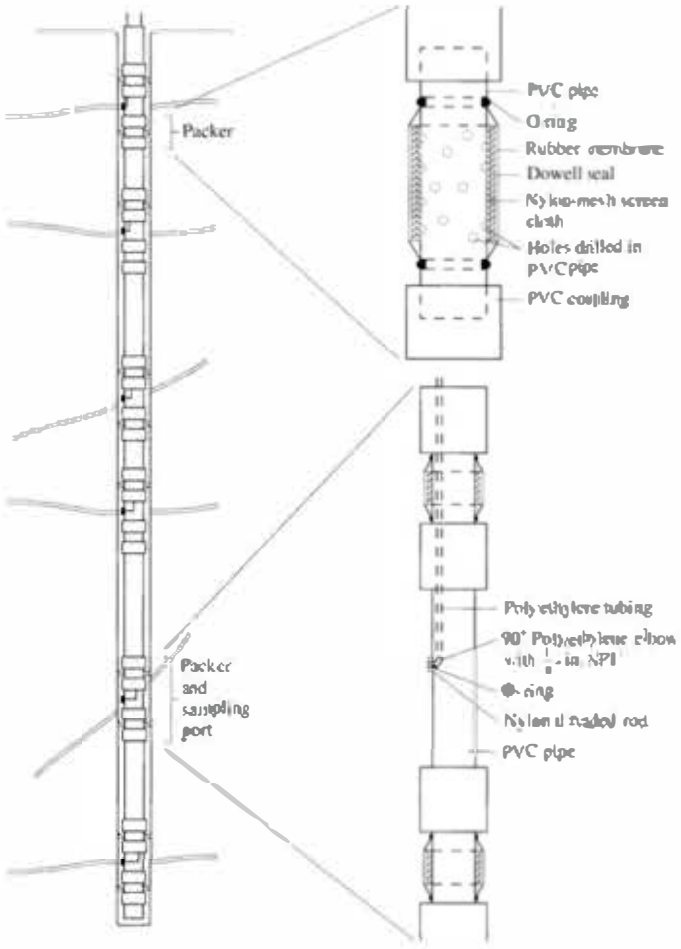
FIGURE 8.15 Multilevel groundwater sampling device for use in fractured rock aquifers.



Source: J. A. Cherry and P. E. Johnson. 1982. A multilevel device for monitoring in fractured rock. *Groundwater Monitoring & Remediation* 2:41–44 Used with permission.

entire borehole above a screened interval is sealed, and prevent grout from entering fractures and altering groundwater chemistry (Parker et al. 2015; Pierce et al. 2015).

8.5 Installation of Monitoring Wells

8.5.1 Decontamination Procedures

Because the purpose of drilling a monitoring well is to collect a sample of water and analyze it for very small concentrations of chemicals, it is highly desirable not to introduce any chemicals into the aquifer as a part of the well-drilling and installation procedure. The process of cleaning the equipment and supplies that will be used is called **decontamination**.

When materials are manufactured, they may become coated with substances such as grease and oil. Therefore, unless the manufacturer specifically guarantees that the article has been decontaminated and has shipped it in a well-sealed wrapper, it should be decontaminated. Equipment that has been used at a contaminated site should be

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assumed to be contaminated and should be decontaminated before it is used at another site. Even at the same site, if a drill rig or a bailer is used at different wells, decontamination is required to prevent cross contamination (contamination from one area being introduced into a clean area) that could occur.

There is wide variability in required and recommended decontamination procedures in the United States between the USEPA and the various states (Mickam et al. 1989). The hydrogeologist must consult with the appropriate regulatory authority to determine if a specific decontamination procedure is required. In the absence of a specific requirement, the following generic procedure should adequately clean equipment and supplies. In some cases not all the steps are required. For cleaning large equipment such as a drilling rig, a specific area must be set aside and a decontamination pad must be constructed to capture all the fluids used in the process. If the rig is contaminated, wash water from it may also become contaminated. Be careful that any solvents used aren't accidentally released to the environment. Small tools such as bailers and Shelby tubes can be cleaned in buckets set on a polyethylene sheet. Sampling pumps can be cleaned by running various wash solutions through them, as well as washing the exterior.

The following steps are used to clean drilling and soil sampling equipment including drill rig, augers, drill rod, tools, sampling tubes, etc.:

1. Use a wire brush or similar equipment to remove all dried sediment and thick accumulations of grease.
2. Wash the equipment with a soft brush and water with phosphate-free detergent.
3. In extreme conditions organic residues can be removed by washing the equipment with an organic solvent such as methanol or propanol. Don't use solvents such as trichloroethene that might be expected to be found at a hazardous waste site.
4. Clean and rinse the equipment with potable water.
5. Rinse the equipment with deionized water.

Steam cleaning with a pressure sprayer can be used in step 4 for equipment that can withstand the heat and force of the spray. After equipment has been decontaminated, it should not be placed on the ground. It can be wrapped in clean paper or aluminum foil or set on polyethylene sheets.

Sampling equipment should also be decontaminated between uses. If the equipment has not come into contact with nonaqueous-phase liquids, rinsing with potable water and washing thoroughly with phosphate-free detergent, including scrubbing the inside of tubes with a bottle brush, followed by a potable-water wash and then a deionized-water rinse, should suffice. If the equipment has come into contact with nonaqueous-phase organic liquids, then an initial solvent wash may be necessary.

The cost of decontamination of sampling equipment and the uncertainty introduced by solvent washing has led many hydrogeologists to specify dedicated sampling equipment in each well. Disposable bailers are also available that are less expensive than the cost of labor involved in cleaning reusable bailers.

8.5.2 Methods of Drilling

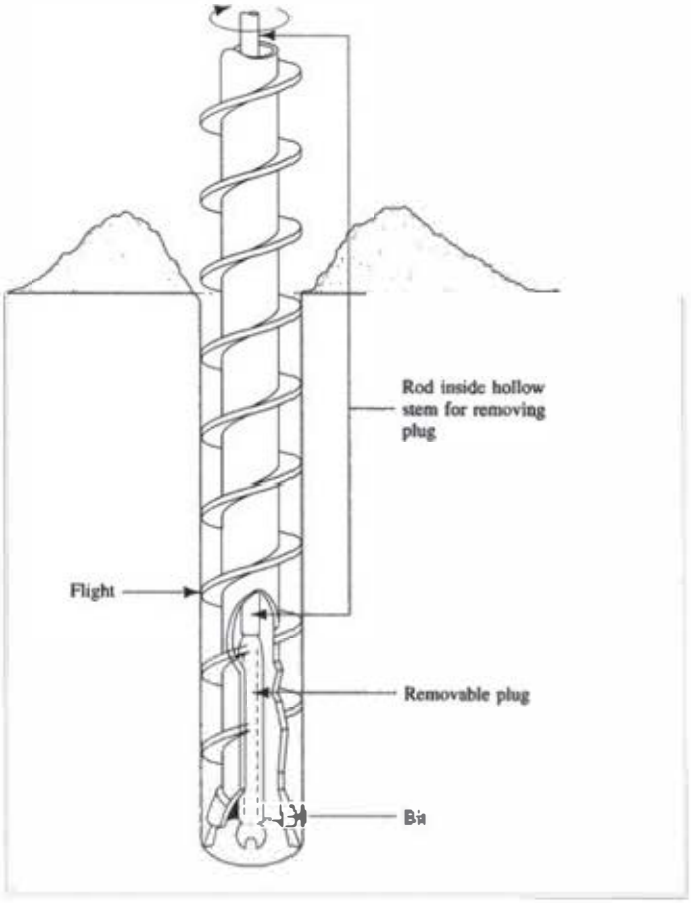
There are a number of methods of drilling that are appropriate for installation of monitoring wells. When working in shallow unconsolidated formations, hollow-stem

R000408

augers are commonly used. If a well is to be drilled deeper than about 30.5 m (100 ft) or into bedrock, a rotary drilling method may be appropriate. Cable-tool drilling is an excellent way of installing monitoring wells in borh unconsolidated and consolidated formations, but it is slow and may be expensive. Hollow-stem augers with a bit that contains carbide teeth can also be used in weak, indurated rock. Newer techniques include sonic drilling and directional drilling.

Hollow-Stem Augers Hackett (1987; 1988) presents an authoritative discussion of all aspects of drilling with hollow-stem augers. A hollow-stem auger looks a little like a large, untapered screw (Figure 8.16). The auger flights are constructed around a hollow pipe. A drilling rig rotates the augers and a bit on the end of the auger loosens the sediment, which is then brought up to the surface by the rotating auger flights. The cuttings accumulate at the surface and must be shoveled away from the augers. Figure 8.17 pictures an auger-drilling rig. The auger is advanced into the ground as it is rotated. A plug on the end of a rod inserted through the hollow-stem may be screwed into the bit to seal the end of the opening and prevent sediment from coming up inside the hollow-stem. Alternatively, a nonretrievable plug can be placed in the end of the

FIGURE 8.16 Hollow-stem auger drill rod and bit.



Source: M. L. Scalf et al. 1981. *Manual of Ground Water Sampling Procedures.* National Water Well Association. Used with permission.

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FIGURE 8.17 Hollow-stem auger drilling rig.

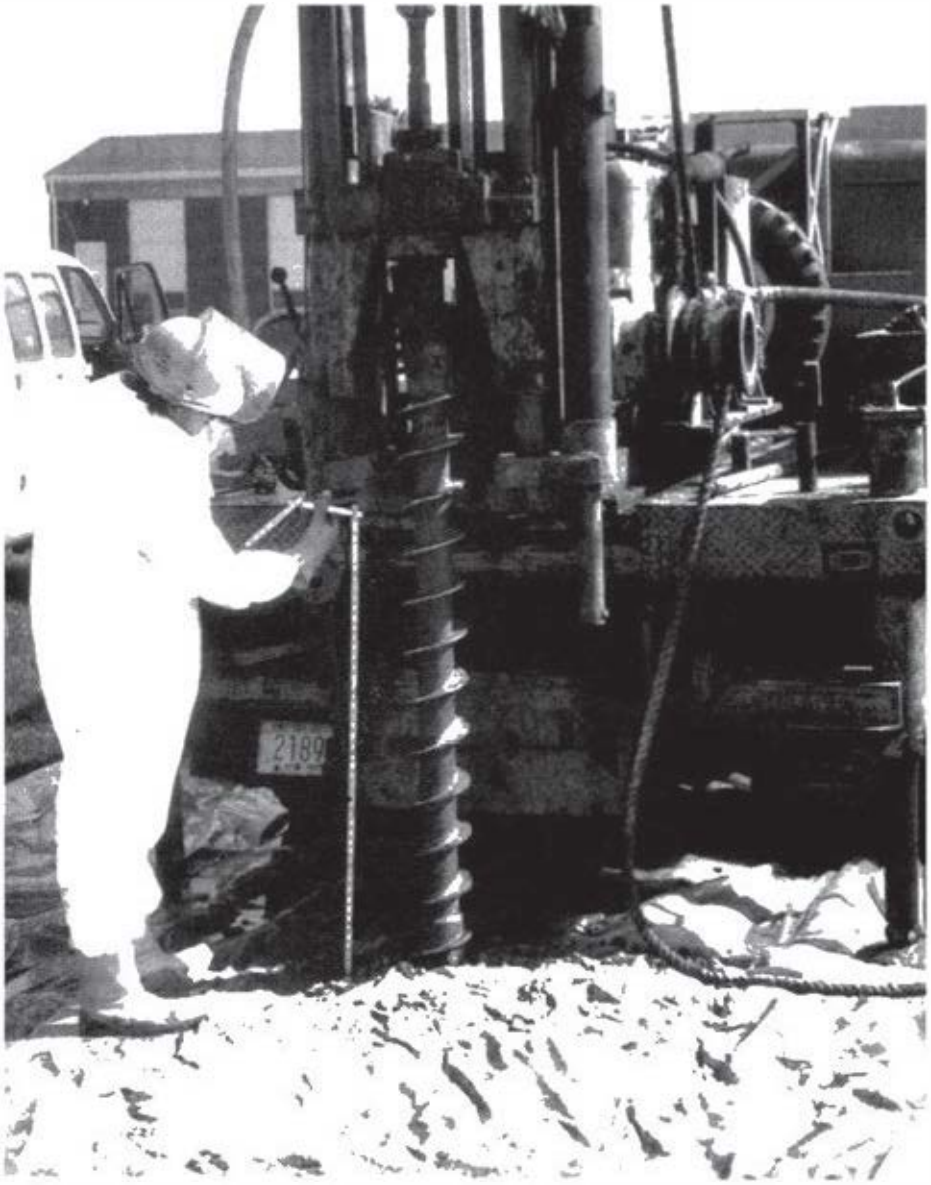


Photo credit: C.W. Fetter.

bit. This plug is knocked out of the end of the augers when the final depth is reached and it is no longer needed. However knock-out plugs preclude the collection of soil and water samples during drilling.

One advantage of drilling with hollow-stem augers is that drilling fluids and mud are normally not required. Circulation of drilling fluids has the potential to spread contaminants throughout the borehole. Drilling mud is a viscous liquid needed in mud-rotary drilling that can line the borehole and partially seal it. However, when drilling in formations with cohesive layers, the auger bit may smear clay from the cohesive layers so that it mixes with sand and gravel layers at the perimeter of the borehole. Auger drilling typically can advance about 15.3 to 30.5 m (50 to 100 ft) per day if samples are

R000410

being taken. Occasionally, downward progress can cease if a large cobble or boulder is encountered (called auger refusal).

Augers usually come in lengths of 1.5 m (5 ft). One flight is advanced into the ground and then the drill stem is disconnected and another flight is attached to the augers in the ground. At this time samples of the formation ahead of the auger bit may be taken. The plug on the end of the bit must be removed before sampling can occur. The maximum depth at which hollow-stem auger drilling can normally be used is 45.8 m (150 ft) (Hackett 1987); as a practical matter, it rarely exceeds 30.5 m (100 ft).

Some loosely consolidated sands, called heaving sands, can enter into the borehole when the plug is being removed. This problem can be avoided by keeping the hollow stem filled with potable water when the plug is removed. The potable water should not contain any contaminants that might be found in the groundwater. If no formation sampling is planned, then a knock-out plug can be used to prevent the introduction of heaving sands into the hollow-stem during drilling. The knock-out plug can be removed after the final depth is reached by pushing down with the well casing if it is stainless steel; otherwise it will be necessary to use a rod prior to the time that the well is installed.

Hollow-stem auger drilling can also be used to sample water quality at various depths during drilling. At a selected horizon the plug at the end of the hollow stem is removed. A well point on the end of a rod is lowered to the bottom of the augers and then is driven ahead of the bit by hammering or hydraulic pressure. The well point is developed by pumping until clear water is obtained. A sample of groundwater at that depth is then obtained. It is best if potable water is not used in the borehole during this procedure, because it could interfere with the groundwater quality. If there is heaving sand inside the augers, the well point can be driven through it. Alternatively, a slotted hollow-stem auger can be used (sometimes called a screened hollow-stem auger or Keck auger) which allows water to flow into the stem.

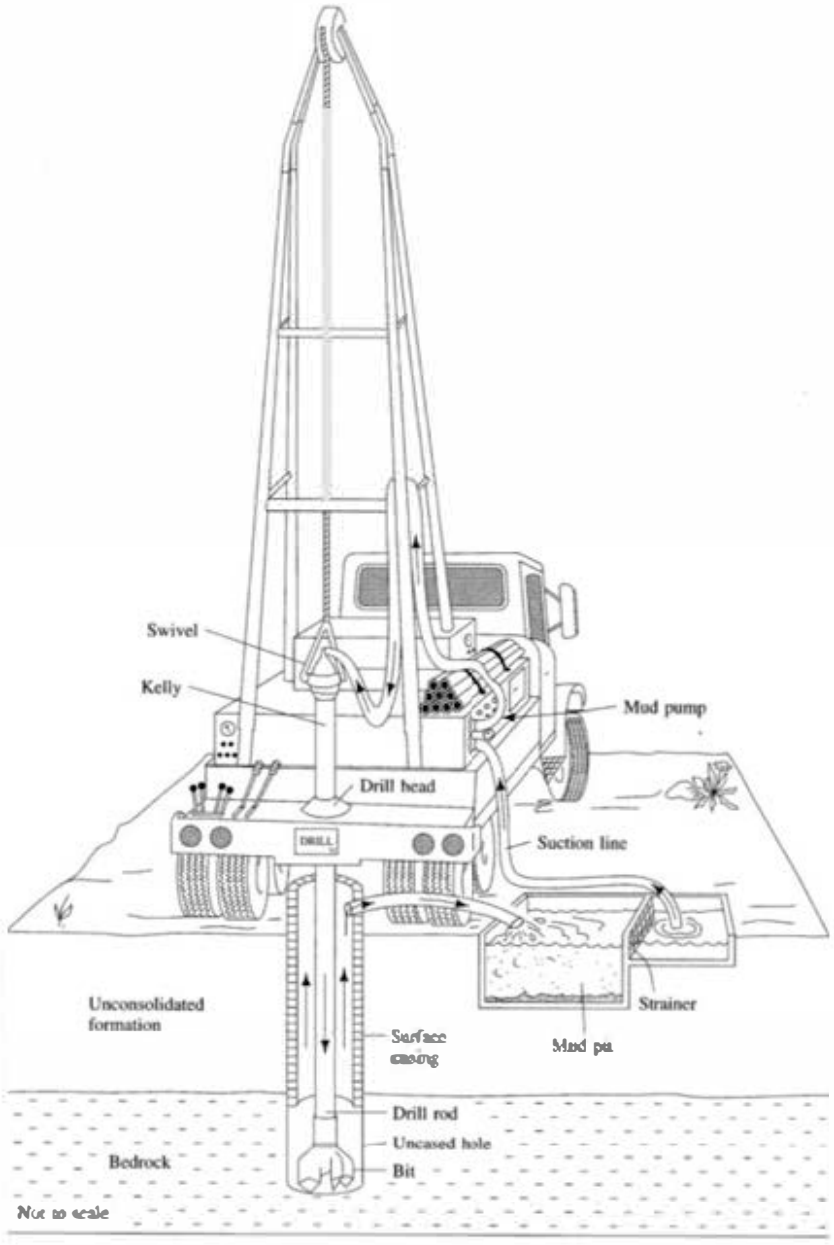
Keeley and Boateng (1987) suggested a modification of the hollow-stem auger drilling technique, in which a temporary casing that is larger in diameter than the auger bit is employed. The auger is advanced several feet and then the temporary casing is driven to the depth of the auger bit by repeatedly dropping a heavy weight on the top of the casing. The advantage of this modification is that it prevents mixing of soil horizons as the augers rotate.

Mud-Rotary Drilling Mud-rotary drilling can be used in both unconsolidated and consolidated formations. It is fairly rapid, up to 30.5 m (100 ft)/day, and can be used to depths far in excess of most that might be required for groundwater-contamination studies. A heavy drilling fluid, made by mixing various additives to water, is circulated in the borehole by pumping it down the inside of hollow drill rods. The mud rises back to the surface in the annular space between the borehole wall and the drill pipe. The rising mud carries with it the drill cuttings, which settle out in a mud tank at the surface. Figure 8.18 shows the circulation pattern for mud-rotary drilling. Alternately, reverse circulation is often used where drilling fluid goes down the annular space and returns upward through the drill pipe (opposite of Figure 8.18). This method, discussed below, can allow greater upward velocities and larger, heavier cuttings can be retrieved.

One advantage of mud-rotary drilling is that the borehole will remain open after the string of drill pipe and the bit are removed. This means that a complete suite of geophysical logs can be run on the hole, which is kept open by the weight of the mud

R000411

FIGURE 8.18 Circulation of drilling fluid in mud-rotary drilling.



inside it. However, the fluid in the drilling mud can penetrate the native formations and alter the groundwater geochemistry. The coating of drilling mud on the borehole walls may be difficult to remove. This can impede the hydraulic connection between the well and the formation. Bentonite-based drilling muds may remove metals from the groundwater and affect the chemistry. Certain additives to drilling mud can also be problematic from a water quality standpoint. Because of the potential problems with drilling mud, rotary drilling may not be as suitable for groundwater contamination studies as hollow-stem augers. However, under many hydrogeologic conditions it is the only drilling method that is practical. Good well development to remove the residual drilling mud in the screen zone is very important

R000412

Air-Rotary Drilling If the monitoring well is to be installed in bedrock, then air-rotary drilling may be considered. First a surface casing needs to be installed through any unconsolidated material. Typically this is done by using mud-rotary drilling. The surface casing is large enough that the air-rotary bit can fit inside of it.

The fluid used in air rotary is compressed air, which is blown down the inside of the drill pipe. The air then blows the cuttings back up the annular space, where they accumulate around the borehole. When the water table is encountered, the air may blow groundwater out of the borehole as well. If this occurs, it is possible to determine when the water table is encountered and the relative yield of the well. However, the air may also force the water back into the formation. Air-rotary drilling using a down-hole percussion bit can drill up to 18 m (60 ft)/hr. Samples are collected as chips, which are brought to the surface with the return flow of air and water.

Air-rotary drilling is fast and can go to depths of a thousand feet of more. Because air is the drilling fluid, contamination problems are minimized. However, the drillers may want to add a foaming agent to the air (air/polymer mix) as it goes down the hole. The foam helps to float the chips to the surface, but it consists of organic chemicals such as isopropyl alcohol, ethyl alcohol, and alcohol ether sulfate, and its use should be avoided. The air compressors have air filters, which need to be in good working condition; otherwise, lubricating oil and other contaminants may be introduced into the borehole with the compressed air. Percussion hammers used for air-rotary drilling may also need lubricants.

Air-rotary drilling may introduce volatile organic compounds into the atmosphere as well as blowing contaminated dust out of the borehole.

Reverse-Rotary Drilling In reverse-rotary drilling the circulating drilling fluid drains down the annular space and then is pulled up the center of the drill stem by a suction pump located on the drill rig. Because the drilling fluid rises with a much greater velocity in reverse-rotary than in mud-rotary drilling, a much less viscous drilling fluid is used. In many cases clear water mixed with the drill cuttings is all that is necessary. This gives the reverse-rotary method an advantage over mud-rotary drilling, since it is much easier to develop the well because there is no mud wall on the borehole to break down. However, reverse-rotary drilling is more expensive than the mud-rotary method, and the minimum borehole diameter is 30.5 cm (12 in.)

Cable-Tool Drilling Cable-tool drilling is one of the oldest drilling methods and has been used widely for the installation of water wells. Although the drilling equipment is less expensive than for some other methods, the drilling is slow and overall costs may be expensive due to high labor costs.

In cable-tool drilling a heavy bit is located at the end of a tool string hanging from a cable. The drill rig repeatedly lifts and drops the hammer, which breaks up consolidated rock or loosens unconsolidated sediment. A steel casing is driven into the formation behind the bit. When the bottom of the casing fills with broken rock and sediment, the tool string and bit are removed, and a bottom-loading bailer is used to remove the accumulated cuttings. Below the water table, the groundwater and cuttings make a slurry. Above the water table, water must be added to make a slurry so that the bailer can be used. Drive casing is needed only until bedrock is reached. In most bedrock formations the hole will stay open without drive casing. Figure 8.20 shows the tools used for cable-tool drilling.

R000413

Advantages of cable-tool drilling include the fact that no drilling fluids are used and that nothing is circulated through the well. Both factors serve to limit contamination problems. It is easy to collect representative samples of the formation during bailing of the casing. Well points can be driven ahead of the casing in unconsolidated formations for the collection of water quality samples. Cable-tool drilling can be used to depths in excess of 305 m (1000 ft). This method however can be extremely slow for deep boreholes, as the tool string and bit must be removed from progressively deeper depths to allow insertion of a bailer for the removal of cuttings, the bailer must then be removed from depth, and the tool string and bit reinserted. As depths increase the time required for this process compounds.

Sonic (Vibratory) Drilling Sonic drilling uses high frequency mechanical oscillation with rotary motion to fluidize subsurface material. As soils and formational materials experience liquefaction, temporary porosity reduction and inertial effects reduce friction on the drill string and drill. The destroyed shear strength of the subsurface formations allows rapid downward advancement in most instances. Advantages include a minimal amount of formation disturbance, reduction of drill spoils and waste compared to other methods, the method can produce continuous cores, sonic does not require circulating drilling fluids, and it can be converted to air or mud rotary or cable tool percussion techniques. Its disadvantages are that the technique is not as readily available as other techniques and is generally more expensive initially.

Other Types of Drilling Other types of drilling include percussion rotary air blast (RAB), air core drilling, and diamond core drilling. RAB combines rotary fluid circulation with the percussive impacts of a pneumatic, reciprocating, piston-driven "hammer" to pulverize rock. This is an effective way to advance drilling downhole in consolidated rock and mixed consolidated/unconsolidated terrain. Like most rotary fluid circulation techniques, circulation can be lost if a large cavity is encountered such as caverns in karst areas, lava tubes in volcanic regions, or human-made features such as subsurface mine shafts. Air core drilling cannot penetrate consolidated rock as well as RAB; it normally is used on weathered regolith or other unconsolidated material. The air core method utilizes hardened steel or tungsten blades to cut into the ground, and collects a more representative sample of solid material compared to RAB. Diamond core drilling is a very slow method used in hard, consolidated rock. It produces a rock core that can be inspected. Often fracture patterns, fracture orientation and aperture size can be determined from these cores. Diamond coring for short intervals can also be used on smaller consolidated formations encountered while drilling with other methods.

When drilling in areas with muddy or spongy soils, it may be necessary to build temporary roads, e.g., laying down a layer of crushed rocks to permit the heavy drilling equipment to reach the drilling locations without getting stuck (Figure 8.19). Alternatively, portable coring drilling machines, originally designed for mineral exploration, can be used to advantage to install hard rock monitoring wells in sites that are hard to access, in remote locations and wilderness sites, and in eco-sensitive areas. Drills, such as the Shaw Portable Core Drill and the Winkie Drill can produce small diameter holes amenable to fractured rock monitoring (Parker et al. 2015).

R000414

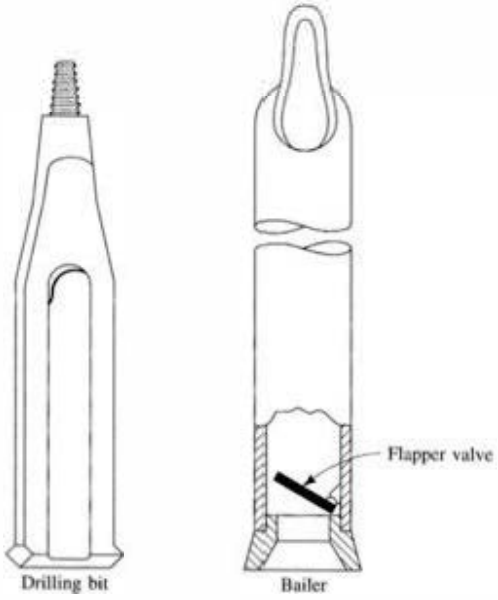
FIGURE 8.19 When drilling in difficult-to-access areas or where soggy soils prevent heavy drill equipment to reach the site, a portable drill rig can be used. Shown here is the installation of an 8-inch bedrock well with a portable air-rotary drill rig in a rice field in Goa, India. The drill rig is powered by pneumatic pressure provided by a truck-mounted compressor which is safely stationed on hard ground approximately 100 m (300 ft) away.



Photo credit: T. B. Boving.

Directional Drilling Directional drilling involves the placement of nonvertical boreholes. Most of the above drilling methods are able to be used in slant drilling (excepting cable tool), where in the simplest application, the mast or drill rig tower is tilted and drilling proceeds at an angle. This modification allows great horizontal access under structures such as buildings, landfills and highly contaminated areas. Drilling through a subsurface NAPL pool, for example, can be avoided in some cases. Traditional drilling methods can be difficult to control in slant drilling because of unwanted deflection, as in slant auger drilling. As slant auger drilling proceeds, cuttings which fall on the bottom side of the hole can eventually force the bit upward into a more horizontal line.

FIGURE 8.20 Tools used for cable-tool drilling.



Controlling wellbore trajectory has become more of a refined technology in recent years. Most modern directional drilling begins in a vertical direction until a desired kick off point where the well inclination is changed using drilling motors and rotary steerable systems. While the use of directional drilling is much more common in oil and gas development, its applications to contaminant hydrogeology are plentiful, particularly where surface or near-surface features or contaminant hotspots must be avoided, but geologic, hydrogeologic, and contaminant information from greater depths directly under these areas is needed.

8.5.3 Drilling in Contaminated Soil

When drilling at a contaminated site, the cuttings that are brought to the surface may be contaminated. Drilling personnel should wear appropriate protective clothing and, if necessary, use breathing apparatus. A large, heavy sheet of plastic should be placed in the work area, and the drill bit should be advanced through a hole in the center of the plastic sheet.

The cuttings augered to the surface can be collected from the plastic sheet and put into containers for proper disposal.

8.5.4 Sample Collection of Solid Material During Drilling

Samples of unconsolidated materials and rock are needed to delineate the geology of a site. They are collected by drilling **borings**. Borings may be made just for sample collection, or they may be made as a part of the process of installing a monitoring well. Borings may be made by any of the methods of drilling discussed in Section 8.5.

During the drilling process, earth materials are brought to the surface. During the augering process, soil and sediment ride up the augers; in the mud-rotary process, earth materials come up mixed with the mud; in air-rotary drilling there is a slurry of rock and

R000416

water brought to the surface by air pressure; and cuttings are brought to the surface with a bailer in cable-tool drilling. In all cases the samples are disturbed, some (such as the samples on the augers) more than others. In addition, it may be difficult to tell the exact depth represented by the sample. Fine layering of sedimentary materials cannot be distinguished in such samples. An imprecise model of the geology can be constructed from these samples, but for more details, undisturbed samples should be collected.

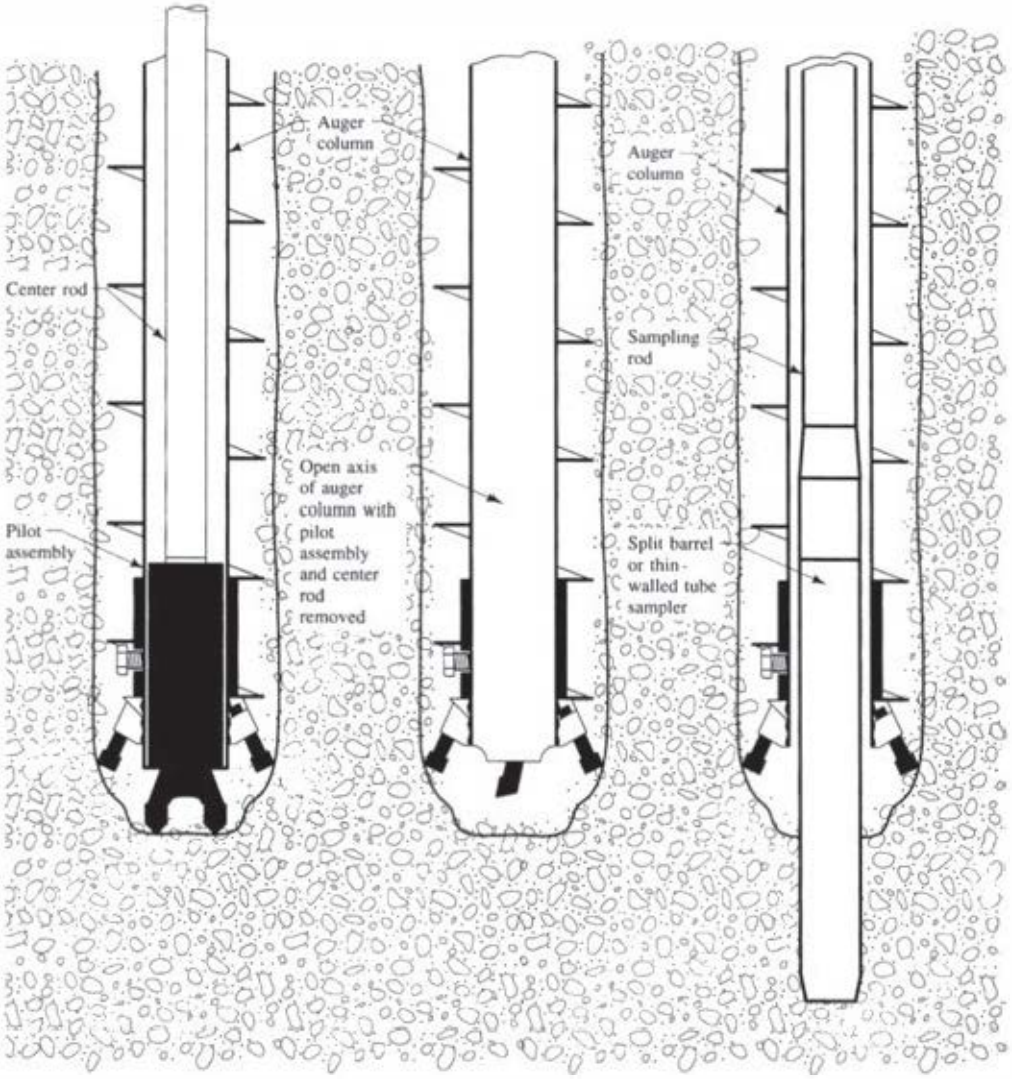
A core sample is collected for consolidated material by obtaining a rock-core sample with a special drilling bit studded with industrial diamonds as mentioned above, or for unconsolidated material with special sampling tubes that are driven into the unconsolidated formations. Interpretation of hard rock cores in consolidated, fractured media suspected of contamination has become quite advanced in the last few decades and can include field geologic core analysis, and laboratory analysis (Parker et al. 2012). The initial field analysis involves determination of the number of fractures, fracture orientation and aperture size, and fracture porosity measurement. This analysis can also observe any occluding chemical precipitates filling (or "healing") the fractures. The orientation of fractures from several core holes can be analyzed to give a three-dimensional view of fractures at a site. Combined with downhole geophysics and tomographic methods, field data can give considerable insight into a fractured rock media and the potential for contaminant movement.

Laboratory measurement of bedrock cores can quantify contaminants in the core, simulate degradation microcosms, and provide core physical, mineralogical, and microbial measurements to determine contaminant phase and mass distribution. Typically, most groundwater flow in fractured consolidated rock occurs through interconnected networks of fractures and secondary porosities, surrounded by low permeability blocks of rock. In adjacent blocks with porosity greater than 1% however, particularly in sedimentary rocks, an appreciable mass of a contaminant can move into the rock matrix. This matrix diffusion in low-permeability blocks or effectively reduces the mass flux in the surrounding fractures (Parker et al. 1997; Parker et al. 2010; Kennel 2008).

Great care must be exercised in the interpretation of rock cores or unconsolidated borings, particularly in the measurement of subsurface contamination or characterization of stratigraphy based on just a few samples. The absence of contamination in a core could be the result of preferential flow (also called "funneling," "fingering," wetting front instabilities, or Rayleigh Taylor instabilities), allowing contamination to completely bypass a boring but still be present in massive amounts. Likewise, unwarranted extrapolation of meager stratigraphic data, particularly assuming continuous layers of unvarying properties, is a common problem particularly in situations where incomplete site characterization goes unchallenged. There are two main types of sampling tubes for unconsolidated samples. Both types of tubes can be used with hollow-stem augering and mud-rotary drilling if the drill rod and bit have a provision for a sample tube to be extended through them into the formation ahead of the bit. Figure 8.21 shows the sequence for the extension of a sampler through the end of the bit of a hollow-stem auger. The sampler is driven or pushed into undisturbed formation ahead of the bit. In cable-tool drilling the drill bit is removed from the borehole and the sampler is lowered on a rod or cable.

A Shelby tube is a thin-walled tube that can be screwed to the end of a rod, lowered to the bottom of the drilled hole, and pressed into cohesive sediments by using hydraulic pressure reacting against the weight of the drill rig. These samples are said

FIGURE 8.21 Sequential steps for the collection of a core sample through a hollow-stem auger.



Source: G. Hackett 1987. Drilling and constructing monitoring wells with hollow-stem augers part 1: Drilling considerations. *Groundwater Monitoring & Remediation* 7:51–62. Used with permission.

to be *undisturbed*, although they are in fact minimally disturbed. The precise method of collecting a Shelby tube sample is described in method ASTM D1587 (American Society for Testing and Materials 1983). The sample can be extruded from the Shelby tube in the lab and trimmed into a permeameter for a permeability test. Details of the microstrarigraphy can be examined as well. Shelby tube sampling does not work with noncohesive sediments.

A split-spoon sampler can be used for the collection of samples of both cohesive and noncohesive sediments. The split-spoon sampler consists of a split tube with thicker walls than a Shelby tube. The two halves are placed together and joined by screwing a circular drive shoe on the bottom and a head assembly on the top. The assembled split-spoon sampler is screwed to a rod and lowered to the bottom of the drill hole. A pipe-like weight of 63.5 kg (140 lb) is placed on the top of the rod.

R000418

The weight is repeatedly raised and dropped a distance of 76 cm (30 in.) in order to drive the split-spoon sampler into the formation. The number of blows necessary to drive the sampler every 15cm (6 in.) is recorded as the sampler is driven 46 cm (18 in.) into the formation. The more dense the formation, the greater the number of blows needed to drive it 15 cm (6 in.). The process is described by ASTM 1586 (American Society for Testing and Materials 1984).

After the split-spoon sampler is driven 46 cm (18 in.), or after refusal, it is brought to the surface and opened. Frequently, less than 46 cm (18 in.) of sediment have been collected. Fine, noncohesive sediment such as sand may fall out of the sampler as it is being retrieved. Sediment greater in diameter than one-third of the diameter of the sampler may not enter it at all. A pebble may lodge in the barrel and not allow any other sediment to enter. Sediments may compact in the sampler so that a full 18-inch sample may actually occupy less than 46 cm (18 in.) of the core barrel. The hydrogeologist examining the split-spoon sample must use his or her judgment in making a log based on the split-spoon samples. Figure 8.22 is a photograph of a split-spoon sample.

FIGURE 8.22 Hydrogeologist describing a split-spoon sample.



Photo credit: C.W. Fetter.

R000419

A standard for core samples is to collect one 46 cm (18 in.) sample every 1.5 m (5 ft). This frequency of sampling is suitable for relatively homogeneous formations. However, if the microstratigraphy of the formations is important—for example, if there are permeable sand seams in a clay formation—then continuous-core samples should be collected. Continuous cores are made by advancing the drill bit to the full depth that was sampled by a split spoon and then immediately taking another core sample of the fresh formation ahead of the previous core. Continuous-core samples can also be collected in cohesive soils by using a special core barrel that collects a 1.5 m (5 ft) long sample inside a hollow-stem auger as the auger is being advanced. If a sequence consisting of a 3-inch split spoon followed by a 6.35 cm (2.5 in.) split spoon followed by a 5 cm (2 in.) split spoon is used, 1.37 to 1.5 m (4.5 to 5 ft) of continuous sample core can be collected before the augers need to be advanced.

In consolidated formation a rock-core sample is collected by use of a core barrel with a diamond-studded bit. The rotating bit grinds up rock in an annular pattern, leaving an undisturbed center of rock that enters the core barrel. There is a core lifter just behind the bit to keep the core from falling out of the core barrel when the drill rods and bit are retrieved from the borehole. For shallow soil sampling, some coring and auger soil sampling devices can be operated by hand. Helical or post-hole augers gather a disturbed, near-surface sample and are superior to coring devices in rocky soils. Soil cores can be taken by hand from the ground surface with specialized coring devices that can allow sampling for VOCs and other potential contaminants. Cores are typically extruded after sampling and readied for transport or analysis. Decontamination techniques for coring equipment between samples is required to prevent cross-contamination.

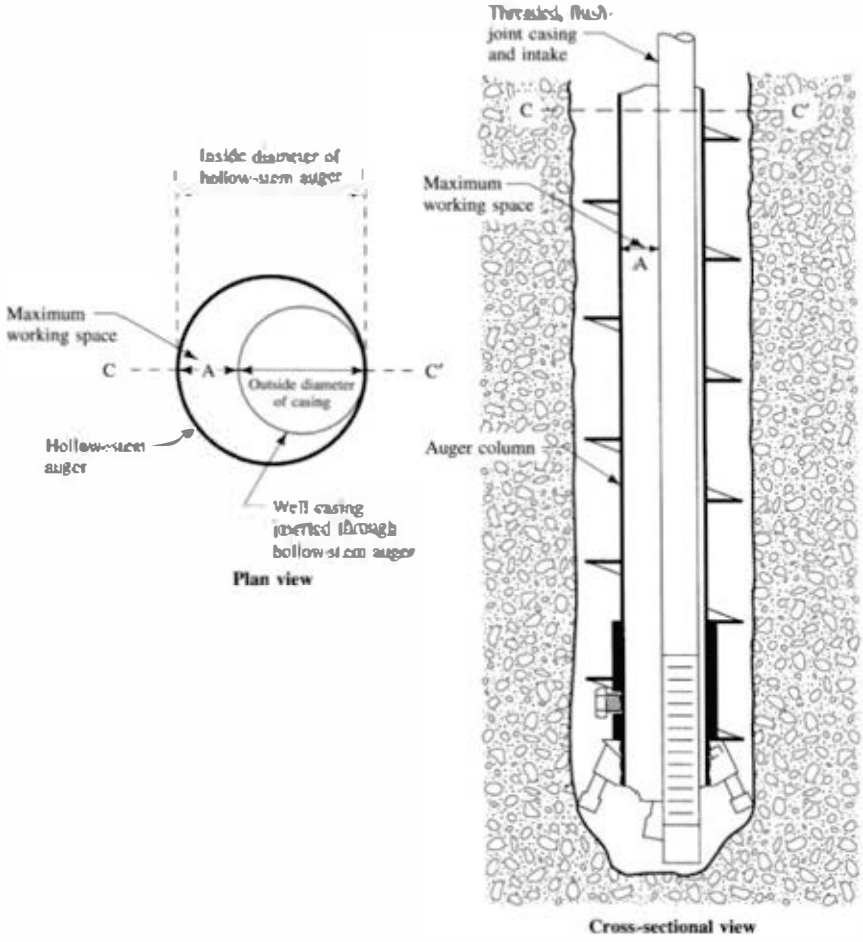
8.5.5 Installation of Monitoring Wells

Following the collection of samples during the installation of borings, a monitoring well can be installed in the borehole. Boreholes drilled with mud should stay open with the drill rod removed. Hollow-stem augers are generally left in the ground and the well is installed through them, as is drive casing in cable-tool drilling. There must be a sufficient working opening inside the casing or augers. For a 5 cm (2 in.) nominal monitoring well, this means a minimum 10.8 cm (4.25 in.) opening is needed. The casing can be offset within the auger to give the largest working opening (Figure 8.23) although care must be taken to keep the well casing and screen as centrally located as possible. With a 10.8 cm (4.25 in.) inside diameter auger and a 5 cm (2 in.) nominal casing, this creates a 4.76 cm (1.875 in.) working opening.

The first step in the installation of a monitoring well is to screw the well screen to the casing and then lower the assembly through the inside of the augers or temporary casing. Prior to installation the casing and screen should be thoroughly decontaminated. The casing and screen may be wrapped in white butcher paper after it has been decontaminated and then kept wrapped until just before it is lowered into the augers. Figure 8.24 shows a 6.1 m (20 ft) casing and screen being lowered by hand. Longer casings need to be lowered on a cable using the drilling rig. In boreholes not drilled by hollow-stem augering, it is generally important to have centralizers (mechanical collars-type devices) attached to the casing/ screen combination to keep them from contacting the wellbore walls (Nielsen 2005).

R000420

FIGURE 8.23 Casing offset inside hollow-stem auger to give greatest working opening.



Source: G. Hackett. 1988. Drilling and constructing monitoring wells with hollow-stem augers part 2: Monitoring well installation. *Groundwater Monitoring & Remediation* 8:60-68. Used with permission.

Once the casing and screen have been lowered into the well, the filter-pack material needs to be placed. The volume of filter-pack material necessary to fill the annular space between the screen and casing and the borehole wall from the bottom of the borehole to a point 0.6 m (2 ft) above the top of the screen should be computed. At least this much material must be on hand before starting the filter-pack installation. A weighted measuring tape is lowered into the working opening between the casing and the hollow-stem auger and the total depth of the borehole is measured and recorded.

If the formation is cohesive and can stand open for a short while, the augers are withdrawn 0.3 or 0.6 m (1 or 2 ft) from the bottom. Filter-pack material is then poured into the working opening, and the annular space is filled to the level of the auger bit. Care should be taken that the filter-pack sand doesn't fill the space between the casing and the augers, because it can lock the casing and hollow-stem augers together. The weighted tape is used to determine the position of the top of the filter pack. The augers are then withdrawn another 0.3 to 0.6 m (1 to 2 ft), and the process is repeated until the entire filter pack is placed. Figure 8.25 illustrates what is known as the free-fall method of filter-pack emplacement.

R000421

FIGURE 8.24 Lowering well screen and casing into hollow-stem augers. Note the white wrapping paper around the decontaminated casing.

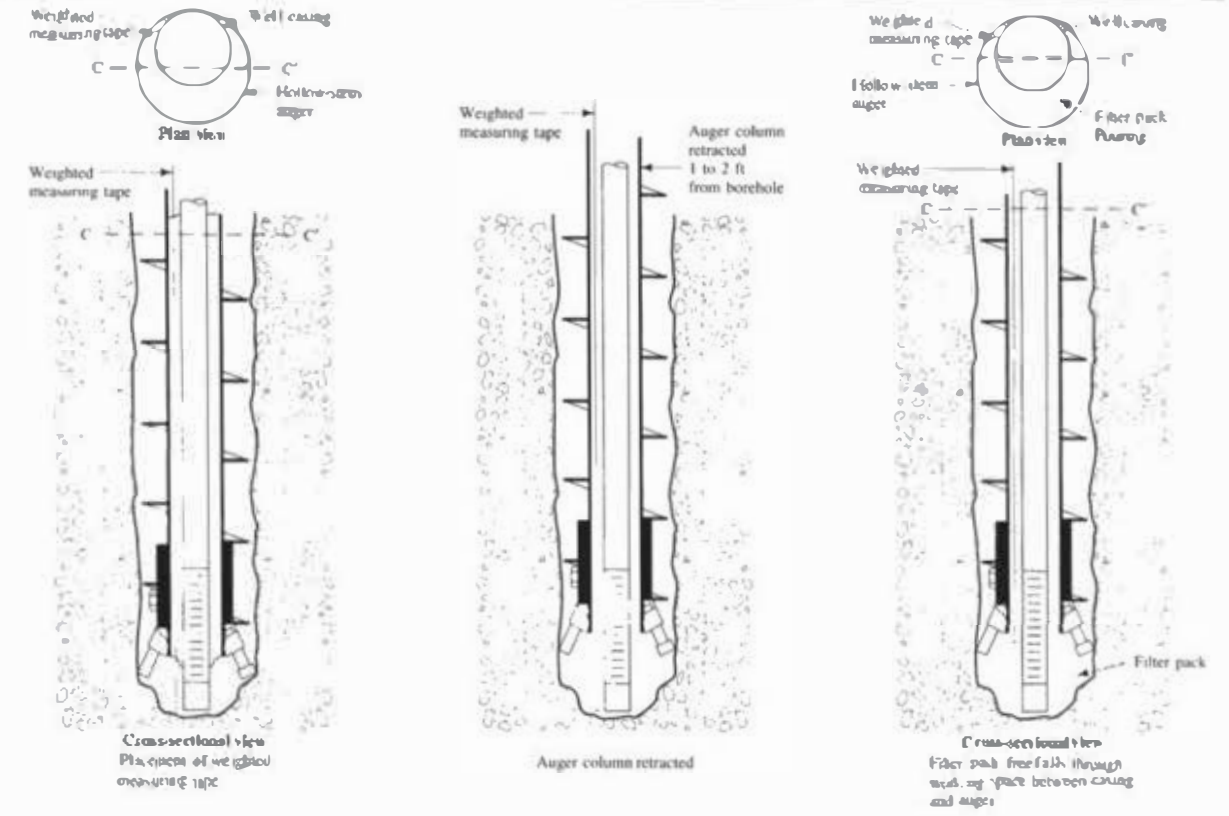


Photo credit: C. W. Fetter.

When filter-pack material drops through a water column, it may separate according to size. It may also bridge the space between the casing and the auger and create a void below. To avoid these problems, a **tremmie pipe** should be used wherever possible (Figure 8.26). A tremmie pipe is a pipe that extends from the surface and through which the filter-pack sand may be poured. After the augers are withdrawn a few feet, the annular space is filled with sand being poured down the tremmie pipe. The tremmie pipe is raised as the level of sand rises. The tremmie pipe can be used to tamp down the sand, and the weighted tape is used to measure the position of the top of the filter pack.

If the formation is noncohesive, it will collapse as the augers are withdrawn. Under these conditions, the withdrawal of the augers and the addition of the filterpack

FIGURE 8.25 Free-fall method of filter-pack emplacement with a hollow-stem auger. The method also works with drive casing.



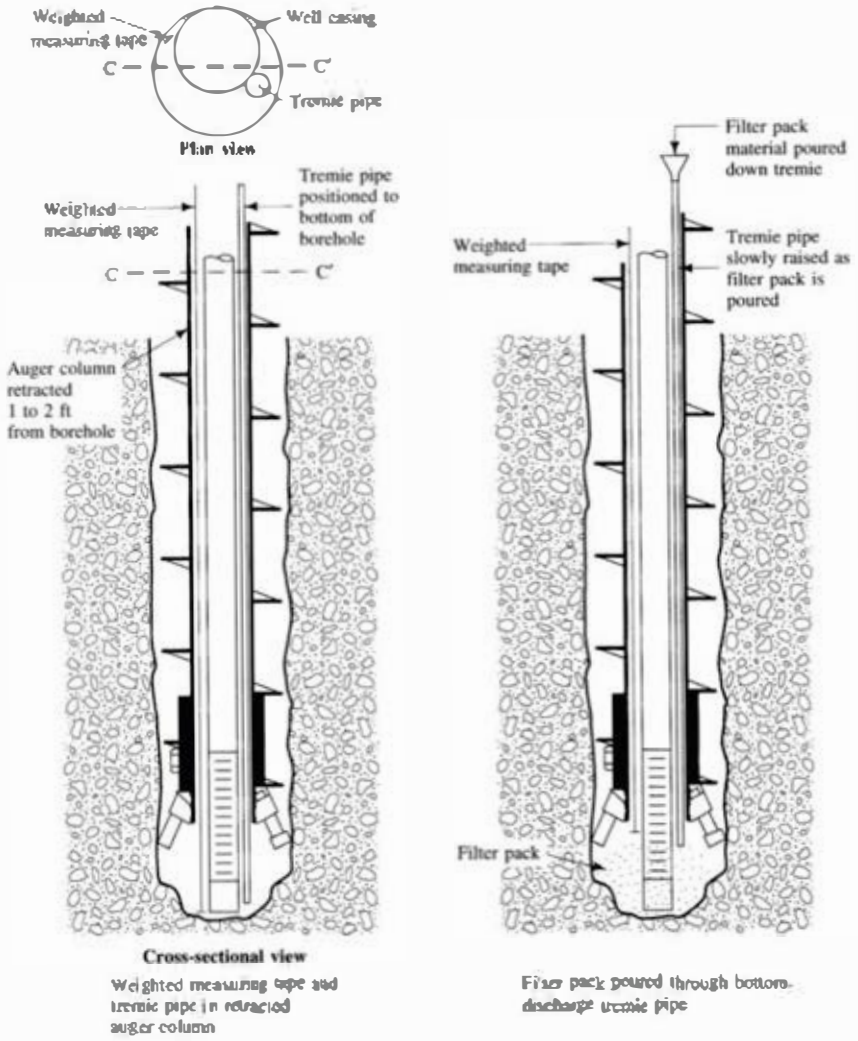
Source: G. Hackett, 1988. Drilling and constructing monitoring wells with hollow-stem augers part 2: Monitoring well installation. *Groundwater Monitoring & Remediation* 8:60–68. Used with permission.

material must occur simultaneously (Hackett 1988). A cable must be attached to the top of the auger string so that the working opening is accessible at all times. The hollow stem of the augers is filled with clean water, and a positive hydraulic head is thus maintained throughout the operation. The augers are very slowly withdrawn, and at the same time filter-pack material is added so that the top of the filter pack is within an inch or so of the bottom of the augers. This requires precise coordination of the rate of addition of filter-pack sand and the rate of withdrawal of the augers.

The final depth of the top of the filter pack is confirmed by measurement with the weighted tape. It should be 0.6 m (2 ft) above the top of the screen. The augers are then withdrawn another 0.6 m (2 ft) and 0.6 m (2 ft) of pure bentonite clay is placed by free fall through the working space. If the area is below the water table, bentonite pellets are used; if the area is above the water table, granular bentonite or slurry is used (see 8.4.5). Pellets should be dropped a few at a time so that they aren't caught in the working space as they start to swell by hydration. The weighted tape is used to confirm the final thickness of the bentonite layer after enough time has elapsed to allow the bentonite to hydrate. Bentonite pellets should not be used as grout in the vadose zone, as hydration is extremely slow even if water is poured through the pellets.

Placement of the annular seal should take place by use of a tremmie pipe. The tremmie pipe should be lowered to the top of the bentonite seal. The augers are

FIGURE 8.26 Use of a tremmie pipe for emplacement of filter-pack material.



Source: G. Hacket; 1988. Drilling and constructing monitoring wells with hollow-stem augers part 2: Monitoring well installation. *Groundwater Monitoring & Remediation* 8:60-68. Used with permission.

withdrawn 0.6 m (2 ft) or so and the annular space is filled from the bottom with grout, which is either pumped down the tremmie pipe or is fed by gravity (Figure 8.27). The weighted tape is used to confirm the position of the top of the grout. The augers are then repeatedly withdrawn and grout is emplaced until it is brought close to the surface. The tremmie pipe can be left at the bottom until the grout is brought to the surface, or it can be raised as the augers are withdrawn. For slumping sediments, the grout must be emplaced simultaneously and at the same rate as the augers are withdrawn.

The final step is the installation of a locking protective cap. Bentonite-cement can be brought all the way to the surface. If bentonite grout or bentonite-sand grout is used, the final few feet filling the annular space must be neat cement or bentonite-cement grout. A slight mounding of the surface grout will prevent the pooling of water at the surface next to the well. The locking protective casing can be pushed into the cement grout when

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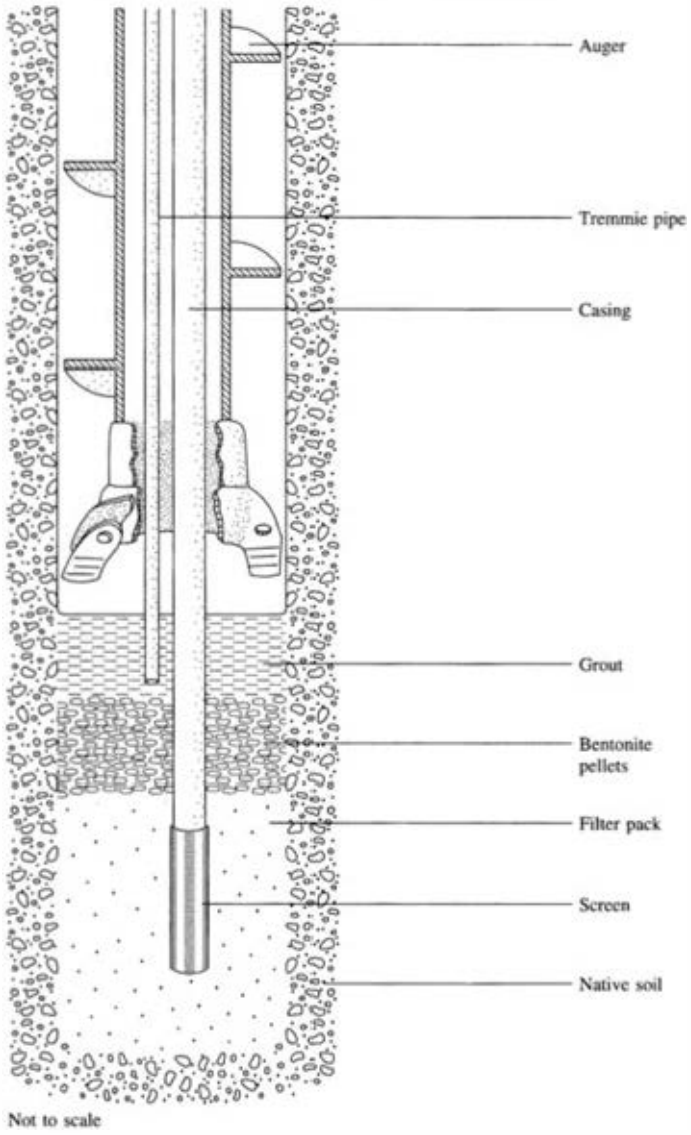
FIGURE 8.27 Use of a tremmie pipe for emplacement of grout above the bentonite pellets.



it is still soft. If the grout settles overnight, its level should be brought to the surface with additional material. A stronger surface seal can be obtained if the top 0.61 m (2 ft) of the annular space is filled with concrete, as opposed to bentonite-cement grout.

8.5.6 Monitoring Well Development

Once a monitoring well is constructed, it is necessary that it undergo development. This is a process of removing fine sand, silt, and clay from the aquifer around the well screen. If drilling mud was used, then vigorous development may be needed to break down the mud pack on the borehole wall. Development is needed to create a well that ideally will not pump silt and clay when it is sampled. It also may create a zone around the well screen that is more permeable than the native soil and that stabilizes the native soil so that the fine sediments do not enter the filter pack.

Aller et al. (1991) made the following observations about monitoring well development:

1. Using compressed air for well development may alter native water chemistry, crack the casing, or blow the bottom cap off the screen.
2. Adding water to the well for flushing the well or surging can alter the groundwater chemistry, at a minimum by dilution.
3. Breaking down a mud wall left in the borehole from mud-rotary drilling is very difficult.
4. Developing a well when the screen is in a clean, homogeneous, high-permeability aquifer is relatively easy.
5. Developing a well when the screen is in a fine-grained, stratified, low-permeability formation is difficult.
6. Developing a large-diameter well is easier than developing a small-diameter well.
7. Shallow monitoring wells are easier to develop than deeper monitoring wells.
8. Monitoring wells that can be bailed dry tend to be turbid because of the steep hydraulic gradients that are developed.
9. In the final analysis, many monitoring wells cannot be developed to the point where a nonturbid, groundwater sample can be collected. This is especially true if the formation does not yield very much water, so that extensive development is not possible.

If the borehole is drilled into a stable, consolidated formation, especially if mud is used during the drilling, it may be advantageous to flush the borehole with potable, fresh water to wash out as much of the mud as possible prior to installation of the well and filter pack. This will greatly cut the time needed for well development. In some cases it will not be permissible to add water to the borehole, since this might alter the groundwater chemistry.

There are three procedures used for monitoring well development: bailing, surge block surging, and pumping/overpumping/backwashing. These may be used alone or in combination.

A bailer for a monitoring well is a section of pipe that is open on the top end and has a foot valve on the bottom end. It is attached to a line so that it can be lowered into the well. Water fills it from the bottom; then when it is raised by the line, the foot valve closes and the water inside is trapped. Figure 8.28 is a diagram of a bailer.

When developing a well by bailing, the bailer should be allowed to freefall to the water surface. When it strikes the water, a pressure wave results, which pushes water from the well screen out into the formation. After the bailer is filled with water, it is withdrawn and water from the formation enters the screen. This back-and-forth motion of water through the filter pack loosens fine sediment so that it can be drawn into the well and removed by the bailer. The bailer should be allowed to sink to the screen area so that the water that fills it contains the fine sediment that is brought into the well from the filter pack. The bailer can also be raised and lowered when it is submerged to force water to move back and forth through the screen area. Bailing can take some hours to develop a monitoring well effectively; this can translate into significant labor cost. Bailing for development can be undertaken by hand or by using a cable attached to a

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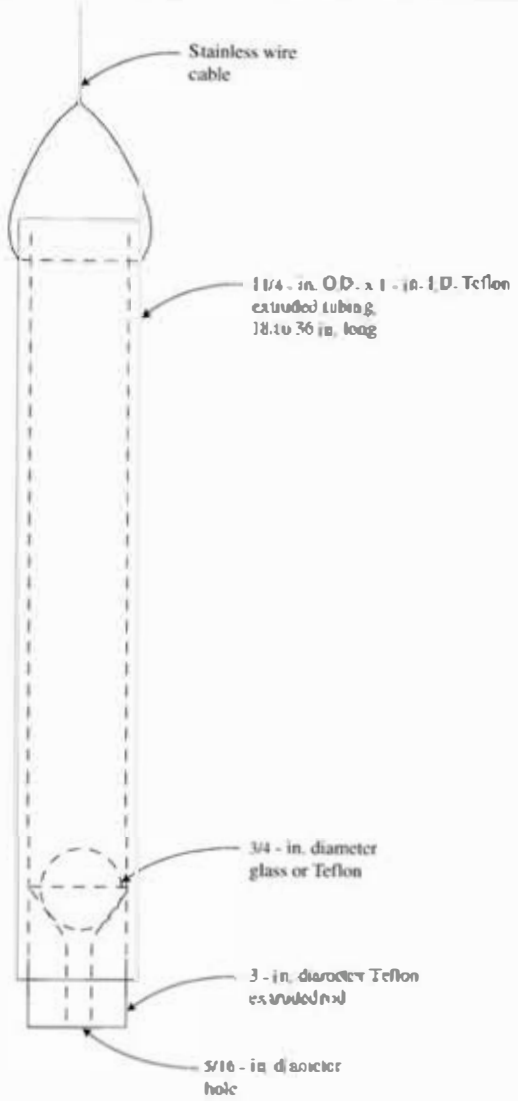
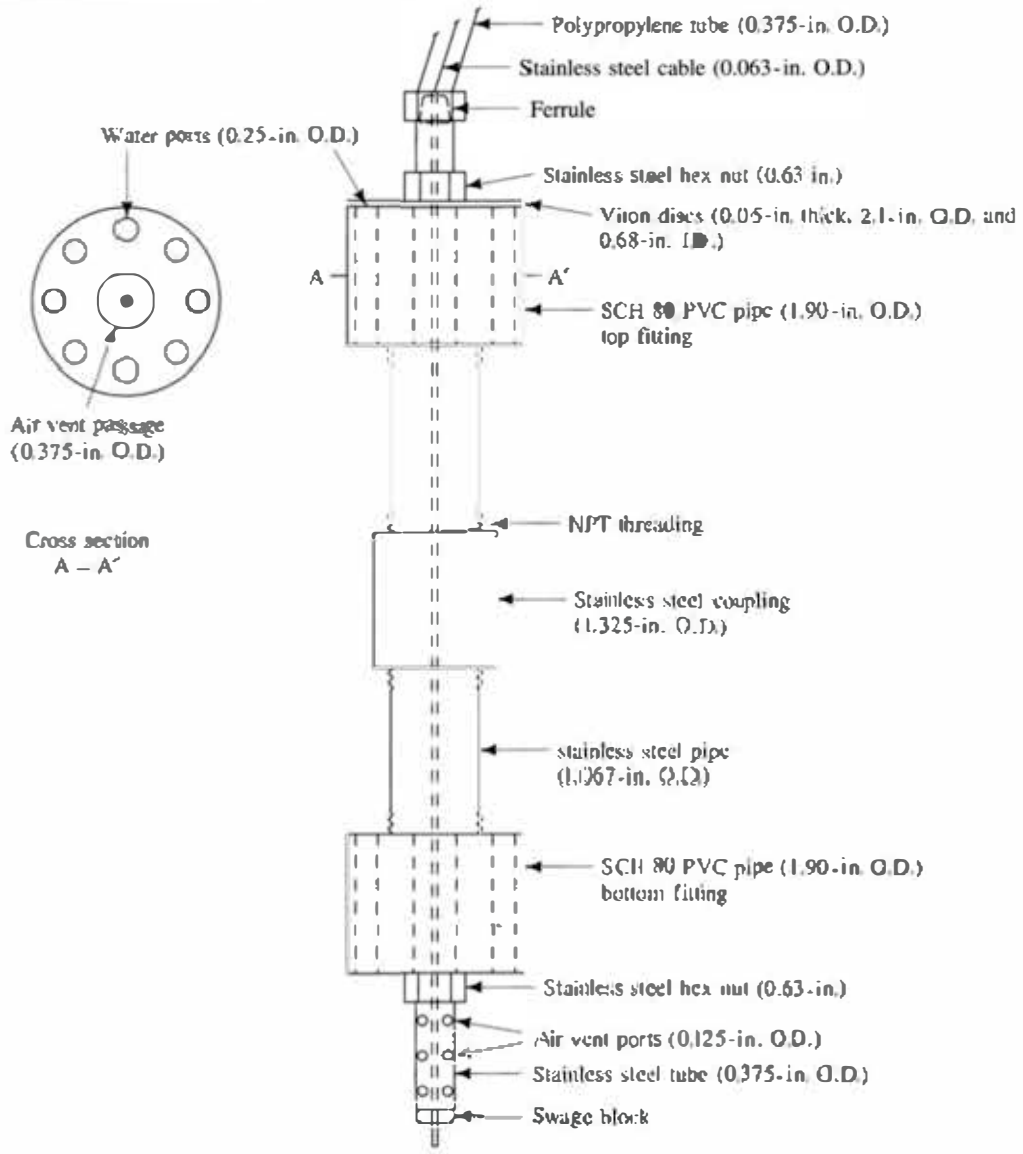
FIGURE 8.28 Diagram of a bottom-loading bailer.



power-operated drum on a drill rig or truck. Some well-development outfits have an arm that can go up and down like a walking beam to create a surging action. Care should be taken so that the surging action is not vigorous enough to collapse the well screen.

A surge block is a device that fits inside the well with a flexible gasket that is close in size to the inside diameter of the well. Figure 8.29 shows the design of a surge block for small-diameter monitoring wells. It is attached to a rod that is raised and lowered with a stroke of about 0.9 m (3 ft). Most of the water is moved up or down by the action of the surge block, although some fraction of the water bypasses the surge block. The surging is initiated with the surge block at the top of the well screen, and the block is gradually lowered until the entire screened area has been surged. Every so often the surge block is removed and the well bailed to remove the sediment that has been brought into the well. If too much sediment accumulates above the surge block, it can bind between the surge block and the casing wall and lock up the surge block. To avoid this, the surge block

FIGURE 8.29 Design of a specialized surge block for monitoring wells.



Source: R. Schalla and R. W. Landick. 1986. A new valved and air-vented surge plunger for developing small-diameter monitor wells. *Groundwater Monitoring & Remediation* 6:77–80. Used with permission.

must be removed and the well bailed frequently. Surging begins with a gentle action; as development progresses it becomes more vigorous, with a more rapid plunging action. Again, too vigorous a surging action might cause the screen to collapse.

Pumping the well can aid in development. A number of different types of pumps are suitable. However, some pumps might be damaged by the sediment that must necessarily be removed during development. The ideal pump for development is capable of a wide range of flow velocities and does not have a valve that prevents backflow. The pump intake should be in the screen zone so that it will immediately pick up sediment that is brought into the well. The pump is started at a low velocity and is shut off every so often. When it is shut down, the water in the pump column between the water

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surface and the pump will flow back into the well and out into the filter pack. When the pump is started again, this water will be drawn into the well and will loosen fine sediment in the filter pack. With time, the rate at which the well is pumped is increased so that the water velocity through the filter pack into the screen is increased. Eventually, the well will be overpumped—that is, pumped at a rate that is greater than the flow into the well through the well screen. There will be a rapid decrease in the water level in the well during overpumping, and it cannot be sustained for very long. Eventually the water from the well should clear. Monitoring wells should be periodically redeveloped.

8.5.7 Record Keeping During Monitoring Well Construction

Many localities have detailed record-keeping requirements for monitoring well construction. Even when detailed records aren't required by statute, they should be kept as a matter of sound professional practice. Figure 8.30 shows a one-page form that can be used to record important information on monitoring well construction. Many firms have their own forms, and many states, provinces, and regions have a required form. The form should be filled out in the field as the information is collected.

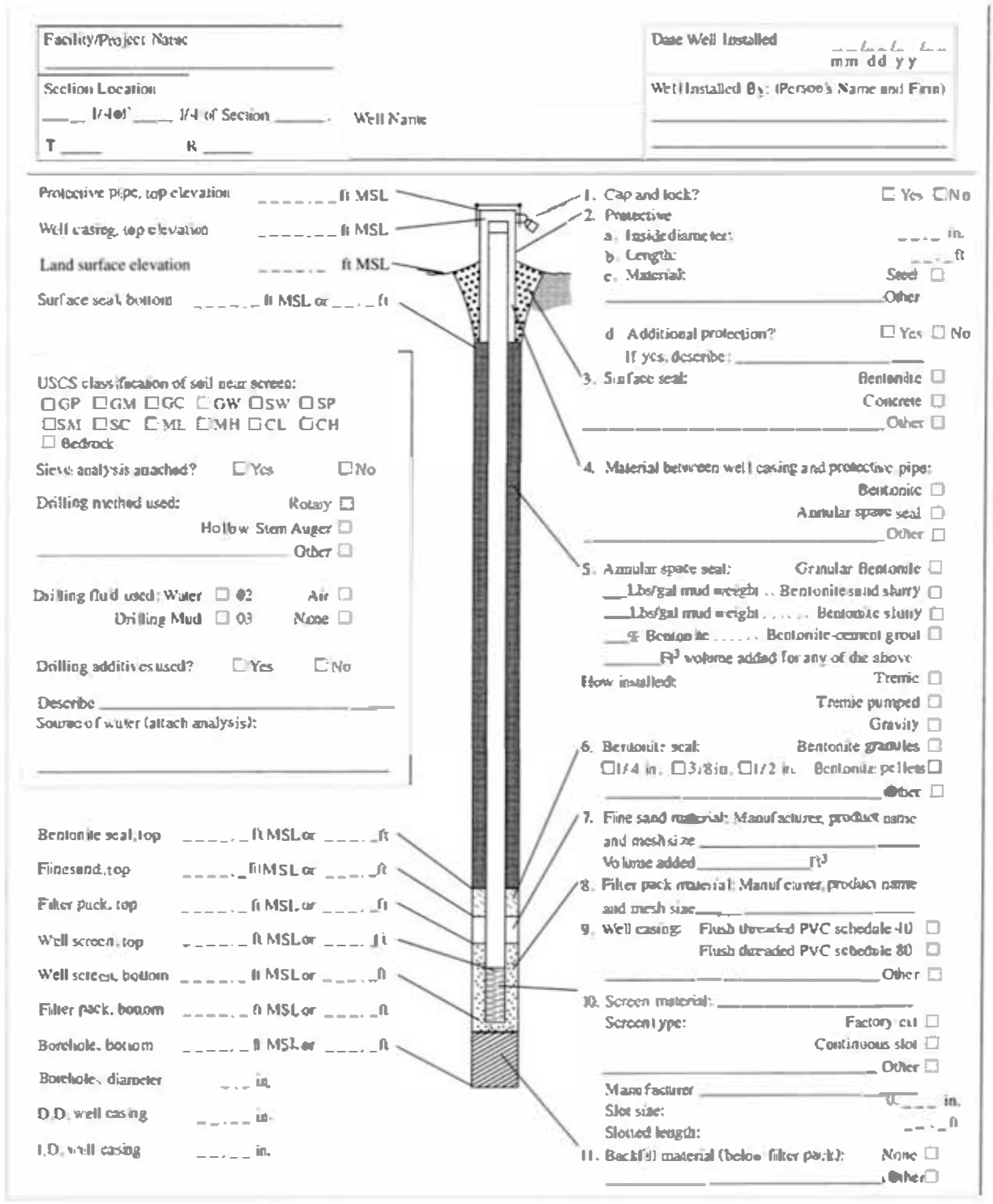
Records should also be kept of well development, including the date that it occurred, the method used, the water level at the start of development, the water level at the end of development, the time spent developing the well, and the volume of water removed. The thickness of sediment on the bottom of the well can be determined by measuring the depth to the bottom of the well with a weighted tape. This measured distance is subtracted from the measured length of the well casing and screen that was installed. The difference between the two dimensions is the thickness of sediment inside the well. This thickness should be measured and recorded both before and after development. If possible, sediment should be removed with a bottom-loading bailer.

8.5.8 Monitoring Well and Borehole Abandonment

Sometimes difficulties are encountered during the construction of a monitoring well that prevent its completion. Monitoring wells may be installed for a specific time period, after which they must be removed. Test borings may be made with no intention of using the borehole for construction of a monitoring well. In all such cases, proper abandonment of the well should be undertaken. Many counties and regions have specific well-abandonment codes. In the absence of specific requirements, monitoring wells and boreholes should be abandoned in such a manner that surface water cannot drain into the aquifer. Otherwise a direct connection for contaminated water from the surface to the aquifer can result. Nor should contaminated water or fluids be allowed to move vertically within the borehole to contaminate other depths.

If a casing and screen have been installed, they should be removed if possible. This can be accomplished by pulling if the annular seal has not been filled with a cement-type grout. If a plastic casing breaks while being pulled, it can be removed by drilling it out with hollow-stem augers. Following the removal of the casing, a tremmie pipe should be used to fill the resulting borehole from the bottom with an appropriate material, such as neat cement or bentonite grout. The grout is placed while the augers are being pulled out of the hole. Material removed from a monitoring well may be contaminated and should be properly disposed of.

FIGURE 8.30 Form for recording information about construction details of a monitoring well.



Source: Modified from Wisconsin Department of Natural Resources.

If the casing and screen have been grouted into place, it may not be possible to remove them. If this is the case, several approaches can be used. The casing could be cut off below grade; then the screen and casing must be filled from the bottom using a

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tremmie pipe and an appropriate material such as neat cement or bentonite grout. If the casing is in poor condition it can be ripped or perforated with casing rippers allowing grout to be injected into the annular space. Alternatively, casing can be gun-perforated using either a device that fires steel projectiles through the casing and into the formation, or a jet type perforator that uses small shaped explosive charges to burn holes through the casing and allow grout injection (Aller et al. 1991).

Boreholes in sediments can be filled with grout or native soils mixed with bentonite. Boreholes into bedrock should be grouted with a cement-type grout.

8.6 Well Sampling

8.6.1 Introduction

After a monitoring well has been designed, installed, and developed, the next step is to collect a water sample. The water sample should be representative of the water in the formation; that is, the sampling techniques should collect water from the aquifer and not from water that has been standing in the well casing or screen. In addition, the sampling device should provide a sample that has not been altered by the sampling process and should not cause cross contamination.

8.6.2 Fluid Level and Pressure Measurement

Several devices are available for the downhole measurement of water levels, pore pressures and NAPL layers in wells or piezometers. Historically, steel tape was used to measure water levels in wells. Chalk would be applied to the tape at the expected water level depth, and then retrieved to the surface. The depth to water would be indicated on depth markings on the tape at the point where the chalk had been washed away by the water. Another historical method to measure hydraulic head is a "bubble tube" which is a pipe or tube sent downhole with a known air pressure to depths below land surface and below the water table or piezometric surface. The tube continues to bubble until it reaches a depth where the water pressure is equal to the air pressure within the tube and the depth below water surface can be calculated. This method is not used in situation where volatilization of contaminants is possible or LNAPLs are suspected in the wells.

Water levels are now often determined by electrical probes with depth demarcations which are lowered in a well or piezometer until a peeping sound indicates that the water level has been reached. For more exacting and quantitative NAPL determinations in wells, depth-discrete and transparent bailers can be sent downhole, or interface probes can be used. An interface probe is a modified electrical water level probe which has an ability to give separate acoustic and visual signals for water and NAPL in the fluid column (Mercer and Cohen 1990; Cohen and Mercer 1993). Unlike the bailer, however, interface probes cannot retrieve a NAPL sample for analysis, but only measure the vertical thickness of NAPL in a well.

Long term water level measurements are now often made with a recording transducer which measures temporal pressure changes in a well at a specified depth, which correlates to overlying water levels. Vibrating wire piezometers are useful in measuring well water levels and pore pressures for geotechnical applications.

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8.6.3 Well Purging

Water that has been standing in the well has been in contact with atmospheric gases and the well casing and screen. This contact can affect the water chemistry. Oxygen can diffuse into the water and dissolved gases can volatilize or oxidize. Trace elements may be leached from the well casing. Organics may be sorbed by the well casing. In order to be sure that the water being drawn into the sampling device comes from the aquifer, the well must be purged of standing water prior to sampling. The goal of purging is to remove all the water that has been standing in the well. The volume of water that must be removed to accomplish that goal depends upon the method of purging and formation permeability.

The first step in well purging is to measure the depth of water in the well, the total well depth, and the inside diameter of the well casing. These measurements are used to compute the volume of water standing in the casing. If a well is purged by a method that withdraws water from the top of the water column, then theoretically only one well volume needs to be withdrawn. For example, purging with a bailer that is lowered slowly into the well to a depth no greater than the length of the bailer will remove water only from the top of the column. If a pump is used to purge the well, the pump intake should be as close as possible to the top of the water column. Although one well volume would theoretically remove all the standing water, good practice suggests that at least three well volumes should be removed to be sure that the standing water in the casing and screen is totally removed. This also removes water from the filter-pack area. If a well is bailed dry, or nearly so, it is not necessary to attempt to remove multiple-well volumes. As soon as the well has recovered enough to contain sufficient sample volume, the sample can be collected.

If the pump intake is lowered to the level of the screen in the well during purging, then most of the water will come from the screen area, and an area of stagnant water will develop in the water column above the pump intake. Under such conditions up to five well volumes need to be pumped to remove all of the stagnant water in the well (Gibb et al. 1981). Keeley and Boateng (1987) advocate a staged technique when purging with a pump. The pump intake is lowered to just below the water surface at the beginning of the purging process and then is gradually lowered through the water column until it is at the screen zone, when purging is complete. Purging three well volumes with this technique should be adequate.

Electrical conductivity and pH can be monitored during the well-development procedure. If they vary widely during the well-purging process, this may mean that water from different sources is being withdrawn. If these values do not stabilize, this does not necessarily mean that the stagnant water has not been withdrawn from the well. There may be instrument drift, or the water quality in the aquifer may be changing as water from different parts of the aquifer is being withdrawn. If possible, the well should be purged until it is not turbid.

The water being purged from the monitoring well may be contaminated. If so, it must be properly disposed of in a treatment facility. For this reason, purging techniques that limit the amount of water withdrawn are desirable.

8.6.4 Well-Sampling Devices

There are a large number of sampling devices available for monitoring wells. They operate under different physical principles and designs and have different applications.

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Most are available in a variety of materials. The following is a partial list of available devices (Nielsen and Yeates 1985; Pohlmann and Hess 1988):

1. *Open bailer*: This device is a rigid tube with an open top and either a closed bottom or a check valve on the bottom. It is attached to a line and is lowered and raised by hand. It withdraws the sample from the top of the water column.
2. *Point-source bailer*: This device has a check valve on both the top and bottom and can be lowered on a line to a given depth below the surface, where the valves can be closed by a cable. It can collect grab samples from any depth in the water column. Some bailers are intentionally disposable to prevent cross-contamination from multiple sampling, and some are transparent or translucent allowing visual identification of colored NAPLs or other compounds in the bailer.
3. *Syringe sampler*: A medical syringe, or similar device, is attached to a length of tubing and is lowered to a selected depth in the water column. A suction is applied to the tubing and the syringe, which was lowered in the "empty" position. The syringe fills as the water comes into the needle because of the vacuum being developed by the suction on the tubing.
4. *Gear-drive pump*: This device is similar to a traditional submersible electrical pump. There is a miniature electrical motor attached to the pump, which rotates a set of gears to drive the sample up the discharge line via positive displacement. A continuous flow of water under positive pressure is developed.
5. *Bladder pump*: This sampler has a rigid tube containing an internal flexible bladder. There are check valves on either end of the rigid tube. When the bladder is deflated, water enters the lower end of the tube through the check valve. When the tube is full, the bladder is inflated with an inert gas pumped down from the surface. The bottom check valve closes, the top check valve opens, and the water sample flows up the discharge line. When the bladder deflates, the water in the discharge line can't drain back into the rigid tube because of the check valve. The water is under positive pressure at all times and doesn't come into contact with the gas.
6. *Helical-rotor pump*: This pump has a submersible electrical motor. It rotates a helical rotor-stator, which drives water up the discharge line under positive pressure.
7. *Gas-drive piston pump*: A piston that pumps the water is driven up and down by gas pressure from the surface. The gas does not contact the sample.
8. *Submersible centrifugal pump*: A submersible electrical motor drives an impeller in the pump, which creates a pressure and forces the water up a discharge line.
9. *Peristaltic pump*: Unlike the others, this is a pump located at the land surface. It is a self-priming vacuum pump that can draw a water sample up tubing under suction. Loss of volatile compounds and dissolved gases may occur due to the vacuum developed.
10. *Gas-lift pump*: A constant stream of gas or air is used to force the water up a discharge tube. The water comes into contact with the gas or air and oxidation and loss of volatiles can occur.
11. *Gas-driven pump*: An inert gas is used to alternately pressurize and depressurize a sample chamber. The sample chamber has check valves to create a one-way flow

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of water up a discharge line. This is similar to a bladder pump except that there is no bladder, so the gas comes into contact with the water sample.

12. *Passive samplers:* Consist of an organic phase, such as a plastic film or polymer, which accumulates contaminants from the aqueous phase or (soil) air. Passive samplers are useful for sampling the water column as well as interstitial water (ITRC 2005; USEPA 2012).

Figure 8.31 is a matrix of sampling devices and the suitable applications for collection of groundwater samples.

Pearsall and Eckhardt (1987), Yeskis et al. (1988), and Tai, Turner, and Garcia (1991) evaluated the efficacy of a number of different sampling devices in collecting representative samples of volatile organic compounds in groundwater. The first two studies were performed by withdrawing water from monitoring wells with different devices and comparing the results. The authors had no controls—that is, they did not know the actual concentration of the contaminants in the aquifer.

Yeskis et al. (1988) tested a bailer, a bladder pump, a piston pump, a submersible electric impeller pump, and a submersible electric helical stator-rotor pump. They found very little variation in the results except for the bailer. The bailer samples were in general less than half of the values obtained by the other devices. Pearsall and Eckhardt (1987) evaluated two 5 cm (2 in.) submersible helical stator-rotor pumps made of different materials, a 4-inch submersible electrical water-well pump, a cast-iron centrifugal suction pump, a peristaltic pump, and a bailer. The submersible pumps all gave similar results; the peristaltic and centrifugal suction pumps gave somewhat lower results. Silicon and PVC tubing appeared to give lower results than Teflon® tubing when used with the same pump. The bailer gave variable results, depending upon the concentration.

Tai, Turner, and Garcia (1991) built a 30.5 m (100 ft) tall, 12.7 cm (5 in.)-diameter, stainless-steel, vertical standpipe with sampling ports at various depths. They were able to use a sampling device to collect a sample from the standpipe, at the same time drawing a control sample from that depth through a sample port. They tested a Teflon® point-source bailer, a manual-driven piston pump, a motor-driven piston pump, a submersible helical-rotor pump, a peristaltic pump, and a bladder pump. Teflon® tubing was used to convey samples to the surface from the pumps. Because they had control samples, they were able to calculate a percent recovery for each sampling device. Table 8.5 shows the percent recovery for each sampling device at different depths. Examination of this table shows that the submersible pump, the peristaltic pump, and the bladder pump all had excellent recoveries, ranging from 98.5 to 100.5%. The other three devices were not as accurate, with the bailer having the lowest recovery.

The low recovery using the bailer was probably due to agitation of the sample as it was being transferred from the bailer to a 40 mL sample bottle for volatile organic analysis. Although it is a simple piece of equipment, an experienced operator is needed for correct use of a bailer.

On the basis of available research (Parker 1994) the piston pump, the bladder pump, and the electrical submersible helical-rotor pump appear to be the best devices for the collection of water samples containing volatile organic compounds. Peristaltic pumps are also suitable for metals and semivolatile organics if used with a rheostat to

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FIGURE 8.31 Matrix showing applications of a number of groundwater sampling devices.

Portable Sampling Devices		Device	Approximate Maximum Sample Depth	Minimum Well Diameter	Sample Delivery Rate or Volume	Ground Water Parameters: Inorganic: EC	pH	Redox	Major Ions	Trace metals	Nitrate, Fluoride	Dissolved Gases	Organic: Non-volatile	Volatile	TOC	TOX	Radiative: Radium	Gross Alpha & Beta	Biol.: Coliform Bacteria
	Grab	Open bailer	no limit	¾ in.	Variable	•			•	•	•		•				•		•
		Point-source bailer	no limit	½ in.	Variable	•	•	•	•	•	•		•	•	•	•	•		•
		Syringe sampler	no limit	1½ in.	0.01–0.2 gal	•	•	•	•	•	•		•				•	•	•
	Positive displacement (submersible)	Gear-drive	200 ft	2 in.	0–0.5 g/min									•					
		Bladder pump	400 ft	1½ in.	0–2 g/min	•	•	•	•	•	•	•	•	•	•	•	•	•	•
		Helical rotor	160 ft	2 in.	0–1.2 g/min	•	•	•	•	•	•	•	•	•	•	•	•	•	
		Piston pump (gas-drive)	500 ft	1½ in.	0–0.5 g/min	•			•	•	•		•				•	•	
		Centrifugal	variable	3 in.	variable	•			•		•						•	•	
	Suction lift	Peristaltic	26 ft	¼ in.	0.01–0.3 g/min	•			•		•		•				•		•
	Gas contact	Gas lift	variable	1 in.	Variable														
		Gas-drive	150 ft	1 in.	0.2 g/min	•			•		•		•				•		

Source: K.F. Pohlmann and J.W. Hess. 1988. Generalized ground water sampling device matrix. *Groundwater Monitoring & Remediation* 8 8 2-84. Used with permission.

TABLE 8.5 Percent recovery of sampling devices compared with control samples.

	Water Depth					
	17.5 ft		54 ft		92 ft	
Sampler	Low[a] Conc.	High[b] Conc.	Low[a] Conc.	High[b] Conc.	Low[a] Conc.	High[b] Conc.
Submersible pump	97.8	99.7	99.5	98.5	100.1	100.1
Peristoltic pump	97.7	98.7	98.7	98.5	97.7	100.0
Bladder pump		101.5		100.5		99.9
Teflon bailer	93.9	96.3	92.4	93.9	92.7	91.4
Manual-driven piston pump	102.2	—	102.5	101.1	102.3	103.5
Motor-driven piston pump	97.4	96.8	99.8	98.4	100.9	100.7

Source: Tai et al. 1991.

create a low pumping rate. A bailer is acceptable if used properly with a minimum of agitation so as not to create splashing in the well and loss of volatiles. Bailers should have a bottom-emptying device. Such a bailer should be able to recover 90% of the volatile organics in the water.

Parker and Ranney (1996) examined the effect on using various rigid and flexible tubing used in water sampling devices on trace-level dissolved-organic compounds present in groundwater. They found that fluorinated ethylene propylene (FEP), FEP-lined polypropylene and polyvinylidine fluoride (PVDF) were the least absorptive of the rigid tubing. In addition, they do not leach constituents into water. Of these, PVDF is the least expensive. Where a flexible tubing is necessary, such as the head of a peristaltic pump, fluoroelastomer tubing and a copolymer of vinylidine fluoride and hexafluoropropylene were much less sorptive than the other flexible tubing. They also leached the fewest constituents into the water. The copolymer is less expensive than the fluoroelastomer.

Wherever possible, dedicated sampling equipment should be used in each well. This prevents the possibility of cross contamination between wells. It also eliminates the cost of decontaminating the equipment between wells and the possibility of interference from solvents used for decontamination. Inexpensive disposable bailers are available and may be an acceptable sampling device for many studies where the cost of dedicated sampling equipment in each well is not justified.

8.6.5 Methods of Collecting a Groundwater Sample Without Drilling a Well

The installation of a monitoring well is a costly proposition, generally in the range of $5,000 to over $15,000 USD for shallow wells in unconsolidated materials. Moreover, the process can be disruptive to the property owner and can damage lawns and crops. At some sites there may be limited knowledge about the direction of groundwater movement and the existence and location of contaminated groundwater. The hydrogeologist may find it desirable to perform some type of screening investigation prior to the installation of permanent monitoring wells. During the screening the

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hydrogeologist may try to find the location and depth of groundwater contamination. There are devices that one can use to collect a groundwater sample without installing a monitoring well. These devices, as well as a standard sandpoint piezometer, can be used during the installation of a test boring.

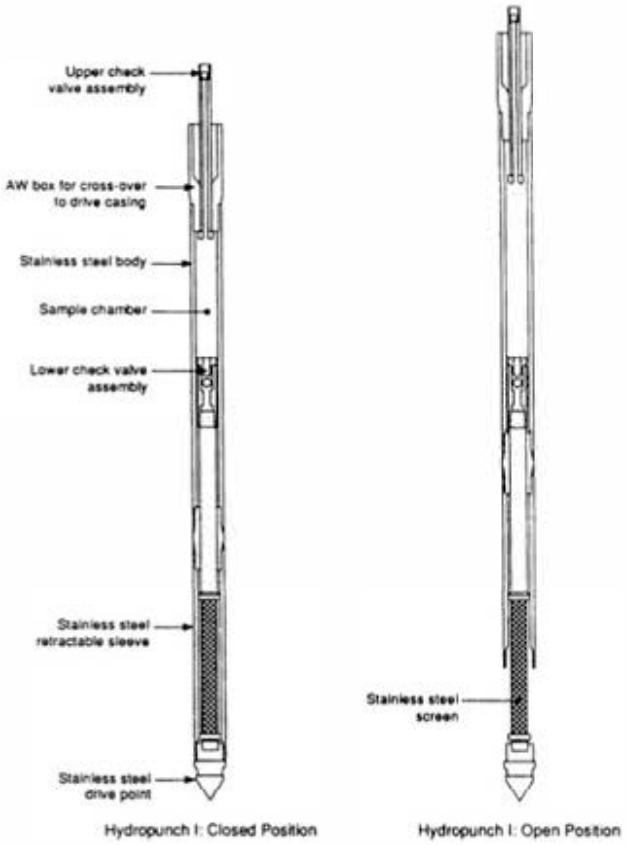
These methods all allow the collection of discrete samples in a vertical profile which gives one the ability to construct a vertical concentration profile similar to that of a multilevel sampler. However, they have a drawback in that the samples cannot be replicated at a future date because the sampler is withdrawn after use.

The HydroPunch™ is one such device, a direct-push sampler, that can be used to collect a groundwater sample from a discrete depth in the earth (Edge and Cordry 1989). It consists of a pointed sampling probe that is attached to a hollow drill rod. The rod is pushed into the earth by the hydraulic ram of a drilling machine or cone penetrometer rig, or is driven into the earth by the dropping of a weight using a drilling machine. Such a device will obviously only work in unconsolidated materials. Moreover, HydroPunch I™ cannot be used in very coarse sediment. As a general rule, if a 2-inch split-spoon sampler cannot be driven into the earth, then the HydroPunch I™ will most likely be damaged if an attempt is made to drive it. A sturdier HydroPunch II™ has been made which can be used with cone penetometers or in conjunction with drill rigs. When the probe has been advanced to the target depth, the drive pipe is retracted about 1.5 ft (0.5 m). This raises a shield on the probe which exposes a stainless steel well screen that is 10 in. (25 cm) long. The probe has to be pushed at least five feet below the water table to completely fill the sampler. Hydrostatic pressure in the aquifer forces water to flow into the screen where it will rise into the probe until it reaches equilibrium with the hydrostatic pressure in the aquifer. Figure 8.32 illustrates the HydroPunch™ in both the closed and open positions. The screen openings in the HydroPunch™ are relatively large, and although water will enter relatively rapidly, the sample may be turbid. A check valve in the probe prevents water from draining back out of the screen and the entire assembly is withdrawn from the ground in order to retrieve the groundwater sample.

The BAT Enviroprobe™ is another type of discrete depth sampler (Mines et al. 1993). It is manufactured by Hogentogler & Co. Inc. of Columbia, Maryland. It is also pushed or driven into the earth to the desired depth by a drilling or cone penetrometer rig. When the drive pipe to which the probe is attached is pulled back about 1 ft. (0.3 m), a stainless steel sleeve is moved upward which exposes a 4-inch (10 cm) long screen. Figure 8.33 shows the BAT Enviroprobe™ in both a closed and an open position. There is a septum on the top of the screen which prevents groundwater from rising higher than the screen. The sample is collected by lowering a device with a double-ended hypodermic needle with an evacuated glass vial, which also contains a septum. The hypodermic needle penetrates both septa, and the water can move from the screen zone into the evacuated vial. The vial containing the groundwater sample is then withdrawn. Should this not contain sufficient sample volume, additional vials can be lowered through the riser pipe.

In the case of both the HydroPunch™ and the BAT Enviroprobe™, the water entering the screen is formation water and there is no need to either develop the well or purge it prior to sampling. This reduces the cost as the sample collection is quicker and also there is no contaminated purge and development water to dispose. Zemo et al. (1995) field-tested both the HydroPunch™ and BAT Enviroprobe™ and found that there was no statistically significant difference in trichloroethylene concentration found in

FIGURE 8.32 Closed and open position of the HydroPunch™ probe.



Source: Zemo et al. 1995. Field comparison of analytical results from discrete depth ground water samplers. *Ground Water Monitoring & Remediation* 15:133–141. Used with permission.

groundwater samples collected from either probe. However, they did find that there was a difference in chlorobenzene concentration. They were unable to determine why such a difference should exist.

If the unconsolidated material is too coarse for the sampling probes to be pushed very far into the earth, then they can be used with a hollow-stem auger drilling rig. The drilling rig is used to install a test boring. At selected depths, either probe can be advanced within the augers and ahead of the drill bit to collect a groundwater sample. This approach has the distinct advantage of gathering stratigraphic data along with water-quality data. In the absence of a specific sampling probe, a standard 2-foot long sandpoint piezometer can be driven ahead of the drill bit to collect a water sample. In this case a bailer is used to collect the groundwater sample. After the water sample has been collected, the device is withdrawn from the borehole and the augers advanced.

8.6.6 Low-Flow Purging of Monitoring Wells

An important advance in contaminant hydrogeology field methods is the development of micropurging or low-flow purging techniques (Puls and Paul 1995). The purging techniques presented in section 8.6.3 are designed to remove all of the stagnant water in both the screen and the casing above the screen. The micropurging technique withdraws

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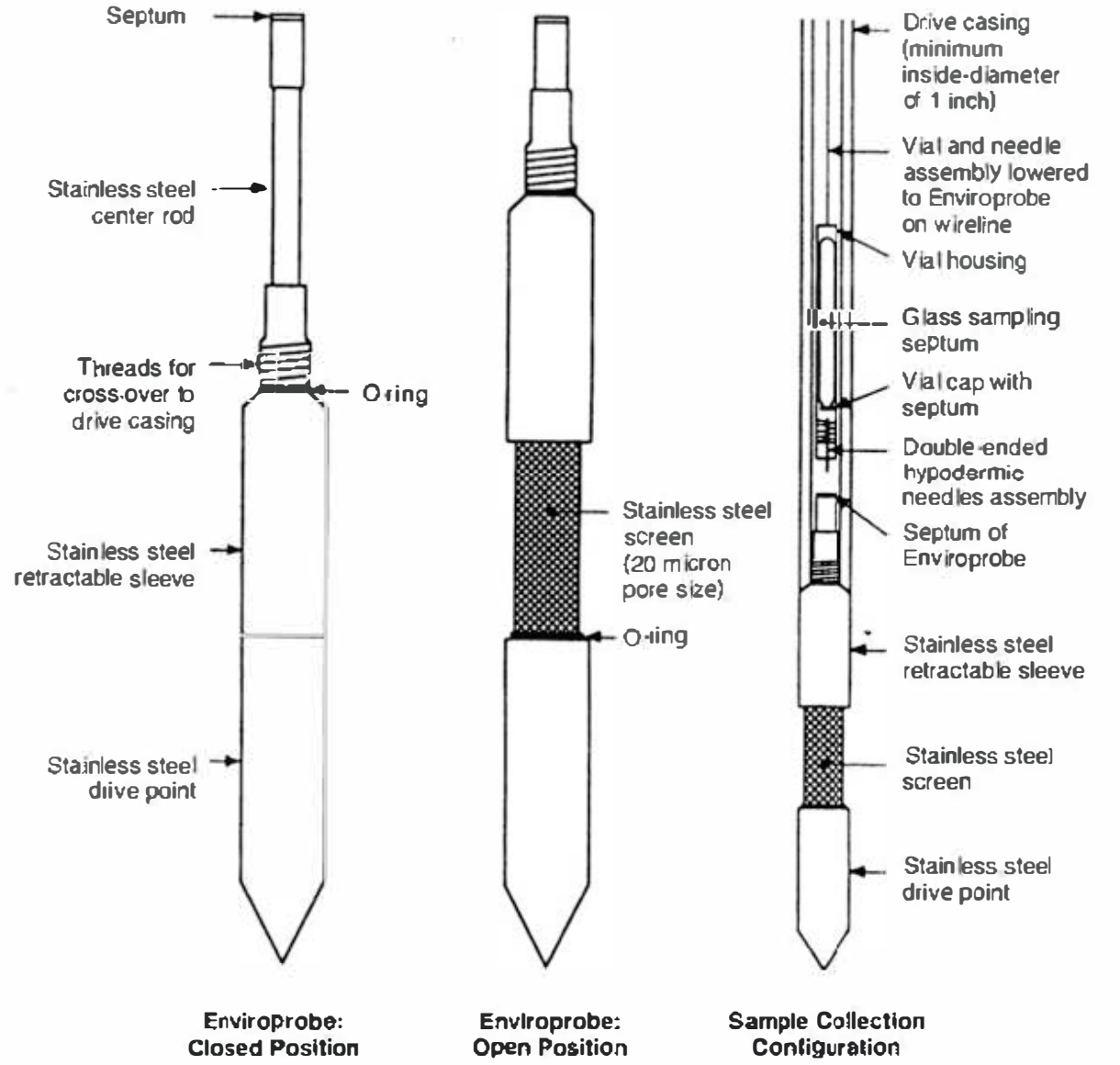
FIGURE 8.33 Closed and open position of the BAT Enviroprobe™ probe.



Source: Zemo et al. 1995. Field comparison of analytical results from discrete-depth ground water samplers. *Ground Water Monitoring & Remediation* 15:133–141. Used with permission.

water directly from the screen zone at a rate that is less than the recharge rate from the aquifer into the screen. The stagnant water in the casing does not mix with the fresh water entering the screen (Powell and Puls 1993). This purging rate is less than 1 L per minute; a suggested rate is only 100 mL/min. At this rate there is minimal drawdown in the pumping well and the water chemistry of the purged water tends to reach a constant value within one-half of a casing volume (Barcelona, Wehrmann, and Varljen 1994).

Micropurging is accomplished by using either a dedicated bladder or submersible pump with the intake set in the center of a well screen or a peristaltic pump with the end of the sample tubing set in the screen zone (Kearl et al. 1994). If a dedicated pump is not used, the pump should be placed in the well at least 24 hours prior to the time that the sample is collected. The purge rate should be about 100 mL/min, although

somewhat higher rates could be used for very permeable formations. Two volumes of water contained in the pump and the tubing should be removed prior to collecting the sample. This will be much less than the volume of water in only one well casing. Samples do not need to be field filtered.

One of the problems that arises when sampling groundwater for metals occurs when the water sample is turbid. The turbidity is due to suspended mineral grains. These particles may contain sorbed metals. Some U.S. EPA programs and some U.S. state agencies prohibit the filtration of samples used for metal analysis as it is known that metals can travel in the groundwater with colloids (Puls and Powell 1992). However, turbidity in a sample can be caused by the process of lowering sampling instruments into the monitoring well (Kearl, Korte, and Cronk 1992) or by high screen-entrance velocities developed when significant drawdown occurs during purging. Micropurging techniques utilizing dedicated sampling equipment in each well will provide a sample with the least amount of artificially introduced turbidity. This will provide the best sample for use in determining total metals.

Kearl et al. (1994) compared samples collected by micropurging with samples collected by traditional purge and sample techniques. For most inorganic analytes and all organic analytes, there was no statistically significant difference between the two methods.

In addition to the ability to collect a nonturbid sample, there are other advantages of the micropurging technique. In some monitoring wells located in low permeability formations, traditional purging may withdraw most or all of the water from the well. This means that one must wait for a day or more for the well to recover enough water to yield a sample. This means that the sampled water was still stagnant for a period of time before being withdrawn. With a micropurging technique, a very low pumping rate could draw fresh formation water into the screen zone without much lowering of the water level in the casing.

There are two variable costs associated with groundwater sampling: personnel time and the expense of disposing of the contaminated purge water (Schilling 1995). With dedicated pumping equipment, the time for micropurging is generally less than that needed for traditional purge and sampling, hence the cost will be lower. The amount of contaminated water which must be disposed is much less in micropurging, hence the cost will be less.

While the impact of turbidity in a groundwater sample can have a significant effect on the concentration of metals in the sample, the same is not true for at least some chlorinated solvents. Paul and Puls (1997) examined the impact of sample turbidity on the concentration of trichloroethylene, cis-1,2-dichlorethylene and vinyl chloride. In both field and laboratory samples they found that solids entrained in the sample had no significant impact on the measured concentration of any of the three compounds. On this basis they concluded that turbidity in the sample does not appear to be of significance when sampling for VOC analysis. They did note that if the turbidity was the result of sample agitation that factor might result in loss of volatiles.

8.6.7 Sampling Frequency

Groundwater sampling is carried out commensurate with efforts to understand the nature and extent of groundwater contamination, predict future movement, ensure that harmful excursions of pollutants do not occur, facilitate remediation, and other goals

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pertinent to site characterization. Many regulatory agencies specify and sometimes codify periodic time frames for sampling of monitoring well arrays, such as monthly, quarterly, or annual sampling. These periodic samplings have the benefits of allowing practitioners to predict many costs in advance, and look for long-term trends in water quality. From a regulatory standpoint this makes sense, although natural events that can alter water quality are not always periodic. For example, in karst systems great changes in subsurface water quality can occur during pulse flow events, and perhaps in many cases the best monitoring strategies for cave systems include sampling immediately before, during, and after intense rainfall and infiltration. Regulatory monitoring requirements are sometimes wrongly viewed as the maximum effort necessary to understand and deal effectively with groundwater contamination, particularly if monitoring costs are to be minimized. In reality, although standardized monitoring intervals make regulatory expectations clear, a one-size-fits-all sampling frequency is not always the best way to understand subsurface contamination at a particular site. Long-term costs are typically reduced with a clear understanding of contaminant distribution and movement, and sometimes this necessitates more frequent, strategic sampling before remedial action and site closure is attempted.

8.7 Other Site Characterization Methods and Groundwater Contamination Forensics

8.7.1 Introduction

Site characterization is much more than just identifying groundwater pollutants and measuring their occurrence in the subsurface. A challenge is that many well-defined characterization goals and objectives require a deep understanding of a site's geology, an understanding of groundwater travel times, knowledge of the chemical characteristics of potential contaminants, and awareness of logistical and safety concerns, just to name a few necessities. These complex objectives are often resolved by geologic testing, detailed environmental chemistry analysis, and environmental forensics.

There are many wide-ranging applications of site characterization techniques and groundwater forensics that support a robust understanding of source water protection, the potential for contaminant movement and transformation, groundwater vulnerability, and the integrity of aquitards or barriers which are relied upon to isolate waste. Numerous monitoring and characterization techniques have been, and continue to be developed, adding to the arsenal of methodologies to characterize subsurface contamination, and many of these methods rely on probes to be driven into the subsurface, measurements to be taken from boreholes, or samples to be taken from wells. In some cases contamination can be suspected based on field conditions. Field observations for NAPLs illustrate this point. For example, if DNAPL chemical concentrations in groundwater increase with depth in a pattern inconsistent with advective groundwater flow, or increase counter to a hydraulic gradient, there is support for the possibility of DNAPL being spread in its free phase. Other indicators of free-phase NAPL include situations where the aqueous concentration of NAPL compounds in groundwater is greater than 1% of the pure phase (for a single NAPL compound) or effective solubility limit (for NAPL mixtures). Note that the opposite is not true; concentrations

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below 1% may or may not be associated with free-phase NAPL. In soils where NAPL concentrations are greater than 10,000mg/kg (1% of soil mass) free phase can be suspected. Other qualitative signs of free-phase NAPL include erratic concentrations of NAPL chemicals in groundwater, soil, and soil gas; rebound of elevated dissolved NAPL concentrations after a pumping system is turned off; the presence of DNAPL chemicals in groundwater that is older than potential release dates; and observed deterioration of pumps and well components.

Quantitative methods can often be used as evidence in legal proceedings and the field of environmental forensics is based on efforts to distinguish pollutant sources (Morrison and Murphy 2006). Environmental forensics is defined by Hester and Harrison (2008) as "a combination of analytical and environmental chemistry, which is useful in the court room context. It therefore involves field analytical studies and both data interpretation and modeling connected with the attribution of pollution events to their causes." There are a vast number of techniques to determine the source and pathways of groundwater contamination that fall into the realm of forensic hydrogeology.

8.7.2 Borehole Geophysics and Downhole Techniques

Many geophysical techniques originally developed for oil and gas exploration are often used in drilled boreholes to define subsurface geology and hydrogeology, directly identify pollutants, and/or understand the potential movement and distribution of contamination. Downhole logging approaches will "ground truth" surface geophysical techniques and results can be directly compared to borehole cuttings or core samples. Like borehole cuttings and core, downhole geophysics provides vertically continuous data, but geophysical methods sample a greater subsurface volume with relatively little bias. As more boreholes are logged at a site and cross-borehole techniques are used, 3-dimensional imaging techniques (tomography) can assist visualization of contaminants and subsurface geological structures, faults, and formations (Obiadi et al. 2012). Downhole surveys have assumed great importance in contaminant site surveys because the specific site characteristics and heterogeneities in porous media and fractured rock can profoundly influence the distribution and the potential for remediation for a host of contaminants. Borehole geophysics can provide information directly applicable to site characterization, including delineation of hydrogeologic properties, subsurface water quality, and determination of a well's construction, status, and condition.

Physical, Visual, and Acoustic Borehole Geophysics Several techniques can measure the physical, visual, or acoustic properties of boreholes. One of the most straightforward downhole techniques is television (TV) logging where a color optical image is made of the borehole walls. This is particularly effective in identifying and characterizing fractures in hard rock materials, but can also identify lithology, water level, cascading water from perched zones (which could transmit contamination vertically), well construction failure, and water quality indicators such as suspended particles, gases, and chemical precipitates. TV logging can be viewed real-time and/or be stored and archived, and cameras and focal lengths can be adjusted to view either straight downhole, angled, or side-looking for inspection of borehole walls. An extension of TV logging is acoustic televiewer logging which records a photographic, digital image of the acoustic reflectivity of the borehole, oriented magnetically. These televiewer logs

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are used in water or mud-filled open holes, and can identify geologic contacts between different strata, and fault location, strike, and dip. Televiewers use a rotating transducer which can transmit and receive many samples per revolution and have azimuthal information from magnetometers on the device. This acoustic or sonic logging can help determine the porosity of a rock, aid in identification of lithology, facilitate estimation of secondary porosity and fracturing, and help assess rock permeability. Seismic logging, which transmits sound at lower frequencies, can be extended to cross-borehole tomography where images of seismic velocity between boreholes is generated, and geologic and hydrologic properties between the boreholes can be better understood.

Another type of physical downhole measurement is a caliper log which measures the varying diameter of an uncased borehole. Variable borehole diameter can indicate the potential for material to fracture or slough away from the walls and into a borehole, and therefore be a sign of media which may transport contamination. Alternatively, hydrogeologically transmissive zones can be directly identified with flowmeter monitoring. Vertical flowmeter testing in a single hole involves moving a flow measuring device up and down a hole during pumping or during nonpumping times, pinpointing zones of high and low groundwater transmissivity. Single-hole flow metering can also measure the rate and direction of vertical flow which can cause pollutants to migrate, and show relative vertical hydraulic gradients. In cross-hole flowmeter profiling, a flowmeter is placed in one hole while water is added or withdrawn from another borehole at a constant rate, allowing calculation of transmissivities, head differences, or storage coefficient between the boreholes. Packer systems (see section 8.4.9) can further isolate individual fractures and/or test hydrologic properties at individual depths between holes. Impeller flowmeters (rotameters, spinners) are most commonly used for these measurements, but have less resolution than heat-pulse or electromagnetic flowmeters. Vertical measurement of water temperature in a borehole can also be useful. These temperature measurements can define hydrostratigraphic layers, vertical flow, and water-bearing zones. Vertical borehole flow is implied by temperature gradients that are inconsistent with the regional geothermal gradient which is typically about 2.5°C per 100 m (1 °F per 70 ft.). Distributed temperature sensing (DTS) has been used in boreholes to delineate hydrostratigraphic heterogeneities by synoptically profiling temperature distribution changes from thermal dilution tests. These tests do not disturb the fluid column (Leaf, Hart, and Bahr 2012).

Gamma and Neutron Logging Other borehole logging techniques are useful in site characterization. Downhole gamma logging records the amount of natural gamma radiation emitted by a formation in the vicinity of a borehole. Specific sources of gamma emission are potassium-40 (^{40}K) and daughter products of uranium and thorium decay series which are common in clays and shale. This is because these geologic materials contain weathered products from potassium feldspar and mica, and are apt to concentrate uranium and thorium. Importantly, clay and shale typically have low permeability and are barriers to contaminant flow. Another technique, neutron logging, measures the amount of water in any particular vertical section of borehole. Energetic or "fast" neutrons are sent out into the formation surrounding the borehole usually from an Americium Beryllium (Am-Be) or Plutonium Beryllium (Pu-Be) source, and these neutrons are slowed down by collision with hydrogen ions associated with water. The returning "slow" neutrons are measured by a detector and indicate water bearing strata in the vadose zone, and water-filled porosity below the water table.

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Electrical Techniques in Borehole Geophysics Several borehole electrical techniques are available for site characterization. These include single point resistance logs, normal-resistivity logs, spontaneous-potential logs, electromagnetic induction logs, and fluid-resistivity logs. Single point resistance logs measure the electrical resistance between selected points in the borehole and an electrical ground on the surface, and are useful for understanding lithology, water quality and the amount of fracturing in hard rocks. Interpretation involves identifying zones of increasing resistance associated with small diameter boreholes, whereas lower resistance is related to saline water, large borehole diameter, and highly fractured media. Normal-resistivity logs record the resistance to electrical flow immediately outside an open, uncased borehole, and interpretation generally is similar to that of single point resistance measurement. Normal-resistivity logs typically involve deployment of a string of vertically displaced electrodes in a single hole.

Electromagmetic-induction (EM) logs also measure electrical conductivity or resistivity immediately outside a borehole and are excellent for indicating porosity, permeability, clay content, and total dissolved solids in fluids. Further, EM and other electrical techniques are proficient in identifying landfill leachate and saline water intrusion. EM borelog techniques are designed to optimize readings outside the borehole and minimize influence of the borehole and borehole fluids. Conversely, fluid-resistivity logs are geared toward examining borehole fluids, particularly the dissolved salt and solid concentrations.

Other Borehole Geophysical Techniques One versatile monitoring procedure for organic compounds is laser induced fluorescence (LIF) that uses laser light to excite fluorescent molecules in petroleum products. The excitation is specific for PAH compounds, but nearly all petroleum products contain some PAHs. LIF field measurements utilize a direct push logging arrangement which allows vadose zone and aquifer material to be examined at depth below ground surface. Further, LIF can distinguish different NAPLs in the subsurface using the intensity of the fluorescence in the media, its spectral signature, and the lag time between the laser pulse and emission of fluorescence. The laser light is transmitted down and uphole by two separate fiber optic threads, and the signal is processed and analyzed in real time.

Fiber optic chemical sensors (FOCS) are a variant of LIF and have been developed using a sensor for analysis of soil, air, or water that records changes in light absorbance, reflectance, fluorescence, and light polarization of the medium. Unlike LIF which just uses fiber optics to transport light down and uphole, FOCS uses the fiber optic cable as an integral part of the sensor. Specifically, part of the fiber optic cladding is removed from the cable in the sensor and replaced with a chemically selective layer that, when placed in the sample media, reacts with a specific analyte of interest. Raman spectroscopy is used to identify specific metals and organic chemicals. The detection limits are typically in the ppm range for VOCs.

8.7.3 Water Quality Indicators of Groundwater Provenance and Movement—Tracers

Beyond sampling water for contaminant concentrations and conducting geophysical surveys for defining subsurface geology, there are many other methodologies and water-quality indicators pertinent to site characterization. The chemical mixtures in measured contaminants and certain characteristic compounds (or "tracers") can be

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key indicators of pollutant source, travel pathways, and transformation. Tracer techniques for groundwater can be divided into water quality surrogates that are either (1) chemicals added to aquifer systems or to potential contaminants in regions where subterranean flow is expected to be rapid, or (2) "environmental tracers" which are groundwater quality changes which have occurred over longer periods of time in groundwater. The former includes dyes and chemicals intentionally added to track movement and flow, and the latter refers to "natural or anthropogenic compounds or isotopes that are widely distributed in the near-surface environment of the Earth, such that variations in their abundances can be used to determine pathways and timescales of environmental processes" (Cook and Böhlke 2000).

Payne et al. (2008) and Suthersan et al. (2014) present guidance for tracer selection, tracer test design, and data interpretation. An optimal groundwater tracer is highly detectable, mimics either groundwater or pollutant movement, is chemically stable for a desired length of time, has little background concentration in the groundwater being investigated, is not sorbed or filtered by the geologic media, and does not have adverse health or ecological effects (Davis et al. 1980). Conservative compounds that are not sorbed or retarded in their flow are particularly useful and these include chloride, bromide, iodide, nitrate, sulfate, and boron. These compounds can reflect groundwater origins with less ambiguity than other dissolved species, because they are often present in groundwater and some, like boron, are relatively unaffected by evaporation or chemical reactions (Barth 1998; Bassett et al., 1995; Vengosh 1998).

Dyes and Injected Tracers, Artificially Introduced Tracers In many fast-flowing (e.g., karst, carbonate rock, and caves) groundwater systems, tracer dyes can be released to track direction and travel times of flow. Optimal systems typically transmit water and pollutants quickly, which is advantageous because a long waiting time for the reemergence of injected tracers is not favorable. Tracers can be artificially injected into wells, sinkholes, caverns, and disappearing streams in karst terrain. Popular tracer dyes include fluorescent dyes such as fluorescein which was developed over 145 years ago, pyranine, lissamine FF, photine CU, amino G acid (7-amino 1,3 napthalene disulphonic acid), optical brightners, and a variety of rhodamine dyes. A downside of some of these dyes is that some have negative health effects. Dyes can be used either qualitatively by visual observation, or collected with adsorbing devices to quantitatively measure flow. A simple adsorption apparatus involves placement of a charcoal packet along expected pathway of subterranean flow. More sensitive devices include filter fluorometers and spectrofluorometers which can determine specific fluorescent wavelengths, quantify flow more accurately, and distinguish background fluorescence and other interferences. In addition to the tracing of natural waters, dyes can help determine pipeline leaks. Nonpolar fuel dyes can be added to demarcate different fuel types and are required in some countries. This can help distinguish the individual impacts of multiple fuel leaks of similar types, but from different sources.

Things other than dyes can be injected as tracers of groundwater flow. A common tracer for groundwater is chloride (Cl^-) which is a component of common table salt. Care must be used when using ionic tracers so that the concentration of salts added to groundwater does not change its density and subsequently impact natural groundwater flow. A more unusual tracer that has been used in cave systems is a signal emitting float which has a delayed explosion. The seismic signals emitted from these generated

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impulses can help locate subsurface passages. Other tracers that have been used with varying degrees of success include silicic acid, boric acid, phosphoric acid, acetic acid, alcohols including ethanol, sugars (sucrose, maltose, dextrose, glucose), and glycerol (Davis et al. 1985). Each of these tracers has disadvantages: acid can react with aquifer material, sugars decompose rapidly, and alcohols tend to be absorbed onto organic material (which can actually be used to advantage by measuring partitioning into suspected organic contaminants).

Tracers developed for contaminant hydrogeology include a class of compounds called partitioning tracers. These newer methods involve circulating a suite of tracer compounds, not just a single tracer, in the subsurface to measure how some tracers are slowed by contaminant mass, particularly a mass of nonaqueous phase liquids. Partioning tracers measure groundwater flow and the mass of a stagnant immiscible liquid pollutant blockinggroundwater's path by observing the differential tracer retardation. The underlying principles of this tracer method have been discussed in Chapter 3.

Scientific developments include the study of colloidal tracers and smaller, nanoparticle tracers. These colloidal tracers have included yeasts, bacteriophages (viruses), fluorescent latex microspheres, bacteria (living and dead), spores (Lycopodium and vegetative spores), and other nanoparticles (Davis et al. 1980; McKay et al. 2000; Zhang et al. 2015). Solid tracers are larger than dissolved aqueous tracers and have the negative possibility of being sieved or filtered through porous media and small-aperture fractured media. Larger particle tracers do, however, have the positive quality of not being absorbed in the rock matrix. Occasionally, solid tracers have been observed to move faster than average groundwater velocity—this has been explained by the notion that larger particles move through larger pore spaces or fracture apertures where groundwater velocities are higher than average (Zhao 2015).

Gases can be used as tracers of vapor migration, and of liquid migration by injection and dissolution of gases into groundwater. Inert radioactive tracer gases have been considered, such as xenon (^{133}Xe) and radon (^{222}Rn), particularly in identifying groundwater/surface water interaction, bur health concerns and a short half-life for radon are inhibitory (Xie et al. 2016). Noble gases of helium, neon, argon, krypton, and xenon are other potential tracers as their natural background in the environment is low. Chloroflourocarbons (CFCs or Freon® compounds), also have low environmental background and have been used for both groundwater and gaseous tracer experiments (Thompson et al. 1974, Weeks et al. 1982; Kreamer et al. 1990).

Environmental Tracers Environmental tracers which show water-quality patterns and changes do not have to be injected by site investigators, and are directly relevant to understanding a contaminated site. Some of these tracer signals arise due to natural fluctuations in local, regional, or global conditions, while others reflect anthropogenic influences and activities. Some take advantage of short term changes. For example, diurnal temperature fluctuations can be used to define gaining and losing reaches of streams. Probes placed in bottom sediments of streams that show daily temperature variation can be associated with losing reaches as water, affected by daily conditions, infiltrates. Conversely, steady temperatures in stream bottom sediments can be indicative of a gaining groundwater contribution to a stream through the sediments, as most groundwater is typically more constant in temperature. Other tracer signals arise from longer-term changes in climate, recharge differences, or substances that humans

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introduced into the environment decades ago. Compounds and isotopes that have leaked into the atmosphere from human activities (e.g., chlorofluorocarbons from refrigerants, radionuclides from testing of nuclear weapons) return through rainfall to the vadose zone and groundwater, and allow dating of groundwater age, whereas pharmaceuticals, personal care products, and specific compounds in some foods (e.g., caffeine) are not readily removed by sewage treatment and become tracers of wastewater release into the environment.

The source of a pollutant strongly influences its chemical makeup, and chemical differences from dissimilar sources can be used to trace and track environmental contamination. Biogenic gaseous mixtures containing methane are typically "dry" which means a higher concentration of methane and light hydrocarbons, whereas thermogenic gases and those from pipelines have less light 2 to 4 carbon compounds (C2s to C4s) and are "wet" with a higher concentration of 5 carbon (C5) and higher molecular weight compounds. Landfill gases are often approximately half methane and half carbon dioxide with an absence of oxygen. Natural gas derived from dewatering of coal layers, an extraction process whose retrieved product is called "coal seam gas" or "coal bed methane," is typically higher in methane than natural gas extracted from other sources and is therefore sometimes called "sweet gas." Crude oil and coal from different regions of the world have different chemical constituents which can be tracked, for example differences in the amount of sulfur compounds designates different quality of crude oil. The petroleum industry has noted that uptake of sulfur into plants is possible. Because different isotopes of sulfur can fractionate in different ways, the transport and fate of sulfur bearing compounds can be further tracked. Also, natural gas in pipelines in municipal and urban settings typically has noxious smelling mercaptan added so that leaks of this normally odorless gas are readily noticeable and are often reported. The added gases which allow leak detection and tracking sometimes have descriptive names like Cadaverine and Putrescine.

Human sewage and animal waste have a host of associated compounds and microbes which can be used to track their contamination in groundwater systems. Bacterial indicators, like Escherichia coli (*E.coli*) are useful, but often can be filtered out in porous media, whereas bacteriophages and human viruses are smaller and can travel farther. When microbes occur in groundwater they can indicate source by phenotype, genotype, and speciation (some microbes are more associated with human waste and others with ruminant species). Some genera and species of bacteria studied as indicators differentiating human from other mammalian waste include: *E.coli*, relative amounts of fecal streptococci and fecal staphylococci, *Bacteroides* spp., *Rhodococcus coprophilus* (animal herbivores), *Clostridium perfringens, Bifidobacterium adolescentis* (human), and *Bifidobacterium thermophilum* (animal). Other tracers of human and animal waste include: sterols, steroid estrogens (found in human sewage outfall), fatty acids and lipids, surfactants and detergents, caffeine (human ingestion and sewage outfall), triclosan (an antibacterial and antifungal agent found in hand soaps, body washes, toothpastes, and some cosmetics—sewage outfall), and sewage/septic tank related nonylphenol ethoxylate metabolites (Swartz et al. 2006).

Ionized substances have been used both as artificially injected tracers and measured as natural environmental tracers indicating source. There are a large number of ions which can be tracked and traced, and these substances do not decompose with

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time. Historically, those chemical species with high concentrations, easy detection, and low sorption have been the most popular. This includes negatively charged anion species which are repelled by negatively charged clay surfaces and therefore resist sorption. Traditional tracer ions include Cl^-, Br^-, Li^+, NO_3^-, NH_4^+, $SO_4^=$, Mg^{++},K^+, B, and I^-. Of these, Cl^- and Br^- are the most popular. Organic anions have been used as tracers, including benzoate. Metal complexes with chelating agents have been used to track groundwater flow, balancing the need for a detectable tracer with the potentially negative health effects of mobilizing a heavy metal pollutant (Davis et al. 1980). With the advent of Inductively Coupled Plasma Mass Spectrometers (ICP-MS) investigations of naturally occurring trace elements to identifying groundwater pathways increased (Stetzenbach et al. 1994; Kreamer et al. 1996; Johannessen et al. 1997).

Importantly, CFCs have also been used for dating recharge from precipitation, because the first wide use Freon® refrigerants began after 1930, and subsequently increasing amounts of gaseous CFCs leaked into the atmosphere and mixed with precipitation, eventually infiltrating the ground surface and recharging groundwater. CFCs were also used as aerosol spray can propellants, but because they contribute to ozone layer depletion in the atmosphere, their use has been phased out under the Montreal Protocol. CFCs are greenhouse gases with an approximate residence time in the atmosphere of 65 to 130 years and their abundance or absence in groundwater is an indicator of groundwater age. The ratio of CFCs to SF_6 (sulfur hexafluotide) has a groundwater dating age range of about 1 to 40 years.

8.7.4 Water Quality Indicators of Groundwater Provenance and Movement—Groundwater Composition, Compound Ratios, Daughter Products, Degradation Indicators, and Other Indicator Compounds

A considerable number of methods to track, trace, and date groundwater contamination rely on looking at the changing composition of pollutant compounds, associated chemicals, and differences in the chemical nature of multiple sources. Identifying and utilizing compositional differences is a powerful tool in understanding groundwater and contaminant flow.

Inorganic Indicators One of the simplest ways to distinguish different sources and transformation of contaminants is by analyzing groundwater chemical quality and compound ratios. Significant analytical chemistry advancements have been, and continue to be, made since major anions and cations were first measured in groundwater, but these ions, and the ratios between these ions (particularly the more mobile anions) continues to be a source of groundwater definition. Piper, Stiff, and Maucha diagrams visually portray the major ionic components of water quality and can indicate groundwater provenance. Ratios of ions can also be used to distinguish waters. For example, a common anion comparison used to trace groundwater has been the Cl^-/Br^- ratio. Davis et al. (1998) report on many of the uses and applications of this ratio, including determining the origin and evolution of salt water and brines, and studying salt in potable groundwater. Factors which can affect this ratio include distance from the ocean, dry lake beds, or other sources of salt, including pollution (Davis et al. 2004; Alcala

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and Custodio 2008). These ratios have been used to track septic tank pollution in the United States (Katz et al. 2011). Other useful ratios are total inorganic carbon to total organic carbon ratios, and carbon to nitrogen ratios.

Mining operations for various metals often can have more than one metallic species that can enter groundwater, or mobilizing agents and additives associated with the particular extraction method and target metal. These other species and additives can often be used to track the influence of mining operations on groundwater systems. Several metals, metalloids, and nonmetals can often be found together in metal extraction and mining (e.g., it is possible to observe combinations of uranium, copper, arsenic, gold, silver, vanadium, sulfur, thorium, lead, zinc, or others from some precious metal operations). Other types of mining undertakings have other potential tracers released into the environment. *In situ* leach mining typically uses an injected lixiviant to dissolve and mobilize extractable metals, and these lixiviants can be used as one indicator of potential contaminant migration, with the cautionary note that while a rapidly moving lixiviant can give early warning of potentially slower-moving contamination, the disappearance of the lixiviant does not necessarily indicate the disappearance of the spectrum of potential groundwater contaminants at a mining site. Metals can also be used as surrogate tracers for energetic compounds, that is propellants, explosives, and pyrotechnics (PEP) compounds. For propellants and some fuels particularly linked with the rocket fuel oxidizer perchlorate, Cr^{+3}, Cr^{+6}, Cu^{+2}, and Zn have been evaluated as surrogates. Surrogate compounds in fireworks and flares include Na, K, Ba, Cu^{+3}, Sb, Sr, Al, As, and Cr^{+5} (Motzer 2001).

Organic Indicators Organic compounds, particularly mixtures of organic chemicals, have a wide range of sources, additives, and degradation products which can be tracked in groundwater (Chapter 7). The differing rates of degradation of the compounds in subsurface organic mixtures produce changes in the ratios of those compounds and of generated daughter compounds. Many organic mixtures have unique source compositions and all eventually weather and transform with time. Hydrocarbon fuels in particular have different compositions, depending on fuel type and additives. These differences serve as distinguishing features when several different fuels have leaked or have been spilled. Fuels and oils normally consist of mixtures of hundreds of compounds, and different fuel types have different dominant ranges in the number of their carbon atoms. Crude oil has compounds that range from having one or two carbon atoms (C1 and C2) to compounds with close to sixty (C60). Crude is fractionally distillated to establish different types of hydrocarbon products, and different additives are put in for these varied purposes. Gasoline for cars (petrol) and small airplanes (aviation gas or AV-gas) typically have light hydrocarbons predominantly ranging from the 4 carbon compounds (C4) to about the 11 or 12 carbon range (C11 to C12). Kerosene is a heavier fuel with approximately the C8 to C17 compounds, diesel fuels are roughly in the C8 to C24 range, the jet fuel JP-4 is about C5 to C14, and JP-8 and Jet-A approximately C8 to C18. Stoddard solvent, which was used in the past as a dry cleaning fluid, has a typical petroleum distillate fractions of C7 to C12, heavy fuel oils are generally between C8 and C50, bunker fuel used in ships are approximately C10 to C26, and lubricating oils are even heavier with carbon numbers around the C14 to C50 range. Other residuum from crude distillation often have more than 20 carbon atoms in their constituent compounds, with waxes ranging approximately from C20 to

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Darrah et al. 2013). Recently, examining methane in concert with noble gases in stream beds has been used to identify thermogenic methane fluxes from groundwater overlying regions of shale gas development (Heilweil et al. 2015). Methane isotopes as well as dissolved organic carbon and tritium have been use to evaluate connectivity between aquifers and underlying coal seam gas operations (Iverach et al. 2015).

Quantifying the uptake of nutrient compounds during biodegradation and the resultant production of daughter products and residuals are ways to monitor the rates of transformation of organics. Petroleum degradation is normally an aerobic process which uses oxygen and produces carbon dioxide; by monitoring the extent of change in these compounds one can calculate the rate of biodegradation and, importantly, determine whether the plume is moving faster than the rate of natural or augmented pollutant attenuation.

Harmful compounds can have additives or impurities which are not only good tracers in the environment, but they can be pollutants in their own right. Chlorinated solvents have several stabilizers. For trichloroethene (TCE), 1,4 dioxane is an important stabilizer used to facilitate transport and storage in aluminum containers. It is itself considered a solvent with negative health effects. The ratios of the chlorine-35 to chlorine-37 can be another way to fingerprint chlorinated solvents. Another example of mixtures and impurities is polychlorinated biphenyls (PCBs) which are never a pure, single compound, but mixtures of PCBs by the nature of their manufacture. PCBs can also have co-contaminants of polychlorinated dibenzofurans and polychlorinated naphthalenes. The nature of the mixtures can be a good source of differentiation, and the disparity in the degradation rates of contaminants, additives, impurities, and inert compounds can indicate age and source.

Historically, pesticides were mixed with some hydrocarbon fuels to apply them to crops. Many of these pesticides have comingled substances (some inert) and trace substances (e.g., dioxins and furans) which can help fingerprint their spatial distribution at a site. Like PCBs above, the source and age of pesticide releases can be established by comparing the ratio of inert and degrading compounds.

8.7.5 Water Quality Indicators of Groundwater Provenance and Movement—Isotopic Identification of Pollution Sources and Groundwater Pathways

The measurement and evaluation of stable, radioactive, and radiogenic isotopes has played an important role in hydrologic and geologic investigations, and are equally consequential in the characterization of contaminated sites. Because physical, chemical, or biological transformation of a contaminant can alter the compound's original isotopic ratios (fractionation), transformation processes can often be distinguished from contaminant dilution (which typically does not alter these ratios). The mathematics of Rayleigh distillation to quantify isotopic fractionation accompanying phase changes and chemical reactions are well known, and make available numerical estimates of the magnitude of isotopic change. The analytical detection of isotopes in groundwater and vapors is rapidly advancing, with the required sample volumes becoming smaller, and analyses becoming faster, less expensive, and routine. From older methods like scintillation counting of radioisotopes which required large volumes of water, through

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isotope ratio mass spectrometry advances, to new analytic techniques such as Laser Isotope Ratio Infrared Spectrometry IRIS, which can be portable and field deployable, the analytical chemistry underpinnings of contaminant surveys has increased the ability of the contaminant hydrogeologist to assess a site and its properties. Accelerator mass spectrometry (AMS) can sometimes separate atomic isobars (for example nitrogen-14 from carbon-14) and makes possible the detection of many isotopes, including many that are long-lived. AMS has been applied to the analysis of many isotopes including ^{36}Cl, ^{10}Be, ^{14}C, ^{3}H, ^{129}I, ^{26}Al, ^{236}U, ^{240}Pu, and ^{210}Pb.

Applications of isotope hydrology to challenges of groundwater movement and source are numerous, diverse, and are used worldwide. Isotope hydrology has been used to ascertain renewable and nonrenewable, deep groundwater in Syria (Al-Charideh and Kattaa 2016), the origin of groundwater in the Negev Desert (Vengosh et al. 2007), preferential flow along faults in Germany (Gumm et al. 2016), altered spring flow quality in Grand Canyon National Park in the United States (Ingraham, Zukosky, and Kreamer 2001), assessment of fluid inclusions at the proposed nuclear waste repository at Yucca Mountain, Nevada, as evidence of a hypogene paleohydrogeological event (Dublyansky and Spötl, 2010), baseline measurement and assessment of methane concentrations of a well in Alberta, Canada (Humez et al. 2016), and has been employed for countless other assessments at locales around the globe.

Tracing Groundwater and Pollution with Isotopes More than fifty years ago, paleoclimatologists and environmental geochemisrs began using the stable isotopes of hydrogen and oxygen to track meteoric water movement on the environment (Craig 1961; Dansgaard 1964). An equation showing the average relationship between these isotopes was established (the global meteoric water line) and variations due to temperature, seasonality, precipitation and recharge altitude, latitudinal relationships, and paleo-effects were key in understanding global water movement, including groundwater source and pathway. Because surface waste impoundments (ponds, pits, and lagoons) have the potential to partially evaporate water, then have the remaining surface water leak into the subsurface, isotopic fractionation during evaporation of water is particularly important to contaminant site characterization studies. Evaporated water has a lighter isotopic composition, enriching the remaining liquid with heavier isotopes which can often be tracked into the subsurface, distinguished from background groundwater isotopic signatures, and used to establish mixing ratios of leaked, contaminated water to natural background groundwater signatures. For very old groundwater, past climatic change can be observed and contribute to studies of aquifer isolation and aquitard or aquiclude integrity. Aquitard integrity and the origin of pore water has been investigated in Canada for mining operations and potential nuclear waste storage by comparing Pleistocene age versus modern stable isotope ratios, below and above thick aquitards (Hendry et al. 2013; Hendry et al. 2015). The stable isotopes of water are hydrogen and deuterium, and oxygen-16 and oxygen-18.

The stable isotopes of nitrogen (nitrogen 14 and 15) in concert with those of oxygen have been used to discern anthropogenic sources of nitrate, nitrite, and ammonium in groundwater. These contaminant sources can include septic tank effluent or wastewater, animal manure, and mineral fertilizers, and can often be distinguished by isotopic ratios. Because there is some overlap and ambiguity between isotopic composition in

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wastewater and animal manure, and denitrification processes in the subsurface can result in fractionation after nitrate release, additional indicators can be used to help tell different sources apart. Distinguishing co-contaminants from agriculture can include herbicides, pesticides, and major ions and trace elements from soil amendments. From wastewater, co-contaminants can include pharmaceutical compounds, residuals from personal care products, caffeine, and artificial sweeteners. Some animal feeds contain unique inorganic additives as well. Relatively conservative stable isotopes of boron (10 and 11) have also been used to make a distinction between wastewater and animal manure (Eppich et al. 2012). In China, stable isotopes of hydrogen, and oxygen and sulfur have been used to delineate the sources of anthropogenic nitrate and sulfate groundwater pollution (Li er al. 2006). Sulfate isotopic values indicated much of the pollution came from recharge of air pollutants from the combustion of coal, with some contribution of sulfur additives in fertilizer.

Mining residuals and mineral waste products can be distinguished by isotopic analysis. In uranium oxides, stable isotopes of oxygen can help distinguish anthropogenic mining activities from natural background as can activity ratios of uranium-234 to uranium-238. $^{234}U/^{238}U$ ratios are close to 1, (secular equilibrium) near uranium mining outfall, whereas naturally occurring uranium background in groundwater often has a higher ratio, particularly in old groundwater. Conversion of ^{238}U to ^{234}U can further be examined by its cnncurrent production of alpha particles, ^{4}He. Another isotope, uranium-236 is dominantly anthropogenic, is found in spent nuclear fuels and some reprocessed uranium, and can therefore help trace nuclear waste leaks. Plutonium (Pu) is also of human manufacture, and while trace amounts can be found in nature (parts per trillion in groundwater) larger concentrations of this fissile material indicate contaminant excursion. A potential nuclear waste product and tracer is technetium-99 which is the most significant long-lived fission product of uranium.

Other mining and industrial by-products, including metals and salts, can be characterized with isotopic analysis, sometimes in conjunction with other approaches. For example, stable isotopic analysis of chromium species in groundwater can give a picture of the natural reduction of mobile and harmful Cr(VI) to less problematic Cr(III). It can also characterize the extent and rate of Cr reduction during remedial activities. Another industrially produced compound which has been found in groundwater, and is an endocrine disruptor in humans, is perchlorate. Perchlorate has some naturally occurring salts, but is mostly generated by industrial processes especially for the production of rocket fuel oxidizers. Tracking the compound in the environment bas included measurement of the oxygen and chlorine isotopes of perchlorate itself as well as other isotopic ratios and attendant compounds. Other useful isotopic analyses for perchlorate tracking are stable isotopes of strontium, nitrogen, and tritium, and isotopic ratios of $^{37}Cl/^{35}Cl$, $^{87}Sr/^{86}Sr$, and $^{16}O/^{17}O$. Some of perchlorate's additional surrogates in groundwater that can assist in source identification and age dating include: nitrates, sodium, chlorides, strontium, phosphate, metals, and nitroglycerins (Morrison and Murphy 2006). These methods can help determine whether perchlorate in the environment is natural or synthetic.

Isotopes and Groundwater Dating Isotopes are also used for characterizing the fate and transport of organic compounds. Processes affecting dense chlorinated solvents

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and other volatile organic compounds can be evaluated using chlorine isotopes which are fractionated during biodegradation, but are unaffected by dilution and dispersion. MTBE biodegradation can be analyzed with isotopic analysis, the difference between production methane from natural, shallow biodegradation versus leaks from pipelines or production wells can be ascertained. When a compound such as trichloroethene is discovered at a site, compound specific isotopic analysis can help determine whether it is a daughter product of previously spilled tetrachloroethene, or a leak in and of itself.

Site characterization involves understanding groundwater flow and travel times. Isotopic techniques are pivotal in age dating of groundwater, and there are different approaches depending on groundwater's suspected residence times. Relatively young groundwater is often dated by using radionuclides released into the atmosphere during past nuclear weapons testing. For example, tritium (^{3}H), with a half-life of 12.4 years, with its decay product ^{3}He, provides a useful tracer of recently recharged groundwater. When calculating groundwater age from tritium, adjustments to $^{3}H/^{3}He$ ratios must be made if there is terrigenic helium in the groundwater from the earth's mantle or crust. Tritium to helium-3 ratios are most effective at dating groundwater 0.5 to approximately 40 years old. Another dating technique for modern groundwater 10 years old or younger uses krypton-85, which is produced by nuclear reprocessing and has a similar half-life to tritium, and comparable dating range as well. Nuclear bomb-pulse chlorine-36 is also used to date young groundwater recharged after the 1950s, but in lower, natural concentrations in deep systems can also be used to evaluate submodern groundwater that is 50,000 to a million years old. Methods for dating submodern groundwater (>1,000 years since recharge) include radiocarbon dating (carbon-14). The amount of ^{14}C (half-life 5,730 years) in groundwater can indicate when it was last in contact with the atmosphere, but care must be taken to account for uncertainties due to potential groundwater interaction with carbon from other sources, such as the "dead" carbon in limestones and other carbonate rocks which has no ^{14}C. In optimal conditions ^{14}C can be used to date groundwater about 1,000 to 40,000 years old and can sometimes be used in concert with argon-39 (half-life 269 years). Silicon-32 has the beneficial aspect for groundwater dating of having a half-life of 140 years which allows it to fill a gap between tritium and carbon-14 dating, but its loss and interaction with solid phase silica in an aquifer and analytical difficulties have limited its use. Uranium isotopic ratios are also a useful groundwater dating tool. $^{234}U/^{238}U$ ratios (called uranium isotope disequilibrium) typically increase with groundwater age and can be used to give approximate ages from 10,000 to one million years old. Some isotopes with long half-lives have the potential to date very old groundwater with applications for understanding the isolation of deep contaminant burial, nuclear storage, or deep waste injection. These include iodine-129 (half-life 15.7×10^{6} years), krypton-81 (half-life 2.29×10^{5} years), and Xeon-139 (half-life 2.165×10^{21} years).

8.7.6 Water Quality Indicators of Groundwater Condition—Microbial testing and Genome Sequencing

Studying subsurface microbiology at contaminated waste sites allows groundwater professionals to calculate the rate of natural attenuation of pollutants, the efficacy of amendments added to groundwater to enhance contaminant breakdown, and the

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8.8 Summary

Site characterization involves goal setting and outcome definition, use of noninvasive techniques, followed by strategic application of invasive methods of investigation. In order to collect data for groundwater contamination studies, it is usually necessary to install monitoring wells. Such wells can permit one to measure water levels, collect water samples for analysis, and detect the presence of nonaqueous phase liquids.

Monitoring-well design considers the type and diameter of casing and screen, the material from which the casing and screen is constructed, and whether the well will have an artificial-filter pack or be naturally developed. The annular space between the casing and the borehole must be properly sealed, and the well needs a protective covering. Monitoring wells may be installed by hollow-stem auger drilling, mud-rotary drilling, air-rotary drilling, reverse-rotary drilling, and cable-tool drilling. The equipment used for monitoring-well installation and the material used for the well must be properly decontaminated. Once installed, the well needs to be developed to remove fine material from the area outside the well screen. Water-table wells are installed to monitor the water table and piezometers are used to monitor formations below the water table. Frequently, a water-table well and several piezometers are installed at the same location to form a nest of wells to sample the formations at different depths. Multilevel monitoring devices may be used to collect samples from very closely-spaced vertical intervals.

There are a number of sampling devices that have been developed to withdraw water samples from monitoring wells. These include bailers, bladder pumps, stator-rotor pumps, piston pumps, and peristaltic pumps. The ability of these devices to collect an unbiased sample varies with the design, technique used, and material from which they are constructed. Prior to sampling a well, it is necessary to purge it to remove stagnant water from the casing. Micropurging techniques result in a water quality sample that is as free of turbidity as possible and at a lower cost than traditional purge and sample techniques due to a shorter time to collect the sample and reduced costs for disposal of contaminated purge water. Soil water must be collected through the use of a suction lysimeter. These are installed in boreholes above the water table. Soil gas vapor can be sampled through active probes that withdraw soil gas samples for analysis or passive devices that sorb soil gas onto activated charcoal devices. Monitoring soil gas can indicate areas where the soil has been contaminated and requires remediation. It can also be used to delineate areas where shallow groundwater is contaminated by volatile organic compounds and where there is a layer of a volatile, nonaqueous phase liquid floating on the top of the capillary zone. Phyto-screening, surface geophysics, and aerial photographic interpretation are other noninvasive or low impact characterization techniques that are appropriate at many sites.

There are a host of chemical and microbial analysis technologies that assist interpretation of the source, movement, and transformation of subsurface contaminants. Differences in source chemistry, generation of daughter compounds, and comparison of compound ratios lend themselves naturally to environmental forensic investigations. Chemical compound transformation, the utilization and uptake of nutrient compounds, varying chemical compound ratios, and changes in subsurface microbial communities all can be indicators of bioremediation and compound attenuation. Geophysics, groundwater dating, and borehole core analysis can define the geologic provenance and flow constraints which affect pollutants.

9

Site Remediation

9.1 Introduction

Since the early 1980s groundwater scientists and engineers have developed a number of techniques for both containing and remediating soil and groundwater contamination. In the United States this has been driven by federal legislation including the Resource and Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The Hazardous and Solid Waste Amendments of RCRA address the storage of liquids in underground tanks. Individual states have also passed environmental regulations that may be triggered when property is sold. Regulations associated with these laws dictate when it is necessary to evaluate if a site is contaminated, and if it is, what must be done to remediate the contaminated soil and groundwater. Even in the absence of a specific regulatory requirement, many potential property buyers will require the seller to demonstrate that a property is not contaminated. This may take the form of a Phase I Environmental Study, which involves a detailed review of the historical uses of the property and a review of state records to determine if there is a likelihood of a potentially contaminating activity in the past. This may be followed by a Phase II Environmental Study, where several soil borings are drilled and one or more groundwater monitoring wells are installed. These investigations are for the protection of the buyer and the financing institution because if the property is found to be contaminated after purchase, the new owner would be responsible for some or all of the cleanup costs (Phase III).

In general, remediation of a site must address two issues. If there is an ongoing source of contamination, control of the source will be necessary. There is no point in remediating the environment if new contamination is being released to the soil or groundwater. Examples of sources include landfills, mine tailings piles, leaking underground storage tanks, pipelines, septic tanks, and sewer lines. In addition to primary sources, such as those listed above, there can be secondary sources of contamination due to contaminants which have already been released to the environment. These secondary sources include nonaqueous phase liquids (NAPLS) which may be trapped in the vadose zone, floating on the water table or trapped below the water table. Once the primary source has been removed or isolated, then secondary sources must be identified and isolated. Only after that has occurred is treatment of contaminated soil and groundwater effective.

The final goal of a remediation program for contaminated soils and groundwater is generally subject to approval of a state or federal regulatory agency. In almost all

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cases it will be impossible to completely remove all contamination so that the site returns to a pristine condition. After all, many contaminated sites have been the locus of industrial activities for decades; indeed, some sites in the eastern United States or in Europe have been used by one industry or another for centuries. In the United States of America, state agencies or the U.S. Environmental Protection Agency may have numerical standards for the soil and groundwater that must be met after site remediation. Similarly, in the European Union, the European Environment Agency (EEA) works together with national agencies on defining what are "good" and "poor" quality water bodies (Water Framework Directive 2000/60/EC of the European Parliament and of the Council). Many other countries have modeled their environmental standards on EPA or European regulations. These standards are generally based on anticipated future land use. Soil remediation standards for future residential land use will be more stringent than those for industrial use. Groundwater standards may be based on drinking water Maximum Contaminant Levels (MCLs).

The application of very stringent standards may result in the expenditure of large amounts of money to reduce extremely small or even nonexistent risks (Viscusi and Hamilton 1996). As much as everyone would like to live in a pristine environment, it simply is not practicable in the post-industrial world. There are limited funds available for environmental cleanup; we should expend those funds in a manner that is most effective in terms of reducing real risks. This has led to the concept of risk based corrective actions (RBCA). Rather than cleaning up all sites to a set standard, a risk assessment of the site is made, and risks to specific receptors are addressed. For example, if the groundwater is saline and not used as a drinking-water source, it may not be really necessary to remove a chlorinated solvent to the drinking-water standard.

Contaminant hydrogeologists in collaboration with engineers, chemists, biologists, modelers, and many other experts have developed some very powerful methods of removing contamination from soil and groundwater. However, these methods are not capable of totally removing all contamination. A zero contamination strategy is not possible, even if we were willing to commit unlimited funds.

In this chapter we will examine a number of source zone and groundwater plume remedial techniques, some proven and some experimental. Table 1 provides an overview of some of the most common technologies and their applicability and development status. There are a few textbooks (e.g., Suthersan et al. 2017) and a number of public domain resources that can guide us in the discussion of these remediation technologies. For instance, the Interstate Technology and Regulatory Council (ITRC) makes available documents ranging from technical overviews and case studies of innovative remediation technologies to technical and regulatory guidance documents for applying cleanup technologies (www.itrcweb.org/guidance). Similarly, the Federal Remediation Technologies Roundtable (FRTR) provides access to a remediation technology screening matrix for screening potentially applicable technologies for a remediation project, including a long list of technology descriptions (www.frtr.gov/scrntools.htm). The National Academies of Sciences, Engineering, and Medicine—National Research Council (NRC) publishes periodic reports on the state-of-the-art in the remediation of contaminated sites (http://www.nap.edu/topic). The Strategic Environmental Research and Development Program (SERDP) is an environmental science and technology program, planned and executed by the U.S. Department

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TABLE 9.1 Common and innovative contaminant remediation technologies.

Technology	Application	Development Status
Pump-and-Treat (P&T)	(Source Zone) / Plume / Containment	Established
Physical Containment	Source Zone / Plume	Established
Solidification/Stabilization	Source Zone	Established
Soil Vapor Extraction / Air Sparging	Unsaturated Zone; Source Zone / Plume	Established
Bioremediation and Monitored Natural Attenuation (MNA)	Source Zone / Plume	Innovative / Established
Permeable Reactive Barrier	Source Zone / Plume	Innovative / Established
Chemically Enhanced Flushing	Source Zone	Established
Thermal Treatment	Source Zone / Unsaturated Zone	Innovative / Established
In Situ Oxidation	Source Zone / Plume	Innovative / Established
Phytoremediation	Plume / Unsaturated Zone / Containment	Innovative / Established

Note: The boundary between what is a conventional and innovative technology is fluid.

Source: Modified after NRC 2013.

of Defense (DOD), Department of Energy, and the EPA and others. Together with another U.S. DOD program, the Environmental Security Technology Certification Program (ESTCP), these programs support the development and demonstration of the latest remediation technologies. They also provide access to documents describing innovative, cost-effective, and sustainable environmental cleanup solutions, including for the treatment of DNAPL source zones or groundwater plumes (www.serdp-estcp.org). Funded by the European Union, the EUGRIS (European Groundwater and Contaminated Land Remediation Information System) is an openly available information platform for contaminated land and groundwater information (www.eugris.info/index.asp). While there are many more resources available to students as well as practitioners, one of the largest depositories of information about contaminated site characterization and remediation technologies is maintained by the U.S. EPA (www.clu-in.org). Currently, the website includes information on several hundred field-scale remediation technology demonstration projects.

9.2 Source-Control Measures

9.2.1 Solid Waste

Solid waste may have been buried in an unsecure landfill, placed in an open excavation or old quarry, or simply spread on the land surface. If contaminants continue to be leached from these sources by infiltrating precipitation, or even groundwater if the solid wastes have been buried below the water table, then a source control measure

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is necessary before groundwater remediation is attempted. If the source continues to leach contaminants, then groundwater remediation may be futile.

Source-control measures include physical removal of the waste and transportation to a secure landfill or incinerator, construction of impermeable covers or low-permeability caps to eliminate or minimize infiltration of precipitation, and construction of physical barriers around the waste source.

9.2.2 Removal and Disposal

If the source is removed, then wastes can no longer migrate from it. Solid waste that has been spread on the land surface can easily be removed by conventional earthmoving equipment. Waste that has been buried in a landfill can also be exhumed and transported to a secure landfill. A hazardous-waste landfill was operated near Wilsonville, Illinois, USA, from 1976 to 1981. Hazardous wastes, including liquids, were buried in drums that were placed in 26 trenches, each approximately 3.3 m to 6.5 m (10 to 20 ft) deep, 15 to 30 m (50 to 100 ft) wide, and 53 m to 122 m (175 to 400 ft) long. In 1981, it was found that hazardous wastes had migrated up to 16.7 m (50 ft) from the trenches over a 3-year petiod, a rate 100 to 1000 times greater than predicted prior to construction of the landfill. Following a court order, the site owner exhumed and removed all the drums and transported them to a more secure landfill. The process took 4 years and many millions of dollars (Herzog et al. 1989).

Excavation and removal of hazardous materials must be done in a manner that protects the health and safety of workers and the public. The materials may be hazardous if one comes into contact with them, they give off toxic or dangerous vapors, or if ingestion of these materials would be harmful. The risk of moving material as opposed to leaving it in place must always be evaluated prior to a removal action.

Furthermore, the final disposition must be environmentally sound. In at least one case, spent solvents were moved from an abandoned hazardous-waste site to a solvent-recycling facility. The latter facility eventually went bankrupt and became a hazardous-waste site itself. Under CERCLA, the courts have found that the generator of hazardous wastes is responsible for their cleanup and disposal costs if the disposal-site operator becomes bankrupt. In this case, the generator had to pay twice for the disposal of wastes. This policy is known as "cradle-to-grave" and is designed to ensure that hazardous waste is controlled from the time it is generated until its ultimate disposal. The EPA defines hazardous waste as "waste with properties that make it dangerous or potentially harmful to human health or the environment" (U.S. EPA 2016). In regulatory terms, an RCRA hazardous waste falls into two categories: (1) waste specifically listed by EPA and (2) characteristic waste which exhibits one or more of the following: ignitability, corrosivity, reactivity, or toxicity. These four waste characteristics are communicated in many different ways, including Material Safety Data Sheets (MSDS) or by hazard labels. For instance, the NFPA 704 chemical hazard label standard uses a diamond-shaped diagram of symbols and numbers to indicate the degree of hazard associated with a particular chemical or material (Figure 9.1). You probably have seen this or similar signs posted in laboratories or other places where potentially hazardous materials are being stored. In any given state, the EPA or the state hazardous waste regulatory agency enforces hazardous waste laws and most universities have hazardous waste offices to ensure compliance with those laws.

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FIGURE 9.1 The NFPA 704 chemical hazard label. Each quadrant is labeled with its respective color and hazard.



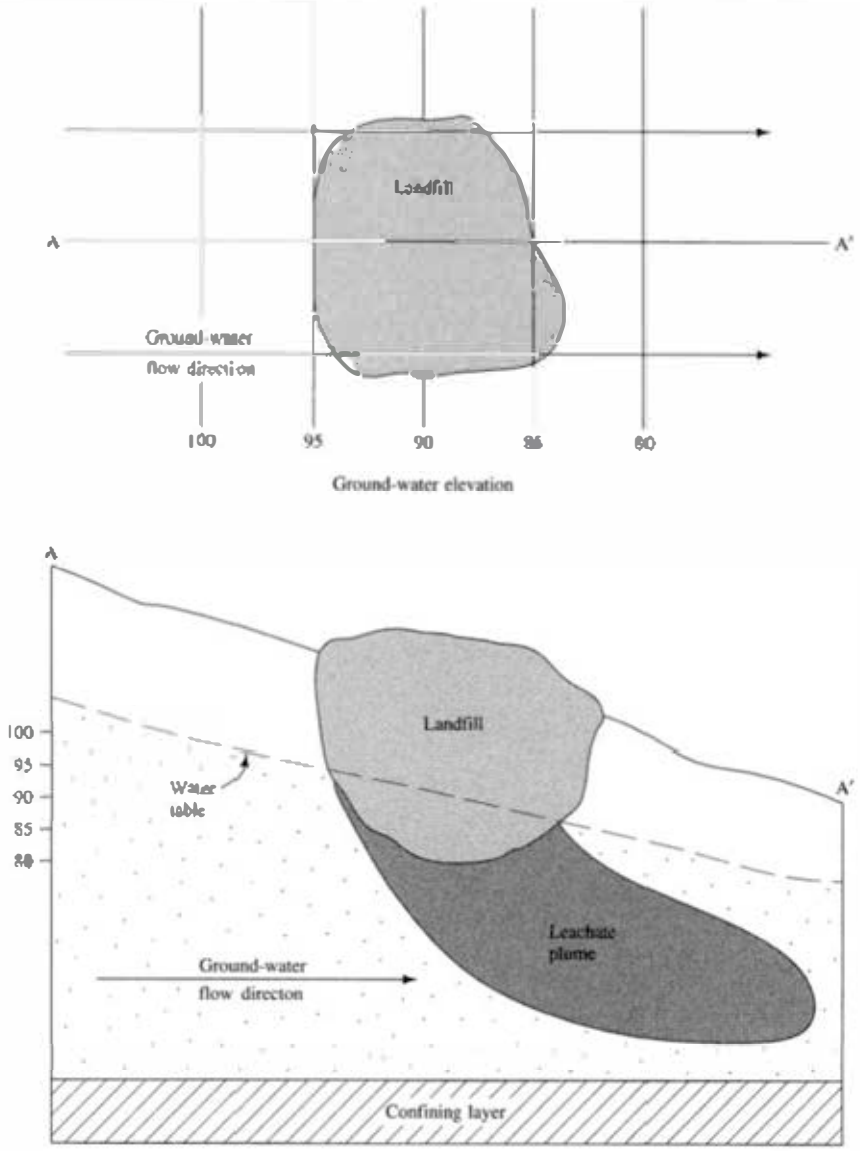
Soil contaminated with organic compounds may be remediated by excavation and incineration. This is a technique that has been proposed for highly refractory organic compounds, such as PCBs and some pesticides. The organic matter of the soil is incinerated while a supplemental fuel is burned in the incinerator. Incineration converts the waste into ash, flue gas, and heat. While the heat can be utilized for beneficial purposes, there is concern about toxic compounds that might accumulate in the ash and gaseous emissions of the incinerator plant. The appropriate disposal of the ash and the filtration of the flue gas add significant cost to the waste incineration and make this process expensive. Compounds with a high BTU (heat) value, such as hydrocarbons, can also be incinerated. This is less costly, since supplemental fuel is not needed. However, permits are needed for incineration, and these may be difficult to obtain from state and local authorities.

9.2.3 Containment

If the waste cannot economically or technically be excavated, then it may be possible to contain it. If the waste is below the water table, flowing groundwater can pass through it and create leachate as illustrated in Figure 9.2a. Such buried waste can be surrounded by a groundwater cutoff wall. The purpose of the groundwater cutoff wall is to divert groundwater flow from passing through the waste so that it cannot form leachate (Lynch et al. 1984; Need and Costello 1984). The cutoff wall needs to be deep enough to key into an impermeable layer so that groundwater cannot pass under the wall, which is referred to as encapsulation. Note that the term encapsulation is not only used to describe the isolation of an area of waste, but is used also to describe the different measure of surrounding an individual container with impermeable material.

There are several ways that cutoff walls can be used (U.S. EPA 1998). The wall can extend all around the waste (Figure 9.2b). If this is done, the groundwater will flow around the wall and be diverted from the waste. The water table will rise on the upgradient

FIGURE 9.2a Top view and cross section of a landfill that was constructed with an excavation that extends below the water table. Groundwater can flow through the waste and create leachate.

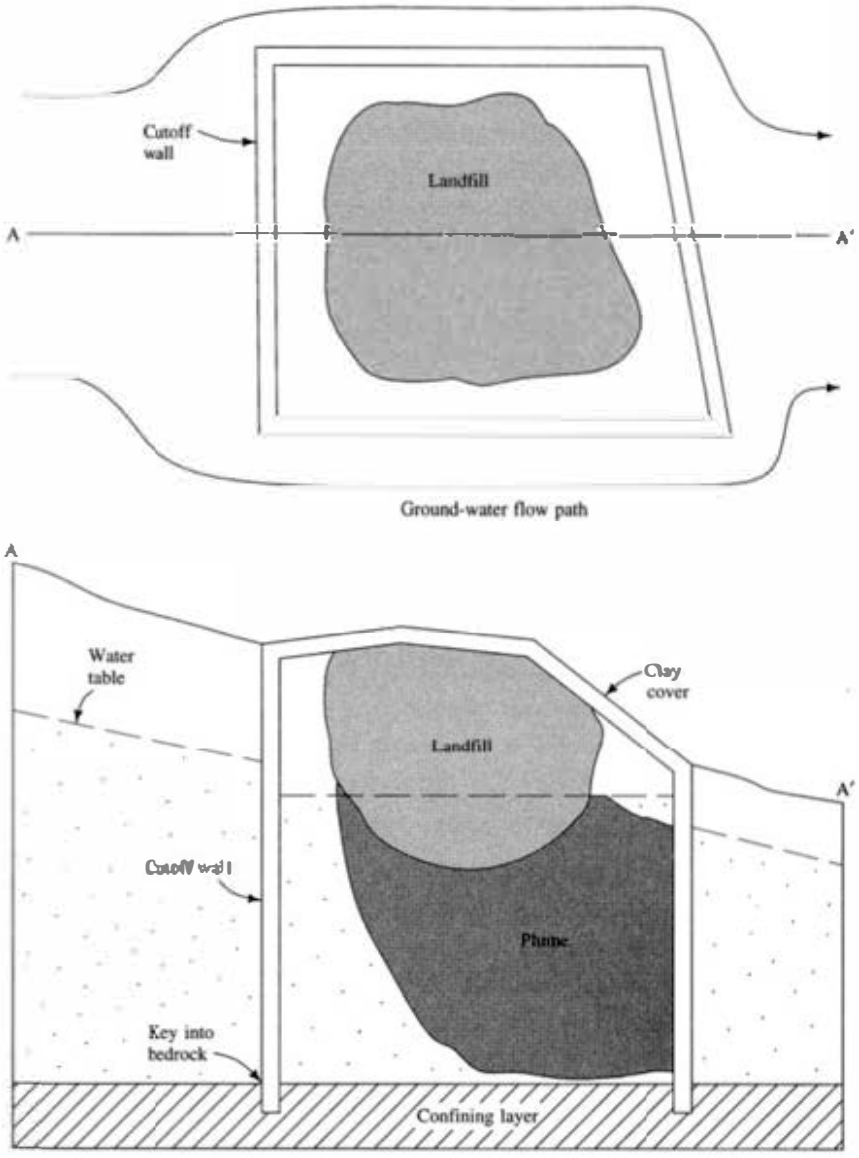


wall and fall on the downgradient wall. If there is no recharge or flow through the cutoff walls, the water table within the cutoff walls will be flat. However, there is generally leakage through the cover or cutoff walls, so some extraction wells will be needed for added hydraulic control within the cutoff walls to prevent build-up of water within walls.

If the cutoff walls are extended far enough to surround both the waste body and the plume of contamination, then remediation may proceed without worry that it will spread further. One of the problems that have arisen with the remediation of groundwater is that the plume may spread rapidly, whereas legal action to assess blame for the plume proceeds through the courts with glacial speed. If a cutoff wall is installed as an emergency action, then the plume can wait until the courts have spoken.

Cutoff walls have also been used to stop the spread of a contaminant plume. At the Rocky Mountain Arsenal near Denver, Colorado, USA, a cutoff wall was constructed

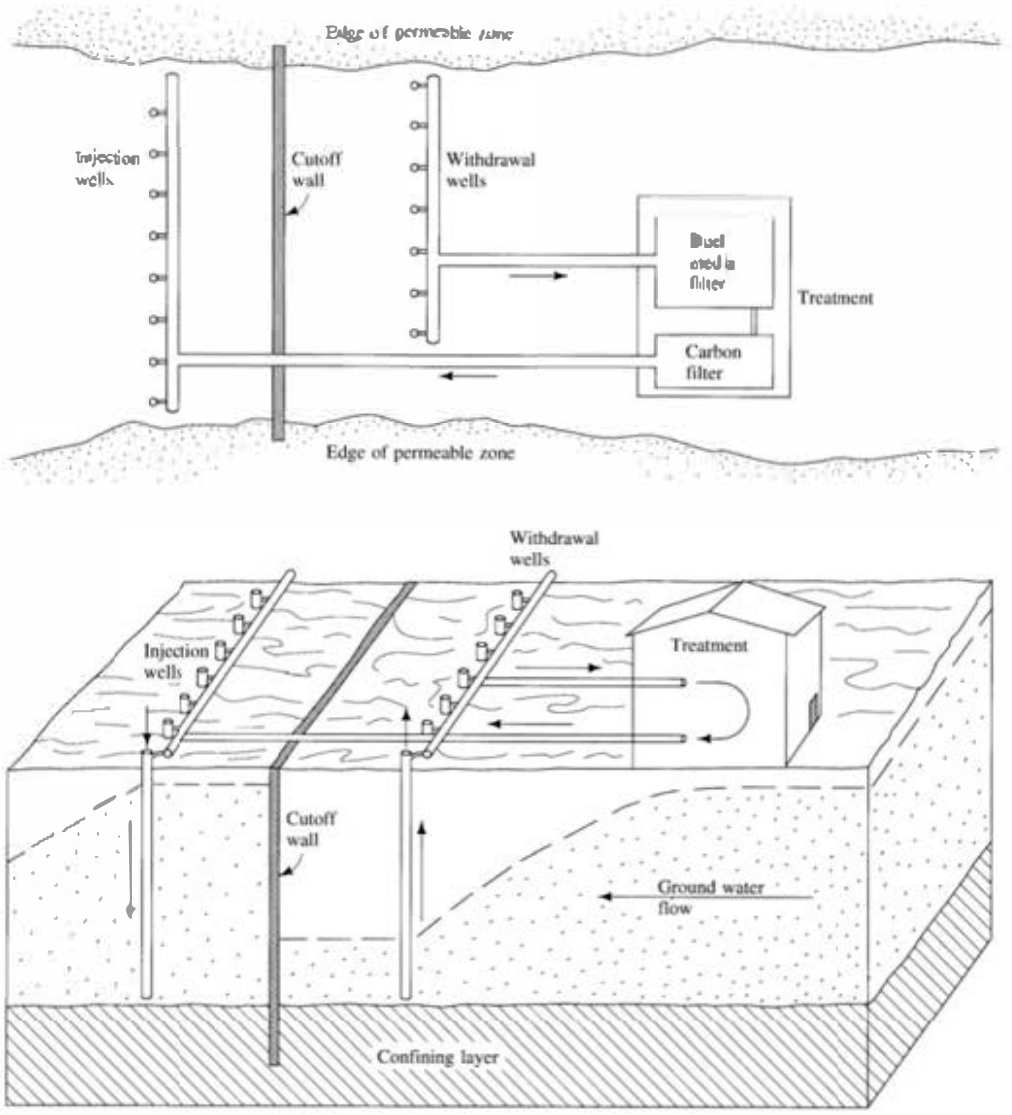
FIGURE 9.2b Top and side view of a cutoff wall that completely surrounds the landfill in (a), opposite page. Cutoff wall is keyed into underlying low-permeability formation.



across a bedrock valley containing higher-permeability, unconsolidated deposits that acted as a pathway for a contaminant plume. The contaminated water is pumped from the upgradient side of the cutoff wall, treated to remove the contamination, and injected into the aquifer on the downgradient side of the cutoff wall (U.S. EPA 1998). This system is illustrated in Figure 9.3.

A number of different types of materials have been suggested for use in cutoff walls (Pearlman 1999). Most are constructed of soil-bentonite slurries, but concrete and concrete/polymer mixtures are also used particularly in regions of topographic relief. A trench is excavated with an excavator or backhoe. The trench is held open by a slurry of bentonite and water. The slurry acts in the same manner as the drilling mud that holds open a borehole. The bentonite slurry penetrates into the more permeable formations and forms a low-permeability filter cake. As the working end of the trench

FIGURE 9.3 Cutoff wall used with extraction and injection wells at the Rocky Mountain Arsenal, Denver, Colorado, to isolate and treat a plume of contaminated groundwater.



is built around the site, the opposite end of the trench is back-filled with a soil-bentonite slurry. The soil-bentonite slurry has a very low permeability and minimizes the movement of most groundwater through it. The trench is typically 1 m (2 to 3 ft) wide and can be up to 18.3 m (60 ft) deep if excavated with a backhoe or up to 36.5 m (120 ft) deep if dug with a clamshell shovel (Need and Costello 1984). While expensive, technology to install cutoff walls as deep as 122 m (400 ft) is available (Valkenburg 1991). Preconstruction design studies are needed to determine if the waste that is to be contained is compatible with the bentonite-soil slurry.

A grout curtain may also be constructed as a cutoff barrier. Grout is injected into the earth through a borehole. The grout is liquid when injected but eventually hardens into an impermeable material. This approach was used to contain radioactive water at the Fukushima nuclear power plant disaster site in Japan, according to the company in charge for the site remediation (www.tepco.co.jp). Other construction methods include

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steelsheet piling, bored pile walls and, as temporary solution, artificial ground freezing. The selection of a cut-off barrier construction method will depend on the desired depth of wall, ground conditions, and geometry of wall.

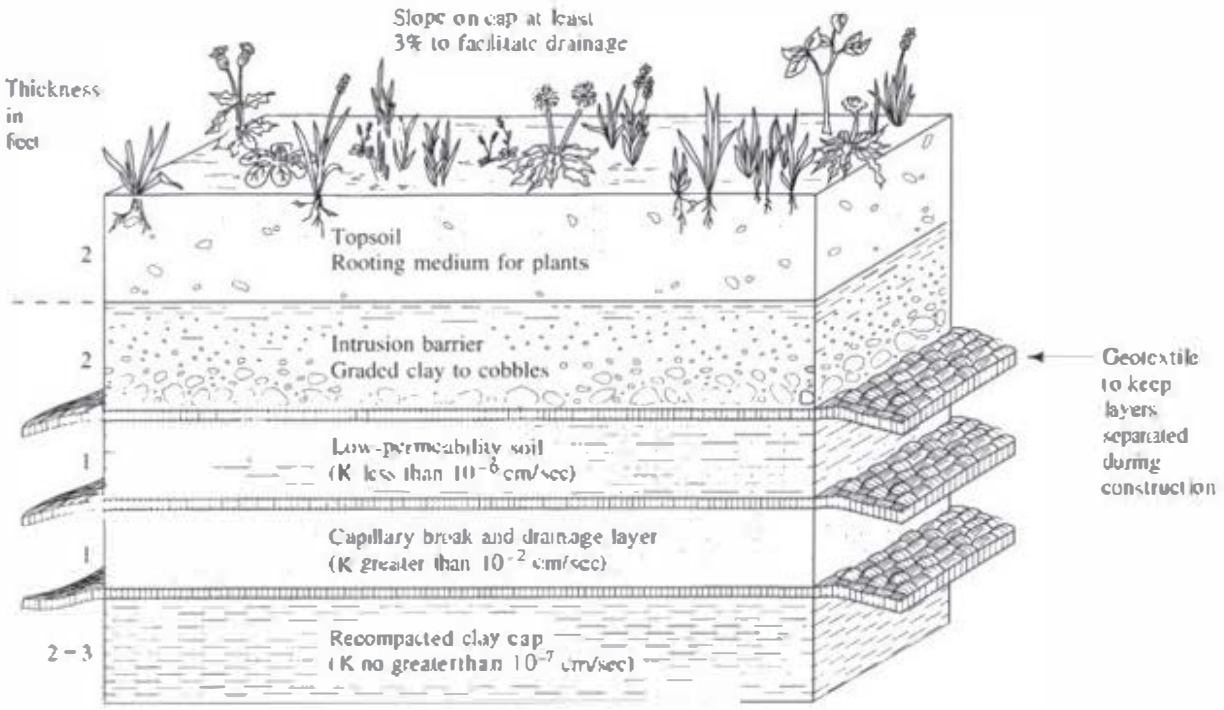
If contaminated material can be immobilized or its solubility reduced through a chemical reaction, this process is called stabilization. Similarly, if the contaminated material can be encapsulated to form a solid and to restrict its migration by decreasing the surface area exposed to leaching, that process is referred to as solidification. **Solidification/Stabilization** is an established technology that has been used for decades to address a variety of *in situ* and *ex situ* solid and liquid wastes. Typically, the contaminated material is treated with an inorganic or organic binder, such as cement, fly ash, lime, soluble silicates or asphalt, epoxide, polyesters, and polyethylene (U.S. EPA 2000).

In most cases it will also be necessary to construct a cover over the waste material to prevent the infiltration of precipitation. If the waste material is above the water table, a cover without a slurry wall might be all that is needed. For a waste material buried below the water table, a low-permeability cover is needed in association with a slurry wall. In the absence of a cover, the infiltrating water will fill the area within the slurry wall like a bathtub.

Covers may be constructed of native soils, synthetic membranes, or a combination of both. Covers are typically sloped in order to promote runoff of precipitation. It may even be necessary to bring in fill material to create the necessary elevation at the center of the cover to form the needed slope.

A multilayer cover constructed of natural materials might have the following elements, starting from the surface (Figure 9.4): (1) 0.6 m (2 ft) of topsoil as a rooting medium for vegetation with shallow roots, such as grass or crown vetch, which is

FIGURE 9.4 Typical design of a multilayer cap for a landfill that is constructed of natural soil materials.



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needed to prevent erosion; (2) a 0.6 m (2 ft) thick compacted layer of cobbles mixed with clay to stop burrowing animals from breaching the cap; (3) a 0.3 m (1 ft) thick low-permeability zone to separate the cobble layer from the next-lower zone; (4) a 0.3 m (1 ft) thick layer of very permeable sand, which acts as a capillary break to the movement of soil moisture and provides for lateral drainage of any infiltrating precipitation; and (5) a bottom layer that consists of 0.6 to 1 m (2 to 3 ft) of recompacted clay with a maximum permeability less than 10^{-7} cm/sec (8.5×10^{3} ft/d) to act as a final barrier to groundwater recharge. Geotextile fabric would be needed between several of the layers to keep the materials from mixing during construction and to distribute the stresses evenly. Figure 9.4 shows the details of this design. Erosion of the soil and penetration of the cover by tree roots are the main concerns for the long-term integrity of this design.

Synthetic geomembranes can also be used in cover designs as low-permeability layers. One advantage of using native soil materials is that their long-term performance is assured, whereas the long-term behavior of plastic membranes, and those made of other materials has not been tested for all types of soil, climatic, and contaminant mixture scenarios. However, for many applications, plastic membrane covers are suitable. They can easily be installed so that monitoring and extraction wells extend through the cap.

Infiltration of precipitation into the ground can also be reduced by paving the surface with a material such as asphalt. However, an asphalt seal is more permeable than a multilayer cover and would require extensive maintenance to seal cracks that form. Diversion ditches and drains might be used to prevent surface runoff from entering an area where it can infiltrate into the soil and come into contact with buried waste material.

There are alternative cover designs that are increasingly being used for waste disposal sites and hazardous waste landfills. For instance, the evapotranspiration (ET) cover system relies on the properties of one or more vegetated soil layers to store water until it is either transpired through vegetation or evaporated from the soil surface (e.g., Hauser et al. 2001). Compared to conventional land fill covers, ET cover systems are less costly to construct. However, ET cover systems are mostly limited to areas that have arid or semi-arid climates, such as the southwestern United States (U.S. EPA 2003; 2011).

9.2.4 Hydrodynamic Isolation

Hydraulic controls can also be used to isolate a zone where the groundwater has been contaminated. An extraction well positioned at the leading edge of a contaminant plume can be used to stabilize the position of the plume or contain it (Figure 9.5). The plume-stabilization well will pump contaminated water, which may require treatment before disposal. It will prevent the encroachment of the plume of contamination to uncontaminated parts of the aquifer. With the contamination thus isolated, work on source control and other remediation measures can progress at the most expedient pace.

The downgradient limit of the capture zone is called the stagnation point. Figure 9.6 shows a water table profile along the y-axis. It can be seen that the stagnation point forms a groundwater divide between flow toward the well and flow in the regional direction. The stagnation point and the capture zone are also shown for an LNAPL spill in Figure 9.7. Note that there is a maximum quantity of water that can be pumped from a single extraction well. If the plume is wider than the capture zone developed by the maximum pumping rate, then multiple extraction wells are needed. One concern with multiple extraction wells is that their capture zones must overlap,

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FIGURE 9.5 Plume-stabilization well used to isolate plume of contaminated groundwater.

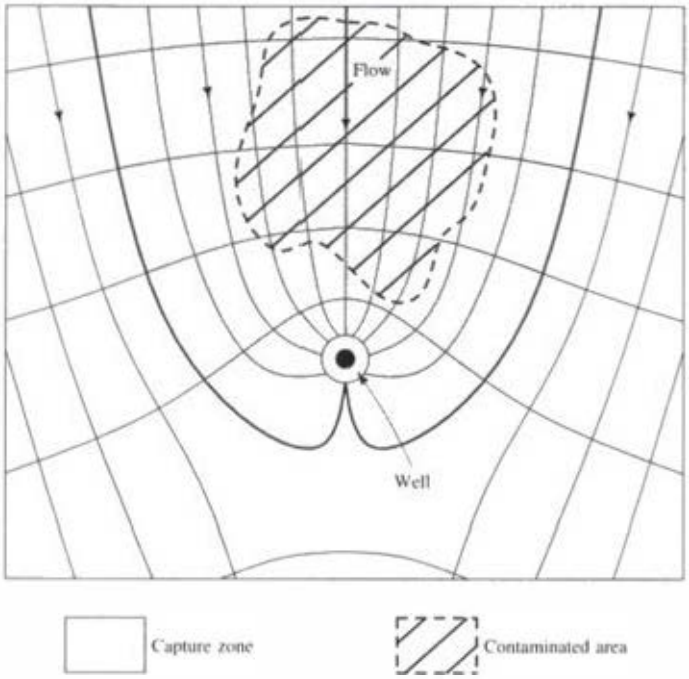
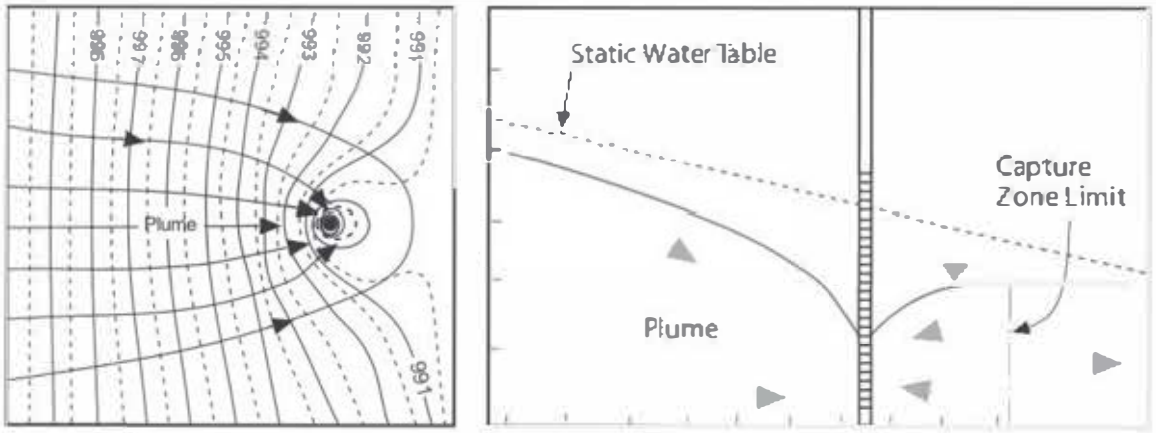


FIGURE 9.6 Example of plume stabilization by a well which is used to hydraulically contain a plume of contaminated groundwater. Shown are plan view and cross sections.

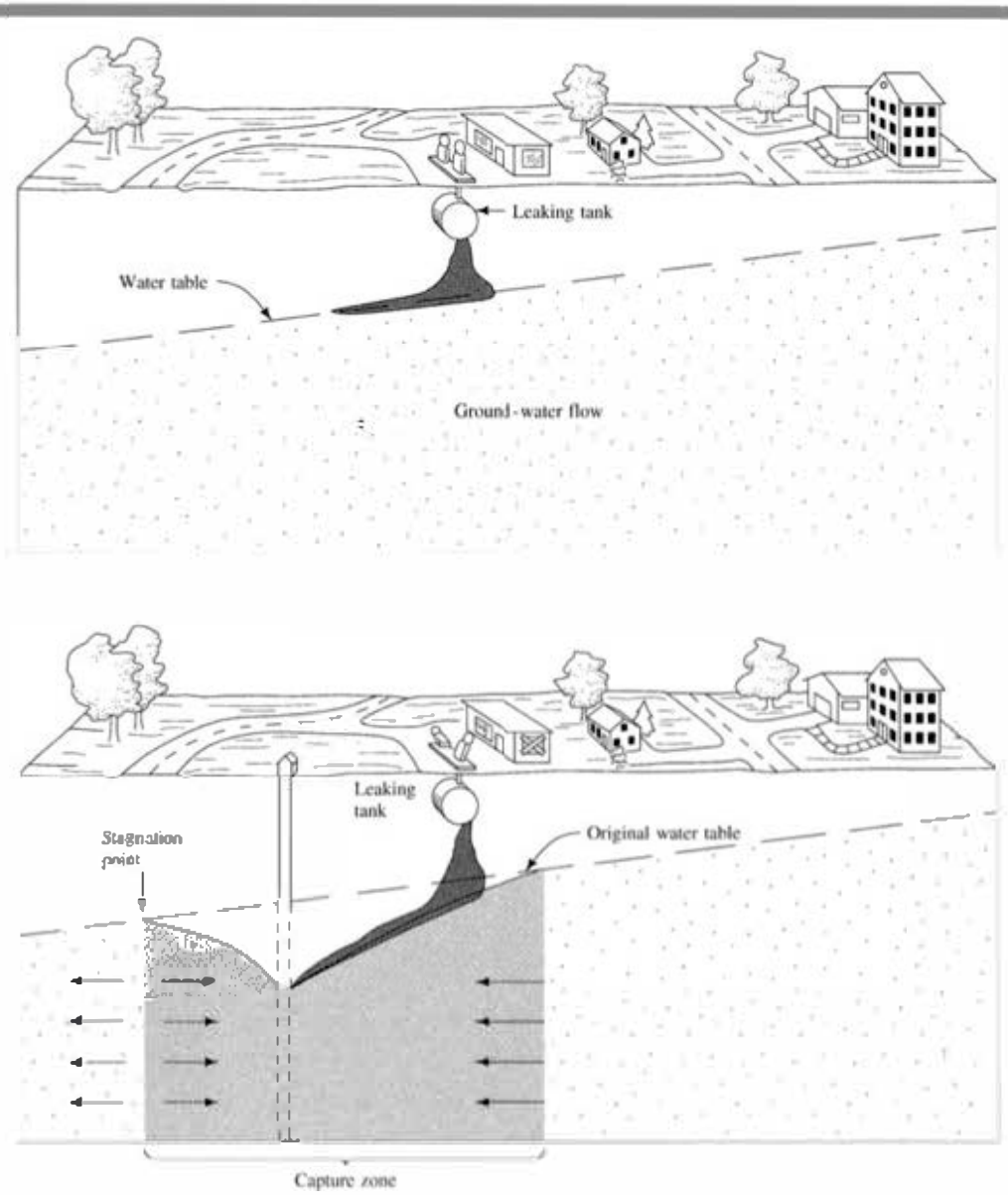


Source: After Cohen et al. 1993; as cited in U.S. EPA 1995, Report EPA/625/R95/005.

or groundwater flow can pass between them. These considerations illustrate why contaminant hydrogeologists regularly rely on groundwater models as an important aide in designing remediation systems.

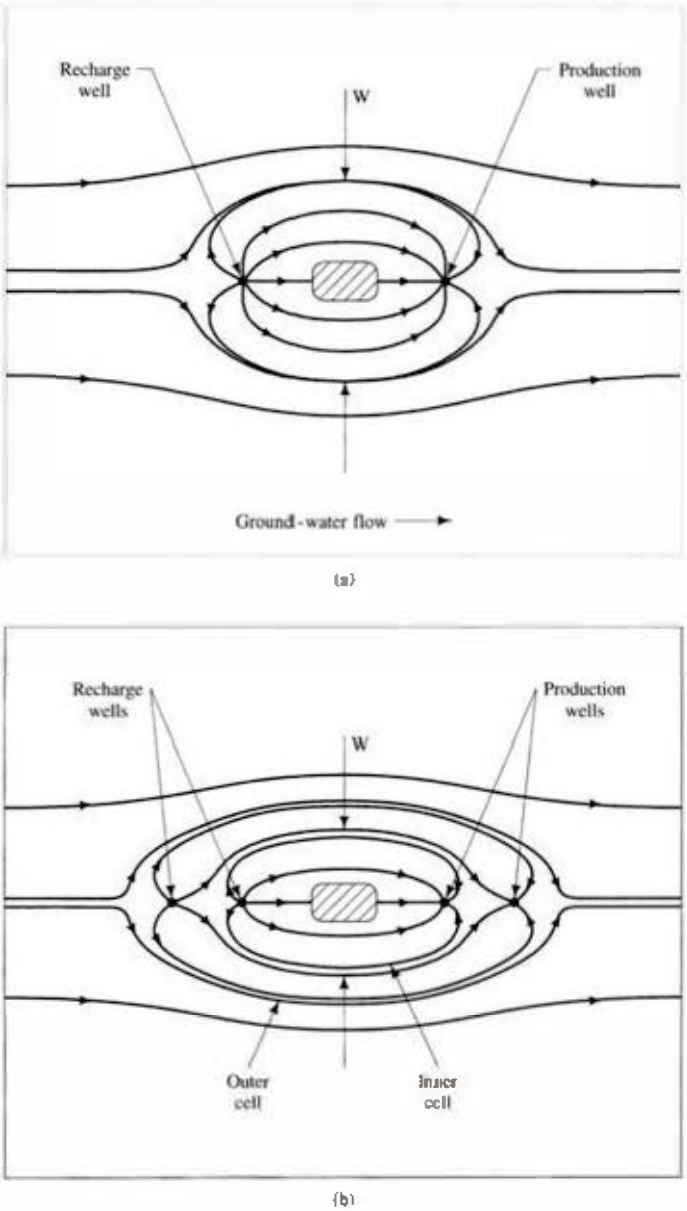
Wilson (1984) described the use of a pair of injection and withdrawal wells to create a hydraulic isolation zone around a plume of gasoline contamination. The withdrawal well draws contaminated water to it; the water is then reinjected into the ground upgradient of the position of the plume (Figure 9.8a). The withdrawn water may be treated prior to injection, or nutrients can be added to promote bioremediation. In addition, treatment systems may need periodic maintenance necessitating a shutdown.

FIGURE 9.7 Cross section along the x axis showing the cone of depression for a single extraction well superimposed on the regional water table.



With a reinjection system the untreated water can still be injected and the downgradient plume-stabilization well can be kept pumping. Otherwise, if the plume-stabilization well is shut down, the plume might be able to spread beyond its hydraulic boundary. Care must be exercised to minimize smearing of LNAPLs by reducing rigorous pumping that results in great fluctuations of the water table. Wilson (1984) also described a double-cell hydraulic containment system with two pairs of injection and production wells, as shown in Figure 9.8b. This system provides further isolation of the plume and also creates a smaller inner cell so that the production well that is pumping contamination will pump a smaller volume of water, which will lower treatment costs. With two injection and pumping wells, there is a possibility of shutting down one well periodically for maintenance and still having the system operational.

FIGURE 9.8 Plan view of (a) single-cell and (b) double-cell hydraulic containment of contaminated groundwater.



Source: J. L. Wilson. 1984. Proceedings of the Fourth National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, 65–70. National Water Well Association. Used with permission.

9.3 Pump-and-Treat Systems

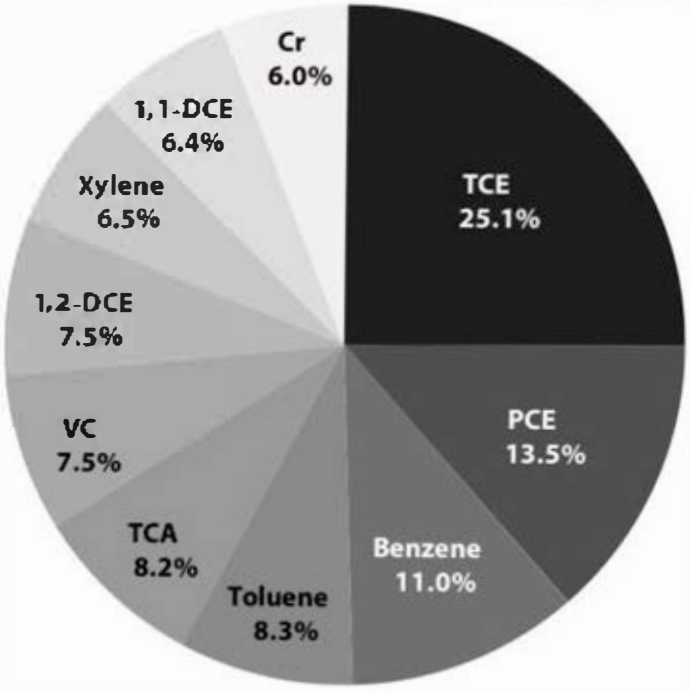
9.3.1 Overview

For a long time, almost all groundwater remediation was based on extraction wells or drains that were usually accompanied by treatment of the extracted water before discharge (Mackay and Cherry 1989). The extraction of groundwater that contains dissolved inorganic and organic chemicals removes the contaminants from the subsurface

so that the contaminated groundwater can be treated at the surface. This remediation approach is known as Pump-and-Treat (P&T). The advantage of the P&T method is that conventional methods of wastewater treatment can be employed. Pump-and-treat was the sole remedy at 56% (485 of 877 sites) of National Priority List (NPL) sires in the United States between fiscal years 1982 and 2005, representing the most common groundwater remedial action during that period (U.S. EPA 2007). Figure 9.9 provides an overview of the 10 most frequently treated contaminants using P&T technology. P&T systems also are frequently used to treat metals and metalloids, including chromium (U.S. EPA 2007). There are, however, a number of disadvantages that limit the usefulness of this technology to emergency responses, plume containment in combination with source-control measures, or treatment of highly water soluble compounds. Since the early 1990s many highly efficient groundwater treatment technologies have been devised and tested so that contaminated site managers now have alternatives to the P&T technologies. Not surprisingly, by 2011 only 22% of groundwater remedies at NPL sites were P&T based (U.S. EPA 2013).

Depending on the efficacy of treatment and regulatory requirements, the treated water can be discharged to a receiving water body, passed to a publicly owned wastewater treatment plant for further treatment and dilution, or reinjected into the ground. Often the disposal of the treated wastewater requires state and local permits or regulatory approval. Discharge to a publicly owned wastewater-treatment plant may require local permits for industrial discharge and there might be pretreatment standards. Water

FIGURE 9.9 Contaminants treated most commonly by pump-and-treat systems: trichloroethene (TCE); tetrachloroethene (PCE); 1,1,1-trichloroethane (TCA); 1,2-dichloroethene (1,2-DCE); 1,1-dichloroethene (1,1-DCE), vinyl chloride (VC), and chromium (Cr).



Source: U.S. EPA 2007.

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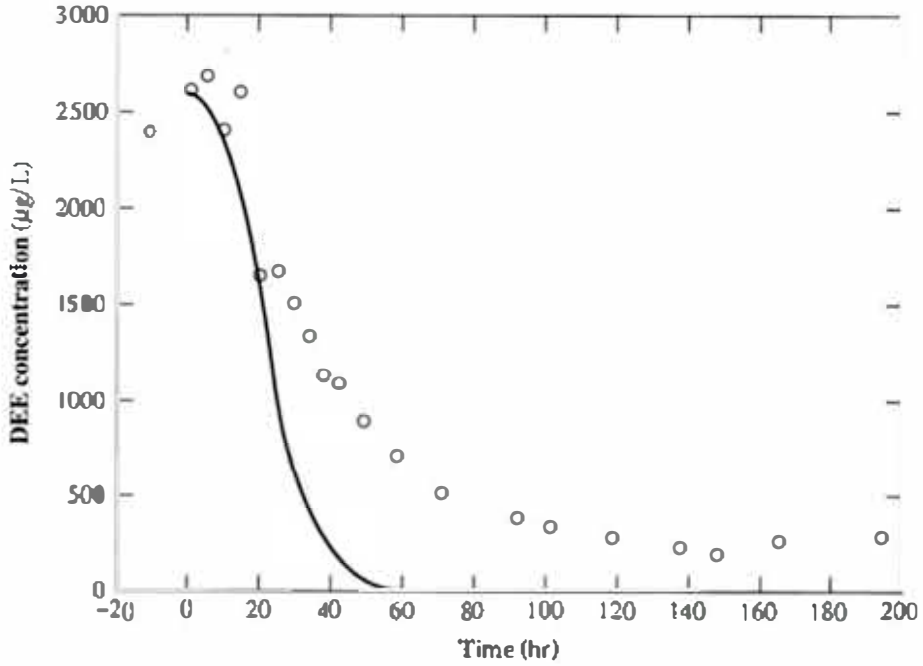
discharged to a surface-water body in the United States requires state permits, including a National Pollutant Discharge Elimination System (NPDES) permit. Many states provinces, and regions require a permit to inject water into the ground and there may be concentration limits specified as a part of the permit. If there are NAPLs present, the situation is much more complex than if all contaminants are in a dissolved form. As long as an NAPL is present, it will partition between the NAPL phase and the dissolved phase. Thus, as contaminated water is withdrawn from the aquifer for treatment, the clean water that is drawn into the aquifer eventually becomes contaminated with pollutants partitioning from the remaining NAPL. If some of the NAPL is mobile, it may be captured by pumping. LNAPLs that are floating on the water table are relatively easy to locate and remove if the LNAPL has not been smeared vertically. However, DNAPLs that sink to the bottom of the aquifer are very difficult even to locate, much less recover (Mackay and Cherry 1989; Freeze and Cherry 1989). Because considerable amounts of residual NAPL will remain even if the mobile NAPL is removed, a great many years may be required for pump-and-treat systems to remove all the residual NAPL by partitioning into the recoverable dissolved phase. In the case of contamination by DNAPLs especially in fractured rock aquifers, it may be very difficult or impossible to remediate a contaminated aquifer (Mackay and Cherry 1989; Freeze and Cherry 1989; National Academies of Sciences, Engineering, and Medicine 2015).

If the dissolved phase sorbs onto the mineral matter of the soil, that phase may desorb as the contaminated water is flushed from the pores. The greater the distribution coefficient, the more slowly the sorbed phase will be released and the longer it will take to remediate the aquifer. The kinetics of desorption dictate that many pore volumes of uncontaminated water might be needed to remove completely the sorbed phase of both organic and inorganic contaminants. Whiffin and Bahr (1984) noted that the observed rate at which organic compounds desorbed from an aquifer was slower than the rate predicted by transport equations that assumed equilibrium conditions between the sorbed phase and the dissolved phase (Figure 9.10). The advection-dispersion equation results were initially fairly accurate; however, when the concentration dropped to about half the initial concentration, the actual rate of removal was slower than the predicted rate.

The discrepancy between the Whiffin and Bahr (1984) model and the observations in the field are related to contaminant residence time in the subsurface and diffusion transport processes. Hence, in heterogeneous media, some contaminants can be sequestered for long periods of time, despite active pumping. Contaminants that have been in the ground for a long period of time have been able to diffuse into the less permeable zones of porous media aquifers or into the bedrock matrix of fractured rock aquifers. Pump-and-treat systems are inefficient in removing these contaminants, because the majority of the water being removed by pumping will come from the most permeable zones of the aquifer. In alternating layers of sand and clay, the contaminated water will penetrate the fine clay, which has very limited permeability, from the highly permeable sands over time. Some of the contamination will remain in the dissolved phase, some will partition onto the surface of the clay lens and associated soil organic carbon and some will diffuse into the clay lens. The fine sediment will have a larger surface area per unit volume of the aquifer than the coarse sediment and thus will sorb more contamination.

These mass transport limitations have been illustrated by Mackay and Cherry (1989) (Figure 9.11). Figure 9.11a shows contamination residing in homogenous aquifer

FIGURE 9.10 Measured desorption values for diethyl ether for water pumped from a purge well (open circles) versus calculated desorption curve based on advection-dispersion equation (solid line).



Source: R. B. Whiffin and J. M. Bahr. 1984. Proceedings of the Fourth National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, 75–81. National Water Well Association. Used with permission.

composed of uniform sand. During the time interval t_0 to t_1, the contamination is effectively flushed out. However, if the porous media is heterogeneous and the aquifer consists of sand with an interbedded clay lens, the concentration in the effluent from the extraction well is still elevated at t_1 (Figure 9.11b). Water removed by pumping will come primarily from the sandy material. The contaminated water in the pores of sand will be fairly quickly removed; perhaps only a few pore volumes of water will need to be flushed through to accomplish this. Contaminants sorbed onto the sand grains will be removed by partitioning into the clean water that then occupies the pores in the coarse sand layers.

Meanwhile, the contaminated water occupying the pores of the clay lens will be flushed from this layer very slowly. It will take the movement of many pore volumes of water through the sand to flush just a few pore volumes of water through the much less permeable clay layer. Hence, it will take much longer to remove the contaminants that are desorbing from the fine sediments after the contaminated pore water is removed from the sand.

There will be an initial rapid decline in the concentration of contaminants in the water being removed by a pump-and-treat system. This decline represents the removal of the contaminated water contained in the larger pores of the aquifer. Initially, when the larger pores in the sandy material are being flushed, the drop in concentration will be rapid. Flushing the much smaller pores in the clay will take much more time and, the rate at which the concentration declines will decrease. The concentration will eventually approach somewhat constant value, which represents a steady state condition where the rate at which the contaminants are being removed by the pump-and-treat

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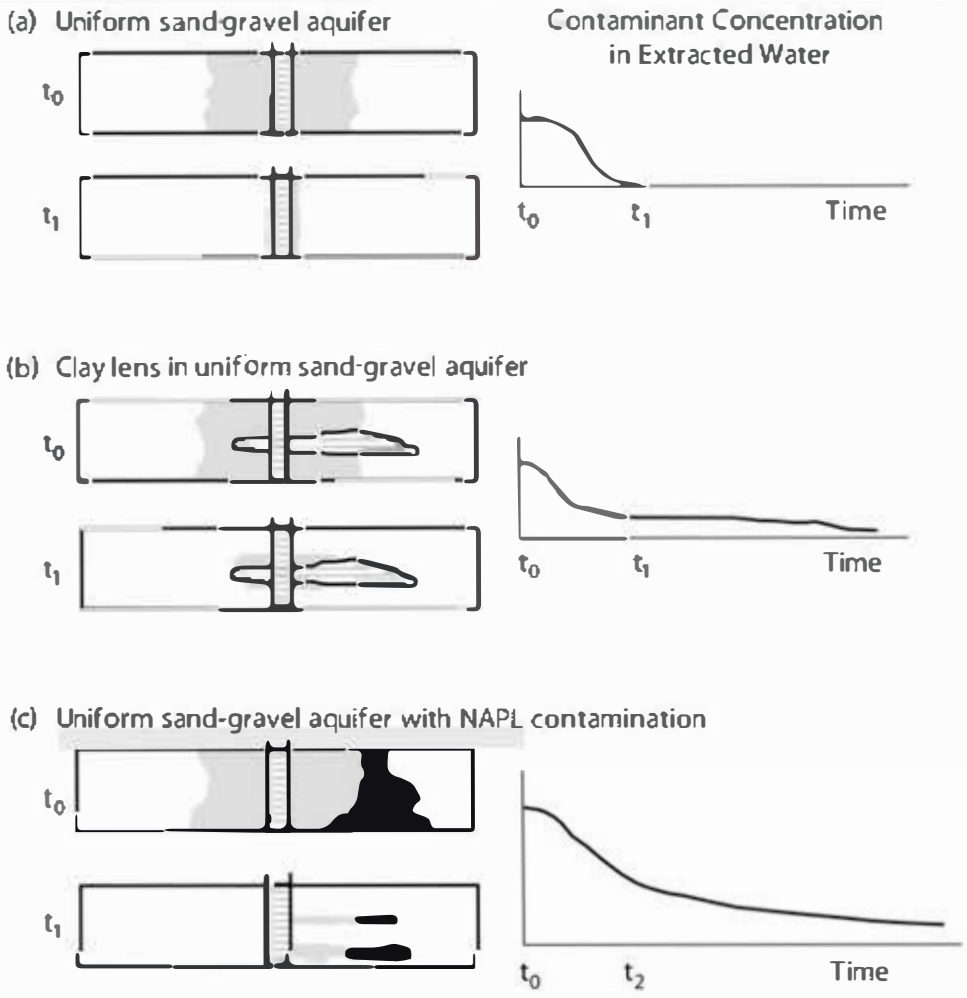
FIGURE 9.11 Hypothetical examples of contaminant removal during pump-and-treat treatment. Gray areas indicate sorbed and dissolved contaminants (uniform initial distribution). Lined shapes indicate clay lens. Black areas indicate NAPL.

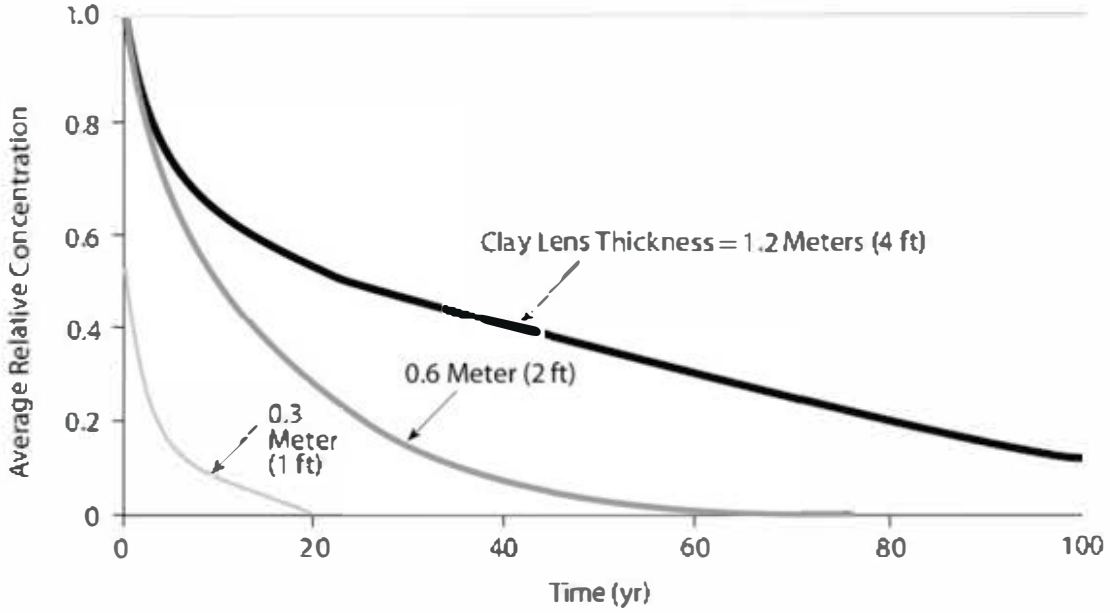


Source: Modified after Mackay and Cherry 1989.

system is equal to the rate at which they are being released into the groundwater by diffusion desorption and/or partitioning from residual NAPLs (Figure 9.11c). The resulting long period of slow release of contaminants to the groundwater is called the **tailing** phase of the remediation.

During the tailing phase in the remediation process contaminant mass is still being removed from the aquifer, but the groundwater is not becoming any cleaner. The concentration at which this occurs may be higher than the cleanup goals for the remediation. It may take many years of pumping at this stage to reduce the amount of sorbed contaminants and/or the residual NAPLs sufficiently for the groundwater quality to improve to a point where it meets cleanup goals. Figure 9.12 depicts how the slow, diffusion-controlled release of contamination from material of low hydraulic permeability (clay) can determine the length of the remediation period. For instance, it would take about 10 years to reduce the TCE concentration by 90% if the clay lens is 0.3 m (1 ft) thick. The time increases to almost 40 years for a lens 0.6 m (2 ft) thick and to over

FIGURE 9.12 The effect of matrix diffusion on the average relative trichloroethene (TCE) concentrations in clay lenses of varying thickness as a function of time.



Source: U.S.EPA 1996.

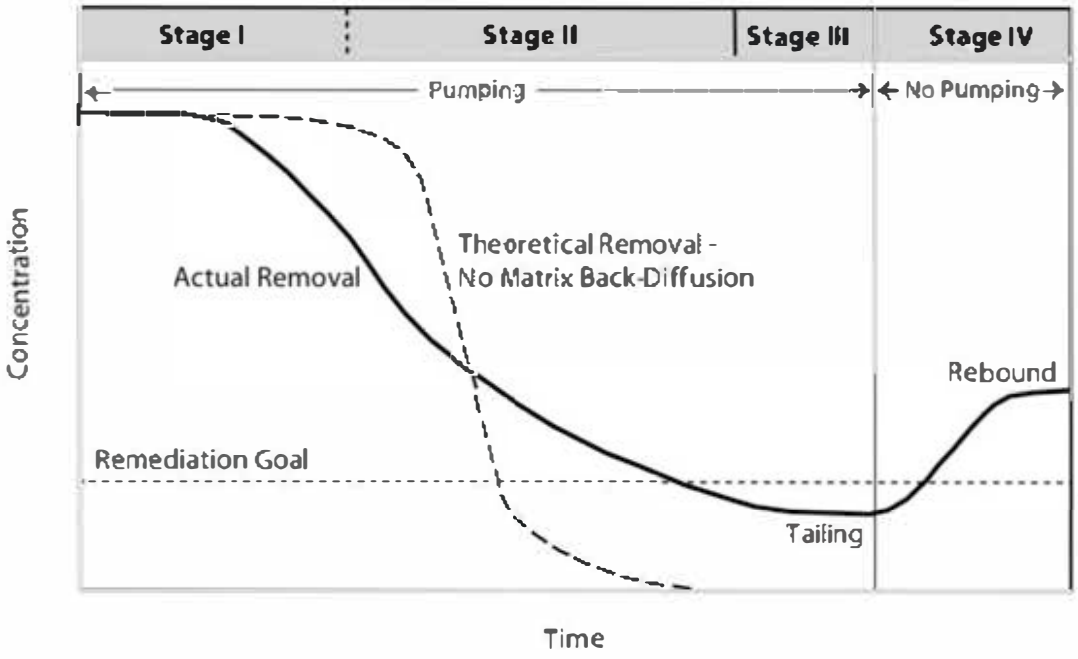
100 years for a lens 1.2 m (4 ft) in thickness. These simulations show that it may take decades or longer to significantly lower the contaminant concentration in clay lenses.

A study of pump-and-treat cleanup at 16 sites in the United States where the groundwater was contaminated with organics revealed that if the initial concentration of contamination was high (>1000 µg/L), pumping could achieve reductions of contaminant concentrations of 90 to 99% before leveling occurred. At sites where the initial concentration was less than 1000 µg/L, leveling occurred before a 90% reduction was accomplished (Doty and Travis 1991). Moreover, if remediation is halted before the sorbed phase is completely removed, the dissolved concentration will eventually rebound and rise above the level detected at the end of the remedial period as additional material desorbs to come to equilibrium with the dissolved phase. Typically, the rebound of the dissolved contaminant concentration is quick, i.e., can occur within a few days after the pumping ceased.

The effects of rebound and tailing on the progress of P&T treatment are illustrated in Figure 9.13. It must be noted that these effects are not solely limited to P&T systems, but also affect other, more innovative groundwater treatment technologies that rely on chemically-enhanced flushing processes to remove contamination from low-permeability material.

Figure 9.13 illustrates the multiple stages in remediation of a contaminated aquifer or soil. Early during the treatment (Stage I), there is rapid removal of contaminant mass and concentrations drop quickly. Stage I transitions into Stage II which represents the diffusion-controlled period as the concentration graph attains an asymptotic shape. During the tailing stage (Stage III), the rate of mass removal slows because the site geology controls the rate at which the remaining contamination is released. The impact of matrix diffusion is illustrated by the dashed line curve, which shows the theoretical removal expected in

FIGURE 9.13 Stages in the remediation of a contaminated aquifer or soil.



Source: Modified after U.S. EPA 1996.

the absence of diffusion from low-permeability domains into higher permeable zones. Remediation efforts continue until a predetermined clean up goal has been reached. In some cases, that remediation goal may be higher than the pollutant specific standard, like the maximum contaminant level (MCL) defined by the U.S. EPA. When at one point the pumping stops, it is likely that the slow, diffusion-controlled release of contaminants from low-permeability domains results in an increase in the dissolved phase concentration. This is Stage IV, the rebound stage. Should the rebound result in groundwater concentrations higher than the cleanup standard, remediation must continue. Under these circumstances, it may be necessary to periodically turn on the pump(s) until the residual concentration drops beneath the remediation goal again. Such a treatment scheme is known as pulsed pumping (U.S. EPA 1996). Another option is to vary the pumping rates or turn injection wells into extraction wells and vise-versa. This adaptive pumping approach limits the development of stagnation zones, which are parts of the aquifer that are not, or only minimally, flushed if the extraction/injection scheme was static.

Figure 9.13 illustrates an aquifer where the contaminant is in the dissolved phase or is sorbed onto soil particles. If there is an undissolved phase (DNAPL) present, then the release of contaminant into the flushing water will be controlled by the solubility of the DNAPL. More soluble DNAPLs, such as trichloroethylene, which has a solubility of 1100 mg/L, will become dissolved much more rapidly than low-solubility NAPLs, such as coal tar or creosote. However, as the DNAPL will tend to form pools on the top of low-permeability layers, the flushing liquid will only come in contact with the top of the DNAPL pool and little dissolution will actually occur (Johnson and Pankow 1992). As a result, pump-and-treat will be inefficient for mass removal in the case of DNAPLs. In spite of this inefficiency pumping still is viable as a means of plume containment.

Pump-and-treat methods have been shown to be effective in removing a large amount of more soluble contaminant mass from the aquifer during the initial phase of pumping. They are also useful in halting the spread of a plume of contamination, i.e., plume containment. However, if the contaminant concentration in the aquifer is still above the cleanup goal once a pump-and-treat project reaches the stage where the contaminant release is diffusion controlled, decades of additional pumping might be required before the aquifer is "clean." This does not mean that the pump-and-treat approach failed, it only means that it was an unrealistic expectation to attain complete remediation of an aquifer with pump-and-treat as the only remedy. The shortcomings of conventional pump-and-treat schemes have led to the development of many innovative remediation technologies, which will be discussed in greater detail later in this chapter.

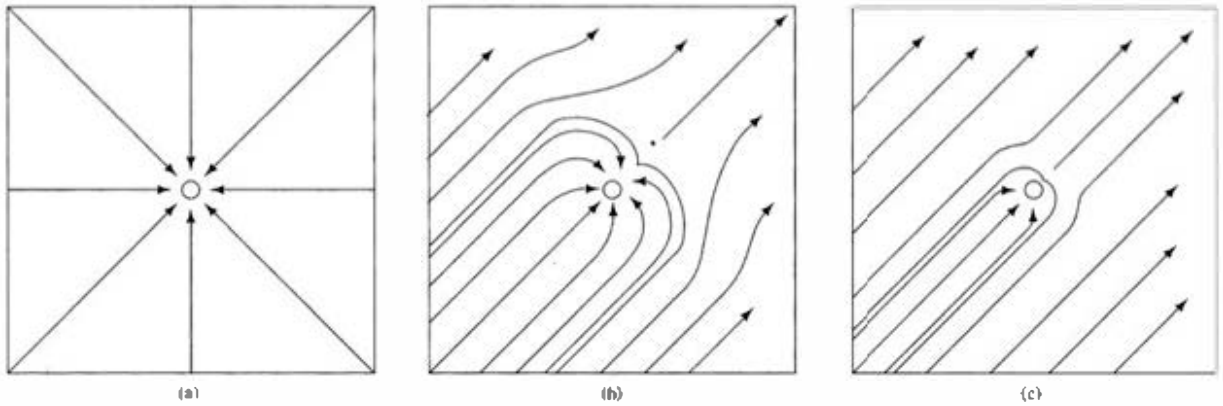
9.3.2 Capture Zones

In order to capture a plume of contaminated water, it is necessary to have one or more pumping wells located downgradient of the source area. Each well will have what is known as a capture zone, which is the area contributing flow to that particular well.

If the water table is flat, there is no regional flow. The capture zone of a well is radially symmetrical, centered on the well and extending as far as the edge of the cone of depression (see Figure 9.14a). If there is a slope to the water table, the groundwater flows and the capture zone are asymmetrical, with the greatest extent in the upgradient direction (Figure 9.14b). As the groundwater velocity increases, the width of the capture zone decreases for a given pumping rate (see Figure 9.14c).

The shape of the capture zone is a function of the average linear groundwater velocity, the quantity of the water being pumped from the aquifer, and the distribution of hydraulic conductivity. The upgradient extent of the capture zone depends upon the length of time over which the pumping occurs. The Wellhead Protection Area (WHPA) program was developed by the U.S. EPA that may be used to delineate capture zone. It is a semi-analytical groundwater flow simulation program that can account for multiple pumping and injection wells and delineates the area contributing flow to those wells.

FIGURE 9.14 (a) Flow lines toward a well in an aquifer with no water table gradient; (b) flow lines toward a well and the capture zone with uniform flow to the upper right of the figure; (c) flow lines toward a well and the capture zone with uniform flow to the upper right at a rate 10 times the rate of (b).



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WHPA is applicable to homogeneous aquifers exhibiting two-dimensional, steady groundwater flow in an areal plane and appropriate for evaluating multiple aquifer types (i.e., confined, leaky-confined, and unconfined) (U.S. EPA 1993).

If the hydrogeology is not homogeneous or if more complex geologic or contaminant transport problems have to be accounted for, there are a number of sophisticated models available today. For instance, FLOWPATH II is a 2-D finite difference, steady-state groundwater flow model for calculation of wellhead protection zones, hydraulic heads, groundwater velocities, time related path lines, capture zones, water balances, and steady state drawdown distributions. Another model is PATH3D, which can help delineating contaminant capture zones or wellhead protection zones or can be used to evaluate the effectiveness of groundwater remedial scenarios under complex hydrogeological conditions. There are a number of other noteworthy programs and the Integrated Groundwater Modeling Center (IGWMC) at the Colorado School of Mines in Golden, CO, USA, provides reviews and links to many of those models.

9.3.3 Computation of Capture Zones

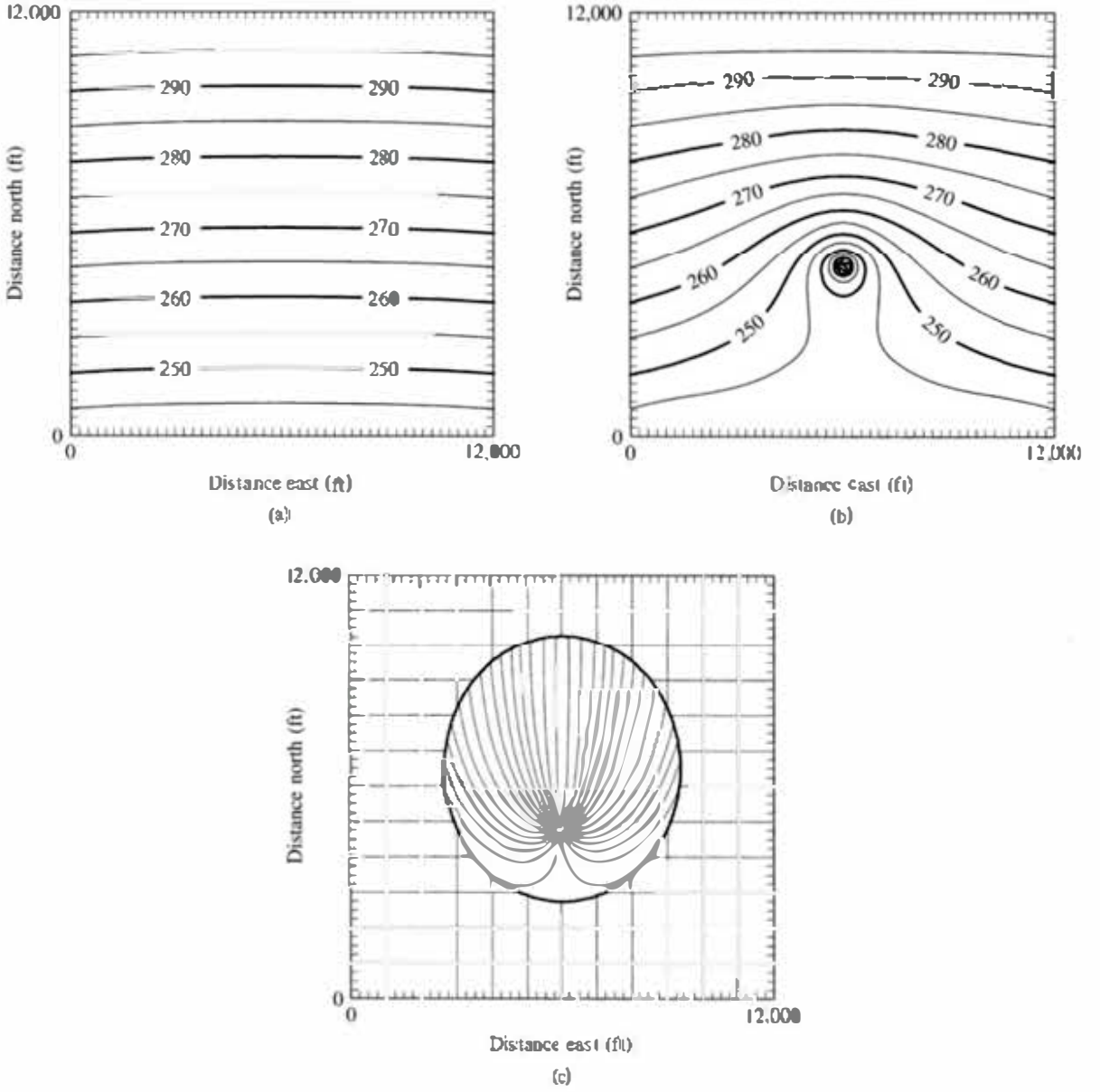
The effect of aquifer heterogeneity was illustrated by Shafer (1987). Figure 9.15a shows the initial hydraulic head for a homogeneous, isotropic, unconfined aquifer. The hydraulic-head distribution after 20 years of pumping from a single well is shown in Figure 9.15b. During this time period, the cone of depression has not spread all the way to the upgradient end of the diagram. The extent of the capture zone is shown superimposed on the model grid in Figure 9.15c. Figure 9.16a shows the distribution of hydraulic conductivity in nonhomogeneous aquifer with the same initial head distribution as the one in Figure 9.15a. In contrast to the homogenous system, the hydraulic head distribution in the nonhomogeneous aquifer with one well pumping is not symmetric and the shape of the 20-year capture zone is irregular (Figures 9.16b and c). The nonsymmetric, irregularly shaped capture zone reflects the heterogeneous distribution of the hydraulic conductivity in the nonhomogeneous aquifer. This example illustrates that ignoring aquifer heterogeneity can lead to incomplete capture of a contaminant plume.

9.3.4 Optimizing Withdrawal-Injection Systems

The rate at which groundwater restoration can be accomplished by pump-and-treat systems depends in part on how many pore volumes of water can be withdrawn from the contaminated zone. If the entire plume falls within the capture zone of one or more withdrawal wells, then we know that the plume will not spread and eventually maximum feasible restoration will occur. However, by increasing the rate (number of pore volumes of water per year) at which contaminated water is pumped, the restoration time can be decreased. For optimal conditions we also want to minimize the volume of contaminated water that is pumped, because that also must be treated.

Satkin and Bedient (1988) used a contaminant-transport model to investigate the use of various pumping and injection patterns to remediate a plume of contamination. They examined the effectiveness of seven different well patterns for various combinations of hydraulic gradient, maximum drawdown, and aquifer dispersivity. The patterns are shown on Figure 9.17.

FIGURE 9.15 (a) Hydraulic head distribution with no wells pumping. (b) Hydraulic head distribution in a homogeneous, isotropic aquifer with one well pumping. (c) Shape of the 20-year capture zone based on hydraulic head distribution of Figure 9.15b.



Source: J. M. Shafer, 1987, Reverse pathline calculation of time-related capture zones in nonuniform flow. *Groundwater* 25:283–289. Used with permission.

If a single pumping well is used, it must be placed so that the capture zone encompasses the plume. The closer the well can be to the center of mass of the contaminant, the faster the contamination can be removed. If the plume can be captured by a single withdrawal well, then multiple pumping wells aligned along the axis of the plume will increase the rate of cleanup over a single well by pumping a greater volume of water. The use of pumping wells without injection wells may create a problem if there isn't a receiving body of water in which to dispose of treated groundwater.

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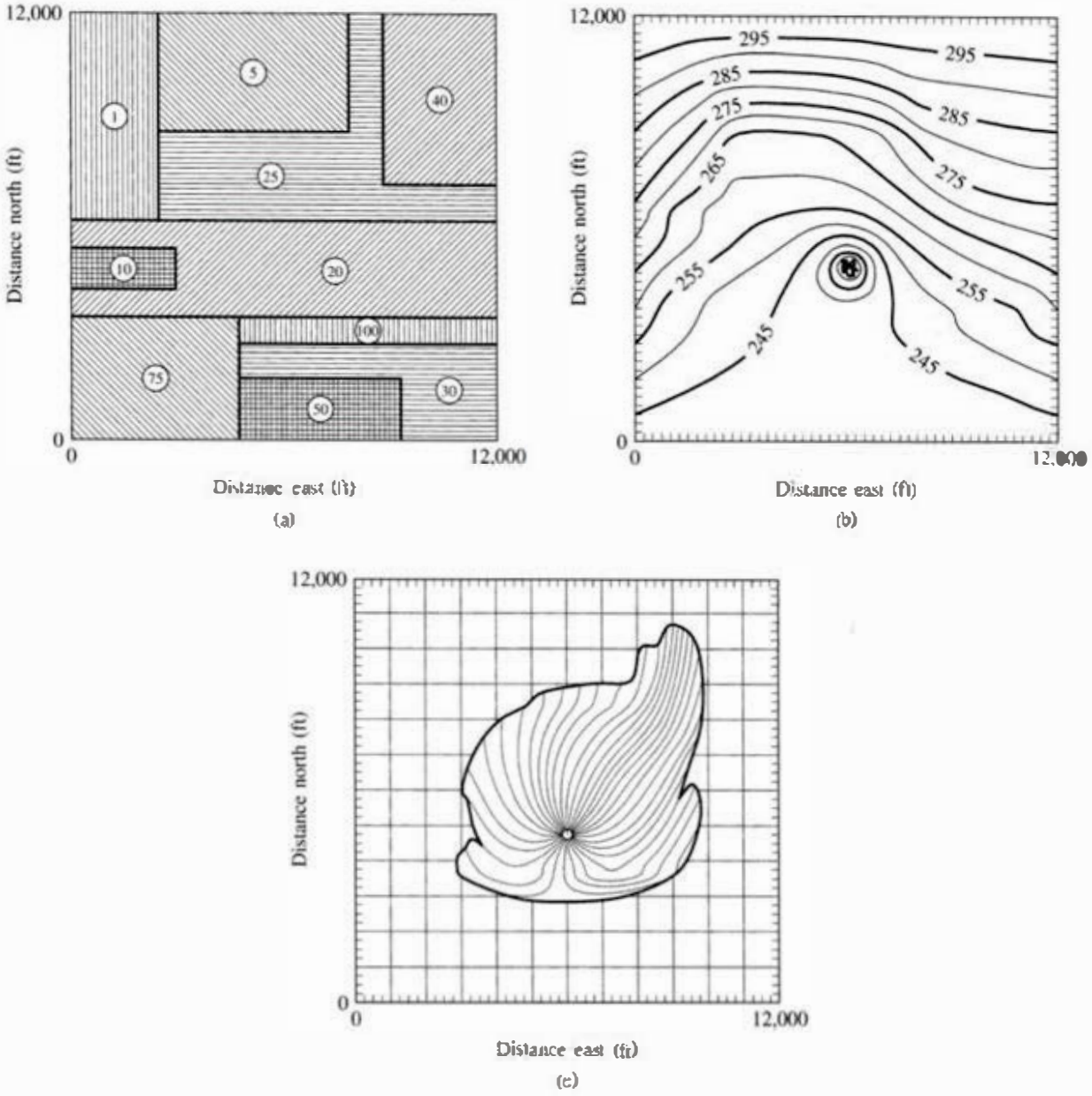
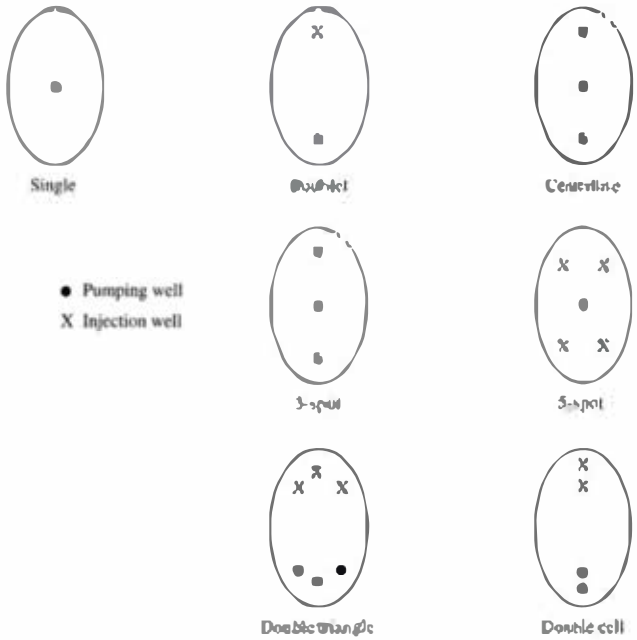
FIGURE 9.16 (a) Distribution of hydraulic conductivity in nonhomogeneous aquifer with the initial head distribution of Figure 9.15a. (b) Hydraulic head distribution in the nonhomogeneous aquifer with one well pumping. (c) Shape of the 20-year capture zone based on hydraulic head distribution of Figure 9.16b.



Source: J. M.Shafer, 1987. Reverse pathline calculation of time-related capture zones in nonuniform flow. *Groundwater* 25:283–289. Used with permission.

If injection wells are used in combination with withdrawal wells, cleanup time can be reduced, because steeper hydraulic gradients can be created. These steeper gradients will produce more water flowing to the withdrawal well(s) than occurs if extraction wells alone are used. We have already seen how a system of a downgradient withdrawal well in conjunction with an upgradient injection well can be used to create a circulation cell

FIGURE 9.17 Possible patterns for extraction and extraction-injection well systems.



Source: R. L. Satkin and P. B. Bedient. 1988. Effectiveness of various aquifer restoration schemes under variable hydrogeologic conditions. *Groundwater* 26:488–498. Used with permission.

to isolate the plume. This is called a doublet on Figure 9.17. Other injection-withdrawal combinations tested included the double cell and double triangle, which are variations of the doublet. Two patterns tested were based on one extraction well and multiple injection wells: the three-spot and the five-spot. When injection wells are used in conjunction with extraction wells, the treated water is disposed via reinjection. However, groundwater injection wells are prone to clogging and may need periodic maintenance (Fetter 1994). Additionally, states, provinces, or regions may have water-quality standards for any water that is reinjected; many locales require a permit for injection wells.

Satkin and Bedient (1988) found that the best well pattern for cleanup was highly site-specific. They also found that even with the same well pattern, variation in the placement of the wells yielded different cleanup times. When the hydraulic gradient is low, the doublet, double cell, and three-spot patterns were very effective. Under conditions of high hydraulic gradient, the centerline was most effective. In this pattern the downgradient injection well, which must be located beyond the leading edge of the plume, creates a hydraulic barrier to further migration of the plume. The five-spot pattern was not found to be very effective under any conditions.

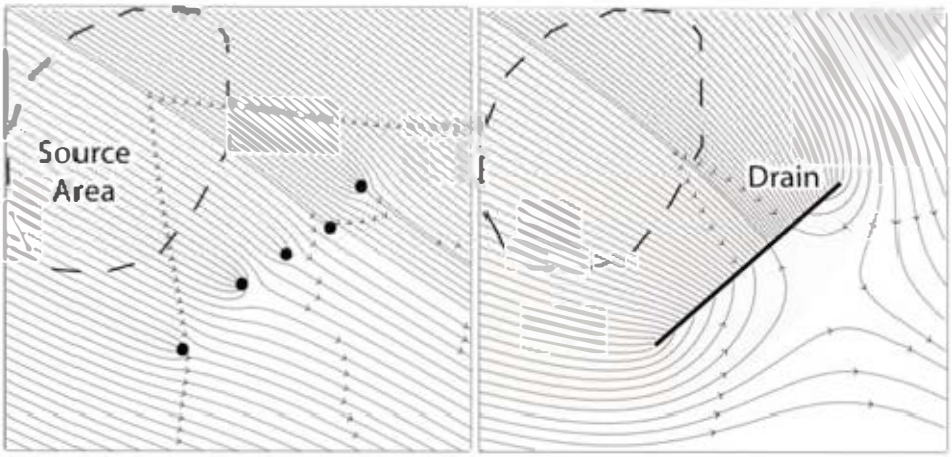
9.3.5 Permanent Plume Stabilization

Decades of experience with pump-and-treat technology showed that in most cases it is not feasible or even technically possible to fully remediate a badly contaminated aquifer by pump-and-treat technology. This is especially true if the source cannot be located and removed, for example, if there are nonbiodegradable residual DNAPLs present in a fractured rock aquifer. For such aquifers the only feasible technology might

well is insufficient to prevent the plume from growing. Pumping at the source zone and downgradient improved the situation but some contaminated groundwater still escaped downgradient. Only the installation of a mid-gradient well prevented the escape of contaminated groundwater. The modeling results underline the importance of source control pumping and the establishment of sufficiently large downgradient capture zones to prevent continued offsite migration of contaminated groundwater.

A different approach to plume containment is to construct a **French drain** perpendicular to the direction of the plume migration. Such a drain system is typically constructed by excavating a ditch to the maximum depth of the plume and back filling it with gravel or other highly permeable material. Embedded at the base of the trench is a horizontal perforated pipe that connects to a vertical well. Contaminated water intercepted by the trench is collected by the pipe and then pumped to the surface for further treatment. As shown in Figure 9.19, a French drain may provide more effective plume containment than a series of extraction wells (Cohen et al. 1997). These drain systems are limited to comparably shallow plumes in unconsolidated material because digging deep trenches (>>30 m or >100 ft) is typically cost prohibitive and often not feasible, particularly if the sediment is unstable and prone to caving. Constructing French drains in bedrock is generally possible, but typically too expensive.

Figure 9.19 Compared to a line of conventional pump-and-treat wells (left), a plume emanating from an up gradient source zone can be effectively intercepted by a trench drain constructed perpendicular to the main axis of groundwater flow (right).



Source: Cohen et al. 1997.

9.4 Treatment of Extracted Groundwater

9.4.1 Overview

It is often necessary to withdraw water during site remediation projects and that water must be treated *ex situ* according to the type of contamination. Different types of treatment are needed for water contaminated with heavy metals or that is contaminated by dissolved organic compounds. Similarly, the treatment approach will be different for compounds that are volatile versus those that are not, or those pollutants that can be chemically or physically destroyed or converted into non-toxic compounds versus

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those that cannot. Most of the treatment techniques that are used were developed for wastewater and have been adapted to contaminated groundwater. Generally, there are two types of treatment approaches (1) separation and (2) destruction technologies. Examples for the former include adsorption to granular activated carbon (GAC), or air stripping. Destruction technologies include, for instance, UV oxidation and other advanced oxidation processes or biological treatment methods. These and other *ex situ* treatment technologies for contaminated groundwater are described in detail on the Federal Remediation Technologies Roundtable (FRTR) or EUGRIS websites and other online information depositories introduced in Section 9.1. Some of these treatment technologies require the contaminated matrix, soil or groundwater, to be transported to the treatment facility; others can be easily set up on the contaminated site. The treatment methods for contaminated soil and sediment are not covered in this chapter.

The design of a treatment system must be cost effective. To this end the designer must consider the trade-off between capital costs and operating costs. Extraction systems can be designed by the hydrogeologist to withdraw the maximum volume of water in the shortest period of time. This yields the fastest, but not necessarily the most cost-effective cleanup of the aquifer. The size of the treatment plant is dictated by the maximum rate by which water will be pumped for treatment. The capital costs for the treatment plant include the treatment vessels, pumps, piping, and tanks. The greater the flow rate at which contaminated water is pumped through the treatment system, the larger these items must be and the greater the initial capital costs.

Operating costs include the electricity to run the plant, the cost of chemicals, the labor to operate the plant, and the cost of repairs. Some of the operating costs will be continuous no matter how long the project lasts (e.g., the cost of chemicals used to treat the water). If the same total volume of water is treated, the same amount of chemicals will be needed, no matter how long or short the treatment period. Other costs, such as labor, depend primarily upon the length of time of the operation. If the total volume of contaminated water is treated over a very short period of time, there will be high initial capital costs for the large-capacity plant and low operating costs because of the short time period. If the same volume of water is pumped over a longer period of time, the capital costs will be lower, since a smaller treatment plant is needed, but the operating costs will be higher. The smallest treatment plant possible is that needed to treat the quantity of water generated by the minimum pumping rate, which is just high enough to capture the plume. There will be some optimum treatment rate that minimizes the combined capital and operating costs.

9.4.2 Treatment of Inorganic Contaminants

The majority of inorganic contamination needing treatment consists of metals, which can be removed by precipitation or adsorption. Often the treatment involves mixing of reactive agent(s) into the extracted contaminated water. Many metal hydroxides precipitate at a specific alkaline pH value. For these metals, adjustment of pH by adding lime can cause precipitation of the metal hydroxide, which is removed via a clarifier followed by filtration. Ferrous iron can be removed by aeration to create ferric iron, which will precipitate at a slightly alkaline pH. Hexavalent chromium must first be reduced to the trivalent state by lowering the pH to 3 and then adding a reducing agent such as sulfur dioxide. The trivalent chromium can then be precipitated as a

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hydroxide by raising the pH above the neutral value. Arsenic can be coprecipitated with iron by adding dissolved iron at a pH of 5 to 6 and then raising the pH with lime to between 8 and 9. Arsenic also adsorbs to activated alumina.

Inorganic compounds can be removed by ion exchange. This process uses a resin to adsorb and retain anionic or cationic contaminants from groundwater. In place of the toxic ions, the resin releases benign anions or cations, such as chloride and calcium. When the resin becomes saturated after all of the resin's functional groups have been occupied, it needs to be recharged before reuse, or possibly disposed and replaced. This treatment approach is used commonly for nitrate, which cannot be removed by precipitation. Ion exchange has also been used for removing radiogenic isotopes, like uranium (Botha, Bester, and Hardwick 2009). Inorganic contaminants can also be removed by reverse osmosis and electro dialysis. In reverse osmosis, water is pressured to flow through a semi-porous membrane. While the water molecule passes through the membrane, many molecules and ions cannot and are retained on the membrane surface. In case of electro dialysis, flow through a membrane is induced by an electric potential and because the membranes are cation- or anion-selective, either positive ions or negative ions will flow through and can be exchanges for benign ions. This method has been used to remove radium, uranium, arsenic, nitrate, perchlorate, and hardness from drinking water (U.S. EPA 2015) or to remove cooper, chromium and arsenic from chromated copper arsenate (CCA) treated timber waste water (Ribeiro, Mateus, and Ottosen 2000).

9.4.3 Treatment of Dissolved Organic Contaminants

Many of the organic contaminants found in groundwater are volatile. They can be stripped from the water by exposing the water to a flow of air. This is accomplished in an air-stripping tower (Figure 9.20). The tower is a tall cylinder filled with an inert packing material, typically made of polypropylene. The packing material is designed to have a very high porosity and a large total surface area. The contaminated water is sprayed into the top of the tower onto the packing material. A blower attached to the bottom of the tower forces air up the tower at the same time that the water, which was broken up into droplets by the spray nozzles, trickles down the packing material. The volatile organic chemicals vaporize from the water into the air and are expelled out of the top of the tower. Care must be taken that emissions from the air-stripping tower do not create an air-pollution problem. For this reason, the exhaust from the air stripper is typically treated by sorption onto activated carbon or a thermal treatment unit, as can be the case for gasoline type vapors. For typical air stripping towers 4.6 to 6 m (15 to 20 ft) in height and containing conventional packing, removal efficiencies of VOC are around 99%. The removal efficiencies can be improved by adding a second air stripper in series with the first, heating the contaminated water, or changing the configuration of packing material (FTRC 2015). A potential problem with air stripping is biological fouling, which describes the buildup of biofilms growing on the inside of the air stripping tower. If not attended to, biofouling can lead to decreasing treatment and eventually clogging of the system. Another common problem with air strippers is precipitation of iron or other minerals. Typically, if the treated groundwater contains more than 5 mg/liter iron or its hardness is greater than 800 mg/liter (FRTR 2015), it becomes likely that mineral precipitates will build up inside the stripper tower. Mechanical filters, such as sand beds, might be needed to filter the precipitated iron from the wastewater stream

An uncontaminated, confined sand aquifer that was 1.5 m (5 ft) thick was instrumented with a line of injection and extraction wells located 6 m apart. The direction of groundwater flow from the injection to the extraction wells was parallel to the regional hydraulic gradient. Intermediate sampling wells were placed at distances of 1, 2.2, and 4 m (3 to 12 ft) from the injection wells. Depending upon the injection and withdrawal rates, travel times from the injection wells to the withdrawal wells were from 20 to 42 hr. When oxygenated water was injected into the aquifer prior to the biostimulation experiments, the oxygen was transported to the extraction wells with little loss.

The compounds that were selected for study were vinyl chloride (VC), *trans*-1,2-dichloroethene (t-DCE), cis-1,2-Dichloroethene (c-DCE), and trichloroethene (TCE). When these were injected prior to biostimulation, they were retarded in the rank order of TCE > t-DCE > c-DCE > VC. It was found that with a long period of injection prior to biostimulation, the sorption capacity of the aquifer could be saturated with respect to TCE, t-DCE, and c-DCE. After 1000 hr of injection, the concentration of these compounds in the monitoring well located 1 m (~3 ft) from the injection well was found to be 90 to 95% of the injected concentration.

After the aquifer reached steady-state concentrations of the organic halides, it was biostimulated by injecting alternating pulses of dissolved oxygen and methane, along with continuous injection of the organic halides. The methane acted as the primary substrate (electron donor) for the growth of indigenous methane-utilizing bacteria, while the oxygen was the electron acceptor. The organic halides were degraded by cometabolism, a process by which the methantrophic bacteria that are utilizing the methane produce enzymes that are able to degrade the chlorinated ethenes. During the biostimulation experiments, decreases in concentration of both methane and the organic halides were observed. Within 2 m (6 ft) of travel through the aquifer, VC was reduced by 90 to 95%, t-DCE by 80 to 90%, c-DCE by 45 to 55%, and TCE by 20 to 30%. Residence times in the aquifer were only 1 to 2 days for this amount of biodegradation. It took about three weeks for the biostimulation experiment to reach these steady-state rates of reduction. An intermediate degradation product, *trans*-dichloroethene epoxide, was detected. When the injection of methane was halted, the concentration of the epoxide quickly decreased and the concentration of the halogenated ethenes slowly increased. However, when the rate of methane addition was increased beyond a certain concentration, it was shown to reduce the rate of transformation of VC and tDCE. Thus, while methane was necessary for stimulating *in situ* aerobic biotransformation, there appears to be an optimal concentration beyond which it inhibits the process.

9.11 Conceptual Site Models

The bioremediation approach serves as an example for the complexity of the biochemical and hydrogeologic interactions and their dependency on aquifer characteristics and the physical/chemical properties of the contaminant(s). Failure to understanding these conditions can determine the success or failure of site cleanup activities. Therefore, the development of a conceptual model of the site is an essential part of the site remediation process. Such a model is referred to as a conceptual site model (CSM). A CSM develops during the course of a site investigation. Elements of a CSM include at minimum a conceptualization of the processes that determine contaminant releases, contaminant migration, and the relationship between contaminant sources and receptors. The CSM is used to integrate all site information and data and to determine whether data gaps exist and whether additional information needs to be collected at the site. The model is used furthermore to facilitate the selection of remedial

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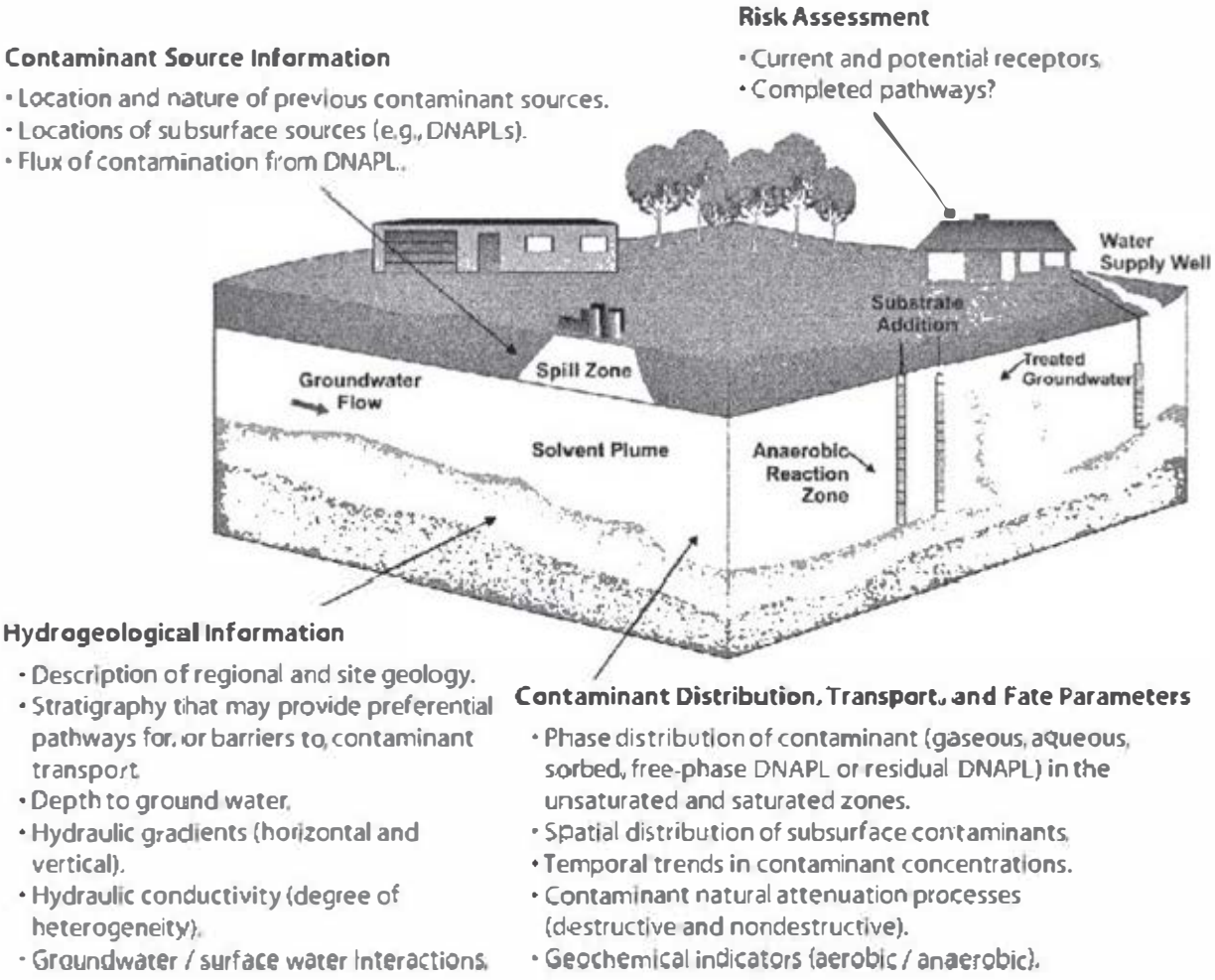
alternatives and to evaluate the effectiveness of remedial actions in reducing the exposure of environmental receptors to contaminants (ASTM 2014). The CSM should be maintained and refined as new information and data is collected from the initial assessment through site closeout. Different types of CSM are common, including text documents and pictorial and graphical depictions of current and future site conditions. Parsons Corporation (2004) provides an example of the elements of a graphical CSM (Figure 9.38). Typical CSM information needs and other elements of a CSM for sites contaminated with unexploded ordnance and/or other hazardous, toxic, and radioactive waste is provided by the U.S. Army Corp of Engineers (2012).

FIGURE 9.38 Elements of a Conceptual Site Model.



Source: Parsons Corporation 2004.

9.12 Permeable Reactive Barriers

A permeable reactive barrier (PRB) is a subsurface emplacement of reactive materials through which a dissolved contaminant plume must move as it flows, typically under natural gradient conditions. Treated water exits on the other side of the PRB. This *in*

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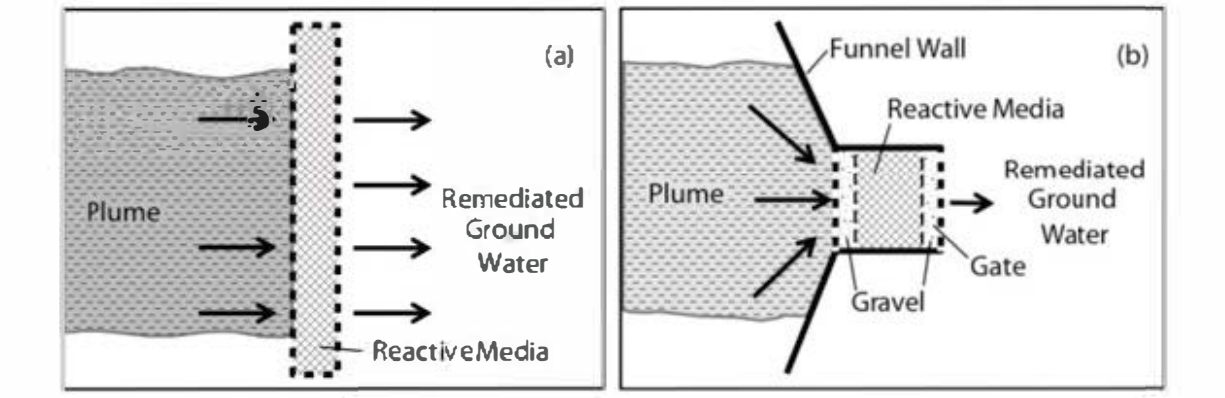
situ method for remediating dissolved-phase contaminants in groundwater combines a passive chemical or biological treatment zone with subsurface fluid flow management (U.S. EPA 2015d). The purpose of a PRB is to intercept a contaminant plume and prevent it from migrating to downgradient receptors, such as drinking water wells.

The concept of placing reactive materials in the path of a plume was developed based on observations by Reynolds et al. (1990). The authors noticed that at their field site concentration of dissolved chlorinated compounds were systematically lower in wells with galvanized iron casing compared to wells constructed from non-metallic pipe material. Laboratory experiments showed that metallic or zero valent iron (ZVI) reacted with the chlorinated compounds and degraded them to non-toxic products, such as ethane and ethane (Gillham and O'Hannesin 1994). The first field trial of a PRB was carried out by Gillham and O'Hannesin on the Canadian Air Force Base Borden, Ontario in 1991. A trench of up to 6 m (20 ft) in length and 2.5 m (8 ft) deep was excavated and backfilled with a mix of 22% of granular iron from a local foundry and 78% coarse sand. The total volume of the reactive matrix was 20 m^3. The groundwater flow velocity in the unconfined sandy aquifer at the site was 9 cm/day (0.3 ft/day). The groundwater concentration of TCE was 258 mg/L and 68 mg/L for PCE. After installation, approximately 90% of the TCE and 86% of the PCE were removed within this proto-type PRB system, with no measurable decrease in performance over the first five year duration of the test. All degradation intermediates, including *cis*-1,2-DCE, were degraded within the reactive barrier. Changes in water chemistry indicated that calcium carbonate was precipitating within the reactive material. However, the clogging caused by the precipitates was inconsequential for the performance of the system within the five year study period. The authors concluded that full removal would have been achieved by increasing the amount of ZVE (O'Hannesin and Gillham 1998). Since these early trials, more than 200 reactive barriers have been installed and PRB technology is now an accepted practice for groundwater remediation, particularly for the treatment of dissolved chlorinated VOC plumes (ITRC 2011).

In situ PRB systems are typically constructed by digging a continuous trench perpendicular to the flow direction of a groundwater plume (Figure 9.39). After excavation, the trench is backfilled with a mix of reactive material and coarse sand and gravel, which provides the mix with a hydraulic permeability and porosity that is greater than the surrounding natural sediments. The length and depth of the PRB is determined by the dimensions of the groundwater plume, i.e., the trench must be large enough to capture the entire plume in both horizontal and vertical direction. If possible, the trench is anchored in a less permeable stratum, such as a clay layer, to prevent the plume from diving under the treatment system. In some cases, funnel-and-gate PRB systems have been installed in which an impermeable barrier blocks the advancing plume and redirects (funnels) the flow of contaminated groundwater through an opening (gate) in the wall and into a PRB system (ITRC 2005a). A funnel-and-gate system is depicted in Figure 9.39. The length of PRB systems is limited by site conditions and typically ranges from a few meters to a few hundred meters. The depth, however, is limited by the equipment available to excavate the trench. Trenches excavated with conventional equipment, such a back hoes or chain trencher, are comparably shallow (10 to 15 m or 33 to ~50 ft). Depths of 20 m (66 ft) or more can be achieved by caisson installation or cofferdam/sheet pile methods. Alternatively, the reactive material can be mixed *in situ*

into the treatment zone or slurries of reactive materials can be directly injected into the subsurface. The cost of constructing the trench and backfilling it with reactive material is the major cost driver of this remediation technology.

FIGURE 9.39 Permeable reactive barrier (PRB) designs (map view).(a) Continuous trench and (b) Funnel-and-gate systems.



The thickness of the PRB wall is a critical design parameter. It depends on hydrogeologic factors, (such as groundwater flow velocities and flow directions which may change over the seasons), the strength and chemical make-up of the source zone including which contaminants are present and how much mass of dissolved contaminant must be treated, and the reactivity of the PRB material, including the geochemical conditions that can influence the reactive material, such as the pH of the groundwater. The reactivity of the material inside a PRB can be quantified in terms of a reaction rate constant or the half-life time of the contaminant coming in contact with the reactive material. Because some contaminants, including PCE and TCE, undergo sequential degradation, which involves the production of toxic intermediates, such as vinyl chloride, reaction rates for each compounds need to be taken into consideration. If the flowthrough thickness and contaminant residence time inside the PRB is underestimated, still-contaminated water will emerge on the downgradient side of the wall. It is therefore not surprising that extensive laboratory and field tests are required to ensure the field performance of a PRB system. A lot of practical information about the proper installation of PRB systems has been accumulated over the past two decades and many PRB installations manuals and guidance documents are available on the internet, including Gavaskar et al. (2000) and ITRC (2011).

Zero-valent iron based PRBs are most commonly used for the *in situ* treatment of chlorinated aliphatic VOC, such as PCE and TCE. The reactions involved in the degradation of chlorinated VOC by metallic iron (Fe^0) within a PRB are abiotic in nature. Zero valent iron is a mild reductant and can react with dissolved oxygen (Eqn. 9.1) and to some extent with water (Eqn. 9.2):

$$2Fe^0_{(S)} + 4H^+_{(aq)} + O_{2(aq)} \rightarrow 2Fe^{2+}_{(aq)} + 2H_2O \quad \textbf{(9.1)}$$

$$Fe^0_{(S)} + 2H_2O \rightarrow Fe^{2+}_{(aq)} + H_{2(aq)} + 2OH^-_{(aq)} \quad \textbf{(9.2)}$$

These two equations illustrate the corrosion (=oxidation) of iron when coming in contact with oxygen or water. The two electrons released during the oxidation of iron can be readily accepted by chlorinated hydrocarbons, which are degraded via reductive dehalogenation, as shown in Equation 9.3

$$\begin{aligned} Fe^0 &\rightarrow Fe^{2+} + 2e^- && \text{Oxidation} \\ RCl + 2e^- + H^+ &\rightarrow RH + Cl^- && \text{Reduction} \\ Fe^0 + RCl + H^+ &\rightarrow Fe^{2+} + RH + Cl^- && \text{Net Reaction} \end{aligned} \quad (9.3)$$

The products of the reductive dechlorination reaction are chloride (Cl^-), ferrous iron (Fe^{2+}), less chlorinated hydrocarbons, and hydrogen. Dechlorination of chloroethenes and chloroethanes is complete with ethene and ethane as the final carbon-containing compounds, respectively (Orth and Gillham 1996; Fennelly and Roberts 1998). The corrosion of the iron can generate large amounts of iron oxides and (oxy)hydroxide precipitates, which may eventually decrease the porosity and permeability of the reactive material within the PRB; particularly at the upgradient side of the barrier. However, these iron precipitates can convert to magnetite, which does not passivate the reactive surface of the iron. Also, field experiences from many PRB sites indicate that the loss of permeability due to precipitation is a relatively slow process that takes decades to cause significant changes in the hydraulic performance of the system. If installed properly, it is therefore likely that the dechlorination reaction is sustainable for many years of PRB operation (EPA 1998).

The degradation of chlorinated hydrocarbons by ZVI is a stepwise process during which intermediates are produced, such as *cis*-1,2-dicbloroethene, vinyl chloride or chloroacetylene in cases where the parent compound is TCE or PCE. The degradation reactions are typically described using pseudo first-order kinetics with respect to the halogenated hydrocarbon, with the rate constant relatively insensitive to the initial hydrocarbon concentration (IRTC 2011).

$$C = C_0^{-k't}$$

or:

$$\ln\left(\frac{C}{C_0}\right) = -k't$$

where C_0 and C are the concentrations of the chlorinated compound of the influent and at time t, respectively. The pseudo-first order rate constant is k, which equals the first order rate constant, k, when the concentration of the iron remains constant. Dehalogenation rates vary for the different halogenated contaminants. The primary determinant of degradation rate is the iron surface area, i.e., the surface area of iron per unit volume of pore water. For this reason, some PRB designs are based on nanoscale iron particles, which have larger surface areas and higher surface reactivity compared to conventional granular iron. Nanoscale iron particles range in size from approximately 10 to 100 nm and have a high iron content (>99.5% Fe) (Zhang 2003).

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The reaction rates can be enhanced further by coating the iron particles with metallic catalyst, such as palladium (Li and Farrel 2000). One advantage of nanoscale iron particles is that slurries of these particles can be injected directly into the treatment zone. This approach alleviates the need of excavating a trench and backfilling it with mixes of ZVI and highly permeable sand/gravel materials.

Dissolved chlorinated compounds were the first groundwater contaminants treated by *in situ* PRB systems using metallic iron as the reactive material. Since then, the list of ZVI treatable compounds has rapidly expanded and now includes many other organic and inorganic contaminants (Table 9.2). For instance, metallic iron can transform explosives, such as TNT (Johnson and Tratnyek 2008), and pesticides, e.g., Lindane (U.S. EPA 2002) or can immobilize inorganic ions, such as arsenic (VI) and chromium (VI). Particularly metals that occur as anions exhibit a high degree of mobility because anions do not readily sorbed to the predominantly negatively-charged aquifer materials. For example, chromium (VI) is usually speciated as chromate, CrO_4^{2-}, which is a known carcinogen. The anion is comparably soluble under typical near-neutral pH and only slightly negative Eh conditions in typical aquifers. However, when reduced to trivalent Cr(III), relatively non-toxic and little soluble precipitates are formed. The immobilization of Cr(VI) by iron is a two-step process: first, Cr(VI) is reduced to Cr(III) (Eqn. 9.4). Subsequently, the Cr(III) precipitates as Fe(III) oxyhydroxide (Eqn. 9.5) (U.S. EPA 1998):

$$CrO_4^{2-} + Fe^0 + 8H^+ \rightarrow Fe^{3+} + Cr^{3+} + 4H_2O \quad \textbf{(9.4)}$$

$$(1-x)Fe^{3+} + (x)Cr^{3+} + 2H_2O \rightarrow Fe_{(1-x)}Cr_xOOH_{(s)} + 3H^+ \quad \textbf{(9.5)}$$

The mechanisms of Cr(VI) reduction by Fe(0) and their effects on the pH and Eh conditions of the system have been described by Powell et al. (1995) and Powell and Puls (1997). At some sites, Cr(VI) occurs together with other contaminants, such as TCE. Research has shown that it is possible to simultaneously treat both chromium and TCE with ZVI (U.S. EPA 1998).

While ZVI remains the most widely used reactive material used in PRB systems, an increasing number of new reactive materials and variations of the PRB based treatment approach are being developed and tested. These advances are greatly expanding the number of treatable groundwater contaminants. They also make it possible to apply this technology to hydrogeologic environments other than the unconsolidated aquifers for which PRB was initially developed. For example, a fractured bedrock aquifer comprised of shale and siltstone is contaminated with PCE at a manufacturing plant in northern New Jersey, USA (U.S. EPA 2011b). The main source area is located in shallow bedrock to a depth of approximately 13 m (42.5 ft) below ground surface, with some contamination in deeper parts of the aquifer. The lateral extent of the PCE plume is approximately 25 m (80 ft) by 37 m (120 ft). The plume was approximately 1.2 km (4,000 ft) in length prior to treatment. A pump-and-treat system and later, an enhanced bioremediation system were installed for containment of the PCE plume. After observing some reduction of contaminant flux, a nanoscale zero-valent iron injection was proposed as a more aggressive strategy. Before the injection of the nanoscale particles into the bedrock, the hydraulic communication within the fracture network was improved by hydrofracturing. This technology involves applying

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TABLE 9.2 Common environmental contaminants that can be transformed by ZVI, including bimetallic and nanoscale iron particles.

Chlorinated methanes	Chlorinated ethenes/ethanes	Chlorinated benzenes	Trihalomethanes
Carbon tetrachloride (CCl_4)	Tetrachloroethere (C_2Cl_4)	Hexachlorobenzene (C_6Cl_6)	Bromoform ($CHBr_3$)
Chloroform ($CHCl_3$)	Trichloroethene (C_2HCl_3)	Pentachlorobenzene (C_6HCl_5)	Dibromochloromethane ($CHBr_2Cl$)
Dichloromethane (CH_2Cl_2)	*cis*-Dichloroethene ($C_2H_2Cl_2$)	Tetrachlorobenzenes ($C_6H_2Cl_4$)	Dichlorobromomethane ($CHBrCl_2$)
Chloromethane (CH_3Cl)	*trans*-Dichloroethene ($C_2H_2Cl_2$)	Trichlorobenzenes ($C_6H_3Cl_3$)	
	1,1-Dichloroethene ($C_2H_2Cl_2$)	Dichlorobenzenes ($C_6H_4Cl_2$)	
	Vinyl chloride (C_2H_3Cl)	Chlorobenzene (C_6H_5Cl)	
	1,1,1-trichloroethane ($C_2H_3Cl_3$)		
	1,1,2-trichloroethane ($C_2H_3Cl_3$)		
	1,1-dichloroethane ($C_2H_4Cl_2$)		
Otherpolychlorinated hydrocarbons	Pesticides	Organic dyes	Other organic contaminants
Dioxirs	DDT ($C_{14}H_9Cl_5$)	Orange II ($C_{16}H_{11}N_2NaO_4S$)	TNT ($C_7H_5N_3O_6$)
Pentachlorophenol (C_6HCl_5O)	Lindane ($C_6H_6Cl_6$)	Chrysoidine ($C_{12}H_{13}ClN_4$)	RDX ($C_3H_6N_6O_6$)
PCBs		Tropaeolin O ($C_{12}H_9N_2NaO_5S$)	N-nitrosodimethylamine (NOMA) ($C_4H_{10}N_{20}$)
		Acid Orange	
		Acid Red Arsenic (AsO_3^{-4})	
Heavy metal ions	Radiogenic ions	Inorganic ions	
Mercury (Hg^{2+})	Uranium (UVI)	Perchlorate (ClO^{-4})	
Nickel (Ni^{2+})	Technetium (Tc VII)	Nitrate (NO^{-3})	
Silver (Ag^{+})		Dichromate ($Cr_2O_2^{-7}$)	
Cadmium (Cd^{2+})		Selenium (Se IV)	
		Arsenic (As VI)	

Source: Modified after Zhang 2003 and U.S. EPA 1998.

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high hydrostatic pressures to the well wall until the solid bedrock fractures. The newly opened fractures permit enhanced injection and farther reach of the nanoparticle slurry into the bedrock. Following hydrofracturing, approximately 800 pounds of nanoscale iron particles was delivered through four injection wells. Performance monitoring of the ZVI injection indicated significant impacts on source area geochemistry, including increased pH levels (~9) and low ORP values (-500 mV). Although it is likely that the iron particles did not reach all contaminated areas of the bedrock aquifer, it appears that amount of injected iron was sufficient to control both the primary PCE source and any back diffusion from the shale and siltstone matrix.

Innovative reactive materials for PRB include surfactant-modified zeolites, metal hydroxides or carbonates, organoclays, peat moss, mulch, compost and agricultural waste products (Thiruvenkatachari et at. 2008). Zeolites are clay minerals that have an elevated permeability (for a clay) and a high capacity for cation exchange. When coated with non-ionic surfactants, the surface of the zeolites becomes more hydrophobic, which makes it attractive to non-polar organic compounds. When modified with cationic surfactants, the zeolite surface has a positive charge and hence a greater affinity for anions, such as dissolved chromate (Bowman 2003; Misaelides 2011). Surfactant modified zeolites retain some of their cation ion exchange capacity. Peat moss has an affinity for both heavy metal ions, such as nickel or uranium and anions, e.g., chromate. Compounds like mulch or agricultural waste products used in PRBs are intended to be long-term sources of organic carbon or, in case of compost, serve as a source of nutrients (IRTC 2011). For instance, Lu et al. (2008) investigated the performance of pilot-scale permeable reactive barrier filled with plant mulch that was installed at Altus Air Force Base in Oklahoma, USA in 2002. The barrier was 139 m long (~450 ft), 7 m deep (~2 m), and 0.5 m (1.6 ft) wide and was constructed to treat trichloroethylene (TCE) contamination in groundwater emanating from a landfill. Data from over four years' monitoring indicated that the PRB stimulated TCE degradation to cis-DCE and vinyl chloride. Ongoing biodegradation reactions were corroborated by the detection of TCE degrading bacteria DNA (*Dehalococcoides*) and the detection of vinyl chloride within and downgradient of the PRB.

Systems like the one described by Lu et al. (2008) are also called biowalls or bio barriers. These *in situ* biowalls use solid low-cost organic materials, such as mulch or compost, to stimulate anaerobic degradation of chlorinated solvents, energetic (e.g., perchlorate) and explosive compounds (e.g., TNT, anions (nitrate and sulfate), and heavy metals (e.g., chromium and cadmium). Biowall materials can be amendment with, for example, emulsified vegetable oil, to stimulate both biotic and abiotic degradation processes. This permits to optimize biowall performance based on the type of contaminant(s) present and the desired degradation pathway(s) to be stimulated (Air Force Center for Engineering and the Environment 2008). Typically, biowalls stimulate anaerobic degradation processes, including reductive dechlorination and biotic anaerobic oxidation, and therefore are most often used for treating dissolved chlorinated compounds like PCE and TCE and their degradation products (DCE isomers and vinyl chloride). According to the ITRC (2011), an advantage of biological PRB systems over purely abiotic systems, such a ZVI, is that the treatment processes may extend downgradient of the constructed treatment zone due to migration of soluble organic carbon, enabling the effects of anaerobic degradation beyond the biowall. In addition,

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the biowall system can be amended with specific bacteria (bioaugmentation) to target one or multiple contaminants and accelerate their degradation. A drawback is that the longevity of biowalls is anticipated to be shorter than that of ZVI walls and replenishment of organic substrate may be required.

The geochemistry of the solution inside a PRB system and downgradient can be adjusted by materials to buffer pH (e.g., limestone gravel) or to adjust the redox potential and further stimulate abiotic biogeochemical transformation processes (e.g., addition of reactive iron sulfite minerals, such as pyrite or mackinawite). The redox conditions in the treatment zone can also be manipulated by injecting sodium dithionite solution. The dithionate reduces ferric iron (Fe III) that is naturally present in the aquifer material to ferrous iron (Fe II). The presence of Fe(II) in the treatment zone can reduce, for example, soluble Cr(VI) to Cr(III) precipitates (Naltz et al. 2002). Also, the injection of oxidants, like hydrogen peroxide (H_2O_2) or potassium permanganate ($KMnO_4$) into the PRB can create strongly oxidizing conditions that are suitable for the *in situ* chemical oxidation and destruction of many organic contaminants, including BETX and other petroleum hydrocarbons (Thiruvenkatachari et at. 2008). Finally, sorbing barriers systems have been developed which use granular activated carbon or ion exchange materials. However, these systems have a limited live time and need to be replacement when the capacity of the sorbent is exhausted.

There now are a great variety of the reactive materials and amendments that permit tailoring the PRB treatment to specific contaminants, including once that cannot be treated with the original ZVI approach, e.g., BTEX compounds. Barriers of different chemistries may also be placed sequentially which further increases the treatment options for contaminated site managers. It is likely that future research into PRB system will further enhance the applicability of this remediation approach.

■ 9.13 Chemically-Enhanced *In Situ* Flushing

Some chemicals, such as surface active agents (surfactants), complexing agents (cyclodextrins) or cosolvenrs (alcohols), can increase the solubility of otherwise slightly soluble hydrophobic organic contaminants, such as petroleum hydrocarbons or chlorinated solvents. In case of some metals or ionic organic contaminants, a similar solubility enhancing effect can be achieved by injecting acidic, basic, or reducing solutions. When injected into the aquifer and flushed through the contaminated source zone, these solubility enhancing agents increase the aqueous phase concentration of the contaminants, sometimes by orders of magnitude. After its passage through the treatment zone, the flushing solution is extracted and treated at the surface. Therefore, in its most basic form, chemically-enhanced flushing technology can be considered an enhancement of pump-and-treat in which water is the flushing solution. Compared to P&T, chemically-enhanced flushing is a much more aggressive and relatively rapid treatment approach with treatment durations often an order or two magnitudes shorter than P&T (ITRC 2009a).

In situ flushing is considered a mature remediation technology. The chemically-enhanced flushing approach is used predominantly to remediate source zones, particularly residual NAPL compounds. It is less well suited for the treatment of dissolved plumes or contaminants residing in the unsaturated zone. Flushing is most efficient in relatively homogeneous and permeable (hydraulic conductivity >10^{-3} cm/sec) soil

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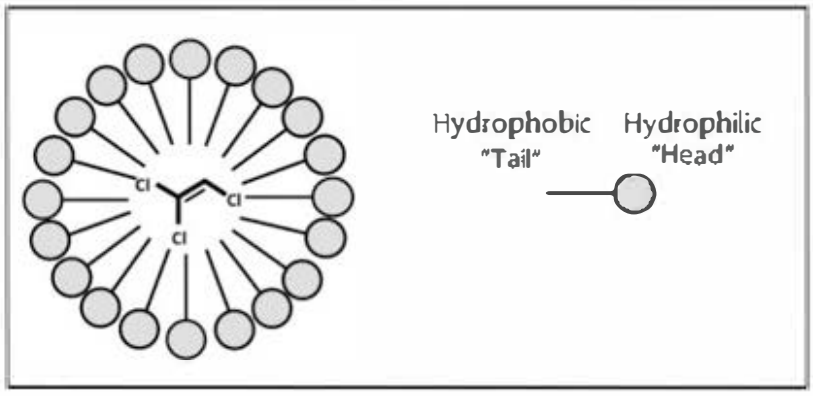
(Naval Facilities Engineering Command 2002). Heterogeneous aquifer conditions, including fractured bedrock aquifers, typically stand in the way of effectively flooding the treatment zone because lower permeable zones may be bypassed. Chemically-enhanced flushing is sometimes used in combination with other *in situ* remediation technologies, such as bioremediation or *in situ* oxidation (e.g., Dugan et al. 2010). Although their effect on the solubility of contaminants is similar, there are major differences between surfactant, cosolvent, or complexing agents. The following sections provide a brief overview of these agents. One disadvantage is that field applications typically have limited areal extent. For further readings, there have been a great number of papers, books, and manuals written about these flushing agents (e.g., Keuper et al. 1997; Lowe et al. 1999; Ward et al. 2000; Boving and Brusseau 2000; Naval Facilities Engineering Command 2002; 2003; ITRC 2003; Pennel et al. 2014).

9.13.1 Surfactant Enhanced *In Situ* Flushing

Surfactants are amphiphilic organic molecules that have both hydrophobic and hydrophilic moieties. When dissolved in water, surfactant molecules tend to cluster together and form micelles (Figure 9.40). These micelles aggregate when a specific threshold, known as critical micellar concentration (CMC), is exceeded. In water, the hydrophilic "heads" of the dissolved surfactant molecules point towards the aqueous phase, assuring that surfactants are highly water soluble. The hydrophobic "tails" of the surfactant molecule project inside the micelle. The "heads" and "tails" of surfactant molecules are typically separated by hydrocarbon chains. The non-polar core of these micelles attracts equally non-polar compounds, like TCE or other chlorinated solvents. This partitioning of hydrophobic contaminants into the micelle structure is the basis of the surfactant enhanced flushing technology, which is also referred to as Surfactant Enhanced Aquifer Remediation (SEAR). The enhancement of contaminant solubility is directly proportional to the concentration of the surfactant above the CMC.

Surfactants also reduce the interfacial tension between the aqueous and NAPL phases. At very low interfacial tensions, larger globules of NAPL spontaneously break

FIGURE 9.40 Surfactants are amphiphilic compounds; they have both hydrophobic and hydrophilic moieties. Above the critical micelle concentration, surfactant molecules aggregate into micelles. Hydrophobic contaminants (TCE shown here) can partition into the hydrophobic interior of the micelle.



up into tiny droplets of about 5 to 50 nm in radius. At that point, the system consists of water, NAPL droplets and surfactants and is called a microemulsion. The reduction in interfacial tension and formation of microemulsions can be exploited to mobilize NAPL. Relative to surfactant enhanced solubilization, NAPL mobilization can remove more contaminant mass in less time. But, in case of DNAPL, there is greater risk of uncontrolled downward movement, as DNAPL is being physically displaced by the surfactant solution. When injecting surfactant solution with the primary purpose of inducing mobilization, it is therefore necessary to prevent vertical DNAPL migration. This can either be achieved by having competent bedrock or a capillary barrier underlying the treatment zone or by manipulating the density the DNAPL, for example, by co-injection of cosolvents. Because of the risk of vertical displacement, mobilization flooding should only be considered when there is a high degree of certainty that the flushing solution can be recovered. In general, a surfactant flushing system can be tailored to remove contaminants either primarily by solubilization or primarily by mobilization (Pope 2015). Under appropriate site conditions, removal rates as high as 98.5% of the original DNAPL mass have been reported (Londergan et al. 1997). A number of very well documented field tests have demonstrated that *in situ* flushing can achieve these high removal percentages in months, and sometimes even days (EPA 2000).

Surfactants are produced at industrial scales and are one of the most widely used chemicals. Many different kinds of surfactants have been developed for a large number of applications, including detergents, fire-fighting agents (see Chap. 5) or pharmaceuticals and cosmetics. Depending on the charge of their polar heads, surfactant can be non-ionic., cationic or anionic. For most remediation applications, non-ionic or anionic surfactants are preferred because they do not sorb as strongly to the charged surfaces of natural minerals (i.e., clays) as cationic surfactants. Also, they are generally less toxic than cationic surfactanrs.

Case Study: Hill Air Force Base, Utah.

The Hill Air Force Base is located near Ogden, Utah, USA. The test site was used continuously from 1967 until 1975 for base-wide disposal of spent degreasing fluids and other solvents. At the site, DNAPL pooled within the topographic lows of a clay aquitard approximately 15 to 17 m (50 to 56 ft) below ground surface. The DNAPL was composed of approximately 70% TCE, 10% PCE, 5% TCA with other minor volatile organic constituents. In addition, there was a significant oil and grease fraction entrained in the DNAPL. The groundwater contaminants included PCE, TCE, TCA, DCE and trace heavy metals. The depth to groundwater was 8.3 m (27 ft). The unconfined aquifer consists of alluvial sands and gravel. The deposits are highly heterogeneous and are underlain by a thick uniform and continuous clay layer. The effective porosity of the aquifer is 20% and its hydraulic conductivity is 6×10^{-3} to 5×10^{-2} cm/sec (17 ft/day to 146 ft/day).

Prior to the surfactant flooding, a DNAPL source-recovery system was installed. Partitioning interwell tracer tests (PITT) were conducted pre- and post- surfactant flooding to characterize the DNAPL distribution and to demonstrate the removal efficiency of the surfactant treatment. The flushing solution injected into the treatment zone consisted of 8% an anionic surfactant (Aerosol MA-80I) and 4% isopropyl alcohol. About 0.7% of sodium chloride was added to adjust the ionic strength of the mixture. The solution decreased the interfacial tension between the surfactant solution and the DNAPL to 0.02 dynes/cm. About 2.4 pore volumes of the flushing solution were injected during a 3 day period, followed by 5.5 days

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compounds by self-sustaining smoldering processes (Switzer et al. 2009; Pironi et al. 2009). This approach is commercialized as self-sustaining treatment for active remediation (STAR) technology.

ISTT field applications are growing in number, partially because clean up goals can be achieved quickly, often within days or weeks. ESTCP (2010) provides a critical evaluation of 182 ISTT applications conducted between 1988 and 2007. Of those 182 applications, 87 used electrical resistance heating, 46 steam-based heating, 26 conductive heating, and 23 other heating technology applications. Measured in terms of reducing contaminant concentration and mass flux from the treatment zone, improvements ranged from less than 10 to over 1000 times. Overall, the electrical resistance heating and thermal conductive heating variants of ISTT are less affected by heterogeneous and low-permeability lithologies (EPA 2014a), which is why *in situ* thermal technology performance appears less hindered by the geologic stratification and mass-transfer resistances that limit other *in situ* remediation technologies (Triplett Kingston, Dahlen, and Johnson 2010).

9.15 *In situ* Chemical Oxidation (ISCO)

In situ chemical oxidation (ISCO) refers to a groundwater remediation technology that relies on the chemical oxidation of a wide variety of dissolved contaminants by strong oxidants, such as permanganate (MnO_4^-), hydrogen peroxide (H_2O_2), ozone (O_3), catalyzed hydrogen peroxide (Fenton oxidation), persulfate ($S_2O_8^{2-}$), peroxone (H_2O_2 and O_3), or percarbonate. The reactive species and other properties of common oxidants are summarized in Table 9.4. Relative to each other, ozone and persulfate are stronger oxidants than permanganate and hydrogen peroxide. Fenton's reagent produces a variety of oxidizing species of different strengths.

An ISCO treatment system is similar to *in situ* enhanced flushing systems, except that generally no extraction well(s) is required. A solution of the oxidant in water is prepared on the site and then injected into the subsurface. Vertical injection wells and direct push probes are the most common delivery methods. As the oxidant solution moves through the treatment zone it comes into contact with the contaminant and degrades it into benign compounds, including carbon dioxide and water. The oxidant concentration and the amount of oxidant mass injected into the treatment zone must be determined beforehand based on the initial soil and groundwater contaminant concentrations. Also, natural organic matter (NOM) or reduced minerals, carbonate, and other free radical scavengers in the subsurface can reduce the amount of oxidant available to degrade the target compounds. Thus, the amount of ISCO reagent that can be potentially wasted on oxidant consuming compounds must be included into the oxidant dose calculations. This natural oxidant demand is an important ISCO design parameter and failure to consider it will influence the treatment performance and cost of the ISCO system. However, there is little advantage in an "over injection of oxidant" approach because there is the potential to enhance the release and migration of the target contaminants, generate excessive heat, and form undesired by-products, including precipitates (NRC 2005b; IRTC 2005; Siegrist et al. 2011).

Oxidizing agents like sodium or potassium permanganate, persulfate and percarbonate are solids, whereas hydrogen peroxide is a liquid and ozone is a gas. Because

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TABLE 9.4 Common oxidants and their most important oxidant reactions, including persistence and electrode potentials of the reactive species involved. Reduction potential is negative.

Oxidant	Reactive Species	Reactions	Persistence*	Electrode Potential (Eh)
Permanganate	Permanganate ion (MnO_4^-)	$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_{2(solid)} + 2H_2O$ ($3.5 < pH < 12$)	>3 months	1.7 V
Hydrogen peroxide	Hydrogen peroxide (H_2O_2)	$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$	min.-hrs	1.8 V
Ozone	Ozone (O_3)	$O_3 + 2H^+ + 2e^- \rightarrow O_2 + 2H_2O$	min.-hrs	2.1 V
	Hydroxyl radical ($^{\bullet}OH$)	$2O_3 + 3H_2O \rightarrow 4O_2 + 2\,^{\bullet}OH + 2H_2O$		2.8 V
Fenton's (catalyzed hydrogen peroxide)		$Fe_2^+ + H_2O_2 \rightarrow Fe^{3+} + {}^{\bullet}OH + OH^-$ (initiation rxn)		
	Hydroxyl radical ($^{\bullet}OH$)	$2\,^{\bullet}OH + 2H^+ + 2e^- \rightarrow 2H_2O$		2.8
	Perhydroxyl radical ($^{\bullet}OH_2$)	$^{\bullet}OH_2 + 2H^+ + 2e^- \rightarrow 2H_2O$		1.7
	Superoxide radical ($^{\bullet}O_2$)	$^{\bullet}O_2 + 4H^+ + 3e^- \rightarrow 2H_2O$		−2.4 V
	Hydroperoxide anion (HO_2^-)	$HO_2^- + H_2O + 2e^- \rightarrow 3OH^-$		−0.9 V
Persulfate ($S_2O_8^{2-}$)	Persulfate ($S_2O_8^{2-}$)	$S_2O_8^{2-} + 2e^- \rightarrow 2\,^{\bullet}SO_4^{2-}$ (initiation rxn)	hrs-weeks	2.1 V
	Sulfate radical ($^{\bullet}SO_4^-$)	$^{\bullet}SO_4^- + e^- \rightarrow SO_4^{2-}$		2.6 V
Activated Persulfate ($S_2O_8^{2-}$)		$S_2O_8^{2-} + \text{Heat}^* \rightarrow 2\,^{\bullet}SO_4^-$ (initiation rxn)	min-weeks	2.1 V
	Sulfate radical ($^{\bullet}SO_4^-$)	$2\,^{\bullet}SO_4^- + 2H_2O \rightarrow 2HSO_4^- + 2\,^{\bullet}OH$		2.6 V
	Hydroxyl radical ($^{\bullet}OH$)	$2\,^{\bullet}OH + 2H^- + 2e^- \rightarrow 2H_2O$		2.8 V

* Literature values and estimates.

* Other persulfate activators: Fe^{2+}, elevated pH >10.5 and peroxone (H_2O_2 and O_3).

Source: Huling and Pivetz (2006); ITRC 2005b.

ozone is inherently unstable, it must be produced at the site immediately before injection into subsurface. Permanganate salts might be delivered to the site in form of an aqueous solution. Most oxidants are hazardous chemicals that must be handled properly by trained field personnel.

ISCO treatment is applicable to variety of contaminants; however, chlorinated solvents are by far the most commonly treated ones. In an analysis of ISCO field applications and performance data, Krembs et al. (2010) found that of 223 sites analyzed, 70% treated chloroethenes and 8% chloroethanes. Other commonly treated contaminants include chlorobenzenes, BTEX and other petroleum hydrocarbons, incl. PAH and gasoline additives (MTBE). About 54% of sites contained NAPL. In general, fuel-related compounds, particularly MTBE, can be treated more effectively relative to chlorinated compounds. However, a number of organic compounds (e.g., PCB or perfluorinated flame retardants) are resistant or even impossible to treat with currently existing ISCO methods. Therefore, the development of advanced oxidation processes is an area of ongoing research.

ISCO is a comparably aggressive contaminant mass-reduction technology and primarily applied to NAPL source zones and groundwater plumes with high dissolved contaminant concentrations. ISCO has been implemented at sites with varied subsurface conditions, ranging from unconsolidated permeable and homogeneous materials to fractured bedrock environments. Generally, ISCO is a relative rapid treatment process that can achieve treatment goals within weeks or months. However, a comparably small percentage of ISCO treatments met pre-defined remediation goals, such as maximum contaminant levels (MCL) (Krembs et al. 2010). This may signify that remediation practitioners overestimated the performance of ISCO or underestimated the impact of site conditions on this technology.

Of the ISCO projects reviewed by Krembs et al. (2010), 89% combined the use of ISCO with other *in situ* remediation technologies. For instance, ISCO has been coupled with surfactants/cosolvents enhanced DNAPL removal, either in sequence or simultaneously (Dugan et al. 2010). Similarly, Eberle et al. (2017) reports on a pilot-scale field project where activated persulfate oxidant was used in combination with cyclodextrin, an enhanced solubilization agent discussed in Section 9.12. The advantage of combining the two treatment approaches is that the enhanced solubilization agent increases the mass of contaminant in solution and thereby makes it available for destruction by the oxidizing agent. This *in situ* "treatment train" approach, when performed as designed, can eliminate the need for extracting and *ex situ* treatment of contaminated liquids. Also, there is ample field site evidence that microbial populations are not permanently reduced by ISCO. In fact, it appears that microbial populations even flourish after ISCO treatment, which permits coupling ISCO with enhanced bioremediation or monitored natural attenuation (MNA) technologies (NRC 2005).

9.16 Phytoremediation

Phytoremediation is a set of technologies that rely on plants and their associated microorganisms to sequester, extract, or degrade toxic compounds in groundwater, soils, sediment and surface water. Because it is a natural process, phytoremediation can be an effective remediation method for a variety of sites and contaminants,

at a reduced rate. A large number of plants have been evaluated for potential use in phytoremediation applications. The selection of one or more plant species is based on factors such as ability to extract or degrade the contaminants of concern, adaptation to local climates, high biomass, depth root structure, compatibility with soils, growth rate, ease of planting and maintenance, and ability to take up large quantities of water through the roots (U.S. EPA 2012c). Recent developments in transgenic plant research may lead to a greater selection of plant varieties or the treatment of contaminants currently not possible (Lee 2013). The duration of the treatment generally depends on the type and initial contaminant concentration, its distribution within the treatment zone, plant selection and their growth rate, hydrogeologic and climatologic conditions, and other site characterisrics.

Phytoremediarion has become an alternative to other, more aggressive cleanup technologies because of relatively low capital costs and the inherently aesthetic nature of planted sites. However, this treatment technology is not a "Do something quick and cheap in the fiield and then walk away" approach. Like any remediation system, phytoremediation requires significant operation, maintenance, and monitoring for several years after planting. For instance, plants may require irrigation, fertilization, weed and pest control or replanting (ITRC 2009).

9.17 Summary

There is great interest in developing effective and efficient methods of remediating contaminated soils and groundwater in order to meet the mandates of public concern and federal legislation such as RCRA and CERCLA in the United States.

In order to have a successful remediation, it is necessary to first isolate or remove the source of the contamination. Sources can include hazardous wastes spread on the land or improperly buried in the earth, leaking landfills, leaking underground storage tanks, or soils that have become contaminated by accidental spills and leaks. If it is not possible to remove sources, they can be isolated by physical barriers, such as slurry walls and impermeable covers or by hydrodynamic barriers created by pumping and injection wells.

While not very effective, contaminated groundwater can be pumped from the ground and treated. Pump-and-treat technologies can be effectively used to hydraulically control plumes. Before initiating a pump-and-treat program, any mobile NAPL present should be removed. Floating NAPLs can be removed by multiphase extraction pumps located in wells. Residual NAPL and contaminants sorbed onto mineral surfaces and soil organic carbon will slowly partition into the clean groundwater that replaces the contaminated groundwater removed by pumping. This will greatly prolong the period of time that it takes to remediate the aquifer. If all the residual contamination is not removed from the aquifer, the concentration of contaminants will increase after the termination of a pump-and-treat operation. It may be impossible to remediate sites contaminated with DNAPLs by conventional pump-and-treat methods. Such aquifers might require permanent plume-stabilization wells to prevent the spread of the plume, or need to be remediated with more advanced technologies.

Water that is extracted from the aquifer can be treated to remove both organic and inorganic contaminants. Methods of treatment of dissolved organics include

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air stripping and carbon absorption. Underground tanks that are leaking should be removed and replaced. Soil and groundwater remediation is frequently necessary after a leaking tank has been removed.

Vadose zone soil contaminated by residual volatile organic compounds (VOC) can be remediated by soilvapor extraction systems. Air, containing organic vapors, is drawn from the soil pores via SVE wells in the vadose zone and replaced with fresh air. Some methods exist that combine pumping water for treatment with soil vapor extraction to treat contaminated soil and groundwater simultaneously.

Soil and groundwater contaminated by organic compounds may be amenable to bioremediation by both aerobic and anaerobic microbes. Electron acceptors and/or donor may be added to the soil or aquifer to encourage microbial activity. *In situ* bioremediation and related monitored natural attenuation (MNA) processes have the advantage of treating the contaminants dissolved in soil and groundwater at the same time as residual contaminants in the soil.

Permeable Reactive Barriers (PRB) are linear structures placed in the path of an advancing groundwater plume. Reactive materials inside the PRB, such as metallic iron, interact with the dissolved contaminants and degrade or immobilize them. PRBs are passive treatment systems because no pumping is required.

Chemically-enhanced *in situ* flushing technology relies on chemicals that enhance the solubility and, in some case, mobility of NAPL compounds in the subsurface. The primary objective of this remediation technology is to remove the maximum amount of contaminant with a minimum amount of chemicals and in minimal time while maintaining hydraulic control over the injected chemicals and contaminant. This approach requires injection and extraction wells with above ground treatment of the extracted liquids.

During thermal *in situ* treatment, heat is delivered to the treatment zone to volatize, displace, or destroy amendable contaminants in the subsurface. Convection and conduction heat sources have been tested and found effective for remediating a variety of contaminants, including some that are not treatable with other methods. However, high temperature necessary to destroy those compounds can also affect the soil properties. Thermal treatment is typically combined with SVE systems to capture volatilized compounds. New approaches include subsurface controlled, contaminant burning, or smoldering techniques.

In situ oxidation relies on strong oxidants that, when injected into the treatment zone, degrade organic contaminants. This aggressive remediation approach typically does not require the extraction of contaminated liquids from the subsurface and is applicable to a large number of organic compounds.

Phytoremediation takes advantage of green plants and their ability to take up, transform or volatilize a number of metal and organic contaminants. While limited to relatively low soil and groundwater contaminant concentrations, and typically requiring many growing seasons to achieve clean up goals, phytoremediation is a green technology.

While great advances have been made in the field of remediation over the past decades, many contaminants and site-settings, particularly fractured bedrock aquifers, remain difficult or impossible to treat with current methods. Hence, this topic will remain an area of active research for many years.

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Chapter Notation

B	Uniform thickness of a confined aquifer
Bgs	Below ground surface
C	Concentration
Co	Initial concentration
U	Regional specific discharge (Darcy velocity)
Q	Pumping rate of plume-capture well
d	Distance between extraction wells
k	Pseudo-first order rate contestant
x	Distance along the x axis
y	Distance along the y axis
$h_0—h$	Drawdown
T	Aquifer transmissivity
S	Aquifer storativity
R	Radius of a pumping well
t	Time since pumping began

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DOCUMENT 10

TITLE 35: ENVIRONMENTAL PROTECTION
SUBTITLE G: WASTE DISPOSAL
CHAPTER I: POLLUTION CONTROL BOARD
SUBCHAPTER j: COAL COMBUSTION WASTE SURFACE IMPOUNDMENTS

PART 845
STANDARDS FOR THE DISPOSAL OF COAL COMBUSTION RESIDUALS IN SURFACE IMPOUNDMENTS

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AUTHORITY: Implementing Sections 12, 22, and 22.59 of the Environmental Protection Act [415 ILCS 5/12, 22, and 22.59] and authorized by Sections 22.59, 27, and 28 of the Environmental Protection Act [415 ILCS 5/22.59, 27, and 28].

SOURCE: Adopted in R20-19 at 45 Ill. Reg. 5884, effective April 21, 2021.

SUBPART A: GENERAL PROVISIONS

Section 845.100 Scope and Purpose

a) This Part establishes criteria for determining which CCR surface impoundments do not pose a reasonable probability of adverse effects on health or the environment. CCR surface impoundments failing to satisfy any of the requirements of this Part are considered open dumps, which are prohibited under Section 21(a) of the Act.

b) This Part applies to owners and operators of new and existing CCR surface impoundments, including any lateral expansions of CCR surface impoundments that dispose of or otherwise engage in solid waste management of CCR generated from the combustion of coal at electric utilities and independent power producers. Unless otherwise provided in this Part, these requirements also apply to CCR surface impoundments located off-site of the electric utility or independent power producer.

c) This Part also applies to inactive CCR surface impoundments at active and inactive electric utilities or independent power producers, regardless of the fuel currently used at the facility to produce electricity.

d) Except as provided in Section 845.170, inactive CCR surface impoundments are subject to all the requirements of this Part applicable to existing CCR surface impoundments.

e) This Part does not apply to wastes, including fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated at facilities that are not part of an electric utility or independent power producer, such as manufacturing facilities, universities, and hospitals. This Part also does not apply to fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated primarily from the combustion of fuels (including other fossil fuels) other than coal, for the purpose of generating electricity unless the fuel burned consists of more than 50% coal on a total heat input or mass input basis, whichever results in the greater mass feed rate of coal.

f) This Part does not apply to the beneficial use of CCR.

g) This Part does not apply to CCR placement at active or abandoned underground or surface coal mines.

h) This Part does not apply to landfills that receive CCR.

i) If a CCR surface impoundment has completed an Agency-approved closure before April 21, 2021, this Part does not require the owner or operator of the CCR surface impoundment to resubmit to the Agency any closure plan, closure report, or closure certification for that completed closure.

j) Upon completion of an Agency-approved closure, the CCR surface impoundment is considered a CCR surface impoundment that has completed closure for purposes of fee applicability under Section 22.59(j) of the Act.

Section 845.110 Applicability of Other Regulations

a) Compliance with the requirements of this Part does not affect the need for the owner or operator of a CCR surface impoundment, or lateral expansion of a CCR surface impoundment, to comply with all other applicable federal, state, tribal, or local laws or other requirements.

b) Any CCR surface impoundment or lateral expansion of a CCR surface impoundment is subject to the following requirements:

1) Illinois Endangered Species Protection Act [520 ILCS 10] and 40 CFR 257.3-2.

2) Surface Water

A) A facility must not cause a discharge of pollutants into waters of the United States that is in violation of the requirements of the National Pollutant Discharge Elimination System (NPDES) under section 402 of the Clean Water Act.

B) A facility must not cause a discharge of dredged material or fill material to waters of the United States that is in violation of the requirements under section 404 of the Clean Water Act, as amended.

C) A facility or practice must not cause non-point source pollution of waters of the United States that violates applicable legal requirements implementing an areawide or statewide water quality management plan that has been approved by USEPA under section 208 of the Clean Water Act, as amended.

D) Definitions of the terms "discharge of dredged material", "point source", "pollutant", and "waters of the United States" can be found in the Clean Water Act, as amended (33 USC 1251 et seq.) and implementing regulations, specifically 33 CFR 323 (42 FR 37122, July 19, 1977).

E) Except as in compliance with the provisions of the Act, Board regulations, and the CWA, and the provisions and conditions of the NPDES permit issued to the discharger, the discharge of any contaminant or pollutant by any facility into the waters of the State from a point source or into a well will be unlawful.

3) Rivers, Lakes and Streams Act [615 ILCS 5/23 and 23(a)] and 17 Ill. Adm. Code 3702.

Section 845.120 Definitions

Except as stated in this Section, or unless a different meaning of a word or term is clear from the context, the definition of words or terms in this Part will be the same as that applied to the same words or terms in the Environmental Protection Act:

"1000-year flood" means a flood of magnitude (or greater) of 1 in 1000 probability of occurring in any given year.

"Act" means the Illinois Environmental Protection Act [415 ILCS 5].

"Active facility" or "active electric utility" or "independent power producer" means any facility, subject to the requirements of this Part, that is in operation on or after October 19, 2015. An electric utility or independent power producer is in operation if it is generating electricity that is provided to electric power transmission systems or to electric power distribution systems on or after October 19, 2015. An off-site CCR surface impoundment is in operation if it is accepting or managing CCR on or after October 19, 2015.

"Active life" or "in operation" means the period of operation beginning with the initial placement of CCR in the CCR surface impoundment and ending at completion of closure activities in accordance with Subpart G.

"Agency" means the Illinois Environmental Protection Agency.
"Aquifer" means a geologic formation, group of formations, or portion of a formation capable of yielding usable quantities of groundwater to wells or springs.

"Area-capacity curves" means graphic curves that readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.

"Areas susceptible to mass movement" means those areas of influence (i.e., areas characterized as having an active or substantial possibility of mass movement) where, because of natural or human-induced events, the movement of earthen material at, beneath, or adjacent to the CCR surface impoundment may result in the downslope transport of soil and rock material by means of gravitational influence. Areas of mass movement include, but are not limited to, landslides, avalanches, debris slides and flows, soil fluctuation, block sliding, and rock fall.

"Beneficial use of CCR" means CCR that meets the definition of "coal combustion by-product" in Section 3.135 of the Act [415 ILCS 5/3.135] and the definition of "beneficial use of CCR" in 40 CFR 257.53, incorporated by reference in Section 845.150.

"Board" means Illinois Pollution Control Board.

"Certified laboratory" means any laboratory certified under Section 4(o) of the Act or certified by USEPA for the specific constituents to be examined.

"Closed" for purposes of this Part means placement of CCR in a CCR surface impoundment has stopped, and the owner or operator has completed closure of the CCR surface impoundment and has initiated post-closure care in accordance with Subpart G.

"*Coal combustion residuals*" or "*CCR*" *means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated from burning coal for the purpose of generating electricity by electric utilities and independent power producers*. [415 ILCS 5/3.142]

"CCR fugitive dust" means solid airborne particulate matter that contains or is derived from CCR, emitted from any source other than a stack or chimney.

"CCR storage pile" means any temporary accumulation of solid, non-flowing CCR placed on the land that is designed and managed to control releases of CCR to the environment. CCR contained in an enclosed structure is not a CCR storage pile. Examples of control measures to control releases from CCR storage piles include: periodic wetting, application of surfactants, tarps, or wind barriers to suppress dust; tarps or berms for preventing contact with precipitation and controlling run-on/run-off; and impervious storage pads or geomembrane liners for soil and groundwater protection.

"*CCR surface impoundment*" or "*impoundment*" *means a natural topographic depression, man-made excavation, or diked area, which is designed to hold an accumulation of CCR and liquids, and the surface impoundment treats, stores, or disposes of CCR.* [415 ILCS 5/3.143]

"Dike" means an embankment, berm, or ridge of either natural or man-made materials used to prevent the movement of liquids, sludges, solids, or other materials.

"Displacement" means the relative movement of any two sides of a fault measured in any direction.

"Disposal" means the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste as defined in section 1004(27) of the Resource Conservation and Recovery Act into or on any land or water or into any well so that the solid waste, or constituent thereof, may enter the environment or be emitted into the air or discharged into any waters, including groundwater. For purposes of this Part, disposal does not include the beneficial use of CCR.

"Downstream toe" means the junction of the downstream slope or face of the CCR surface impoundment with the ground surface.

"Enclosed structure" means:

> A completely enclosed, self-supporting structure that is designed and constructed of manmade materials of sufficient strength and thickness to support itself, the CCR, and any personnel and heavy equipment that operate within the structure, and to prevent failure due to settlement, compression, or uplift; climatic conditions; and the stresses of daily operation, including the movement of heavy equipment within the structure and contact of that equipment with containment walls;
>
> The structure has containment walls that are designed to be sufficiently durable to withstand any movement of personnel, CCR, and handling equipment within the structure;

The structure is designed and operated to ensure containment and prevent fugitive dust emissions from openings, such as doors, windows and vents, and the tracking of CCR from the structure by personnel or equipment.

"Exceedance of the groundwater protection standard" means:

For existing CCR surface impoundments and inactive CCR surface impoundments:

an analytical result with a concentration greater than the numerical value of the constituents listed in Section 845.600(a), in a down gradient well; or

when the up gradient background concentration of a constituent exceeds the numerical value listed in Section 845.600(a), an analytical result with a concentration at a statistically significant level above the up gradient background concentration, in a down gradient well.

For new CCR surface impoundments and lateral expansions of existing CCR surface impoundments, an analytical result with a constituent concentration at a statistically significant level above the up gradient background concentration, in a down gradient well.

"Existing CCR surface impoundment" means a CCR surface impoundment in which CCR is placed both before and after October 19, 2015, or for which construction started before October 19, 2015 and in which CCR is placed on or after October 19, 2015. A CCR surface impoundment has started construction if the owner or operator has obtained the federal, State, and local approvals or permits necessary to begin physical construction and a continuous on-site, physical construction program had begun before October 19, 2015.

"Facility" means all contiguous land, and structures, other appurtenances, and improvements on the land, used for treating, storing, disposing of, or otherwise conducting solid waste management of CCR. A facility may consist of several treatment, storage, or disposal operational units (e.g., one or more landfills, surface impoundments, or combinations of them).

"Factor of safety" or "safety factor" means the ratio of the forces tending to resist the failure of a structure to the forces tending to cause that failure, as determined by accepted engineering practice.

"Fault" means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side.

"Flood hydrograph" means a graph showing, for a given point on a stream, the discharge, height, or other characteristic of a flood as a function of time.

"Free liquids" means liquids that readily separate from the solid portion of a waste under ambient temperature and pressure.

"Groundwater" means water below the land surface in a zone of saturation.

"Hazard potential classification" means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of the diked CCR surface impoundment or mis-operation of the diked CCR surface impoundment or its appurtenances. The hazardous potential classifications include Class 1 and Class 2, defined as follows:

> Class 1 CCR surface impoundment means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.
>
> Class 2 CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.

"Height" means the vertical measurement from the downstream toe of the CCR surface impoundment at its lowest point to the lowest elevation of the crest of the CCR surface impoundment, not including spillways.

"Holocene" means the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch, at 11,700 years before present, to present.

"Hydraulic conductivity" means the rate at which water can move through a permeable medium (i.e., the coefficient of permeability).

"Inactive CCR surface impoundment" means a CCR surface impoundment in which CCR was placed before but not after October 19, 2015 and still contains CCR on or after October 19, 2015. Inactive CCR surface impoundments may be located at an active facility or inactive facility.

"Inactive Closed CCR surface impoundment" means an inactive CCR surface impoundment that completed closure before October 19, 2015 with an Agency-approved closure plan.

"Inactive facility" or "inactive electric utilities or independent power producers" means any facility that is not in operation on or after October 19, 2015.

"Incised CCR surface impoundment" means a CCR surface impoundment that is constructed by excavating entirely below the natural ground surface, holds an accumulation of CCR entirely below the adjacent natural ground surface, and does not consist of any constructed diked portion.

"Inflow design flood" means the flood hydrograph that is used in the design or modification of the CCR surface impoundment and its appurtenant works.

"In operation" means the same as "active life".

"Karst terrain" means an area where karst topography, with its characteristic erosional surface and subterranean features, is developed as the result of dissolution of limestone, dolomite, or other soluble rock. Characteristic physiographic features present in karst terrains include, but are not limited to, dolines, collapsed shafts (sinkholes), sinking streams, caves, seeps, large springs, and blind valleys.

"Lateral expansion" means a horizontal or vertical expansion of the waste boundaries of an existing CCR surface impoundment made after October 19, 2015.

"Liquefaction factor of safety" means the factor of safety (safety factor) determined using analysis under liquefaction conditions.

"Lithified earth material" means all rock, including all naturally occurring and naturally formed aggregates or masses of minerals or small particles of older rock that formed by crystallization of magma or by induration of loose sediments. This term does not include man-made materials, such as fill, concrete, and asphalt, or unconsolidated earth materials, soil, or regolith lying at or near the earth surface.

"Maximum horizontal acceleration in lithified earth material" means the maximum expected horizontal acceleration at the ground surface as depicted on a seismic hazard map, with a 98% or greater probability that the acceleration will not be exceeded in 50 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment.

"New CCR surface impoundment" means a CCR surface impoundment or lateral expansion of an existing or new CCR surface impoundment that first receives CCR or starts construction after October 19, 2015. A new CCR surface impoundment has started construction if the owner or operator has obtained the federal, State, and local approvals or permits necessary to begin physical construction and a continuous on-site, physical construction program had begun after October 19, 2015.

"Operator" means the person or persons responsible for the overall operation of a CCR surface impoundment.

"Outermost damage zone of a fault" means the volume of deformed wall rocks around a fault surface that results from the initiation, propagation, interaction and build-up of slip along faults.

"Owner" means the person or persons who own a CCR surface impoundment or part of a CCR surface impoundment.

"Poor foundation conditions" means those areas where features exist which indicate that a natural or human-induced event may result in inadequate foundation support for the structural components of an existing or new CCR surface impoundment. For example, failure to maintain static and seismic factors of safety, as required in Section 845.460, would cause a poor foundation condition.

"Probable maximum flood" means the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin.

"Qualified person" means a person or persons trained to recognize specific appearances of structural weakness and other conditions that are disrupting, or have the potential to disrupt, the operation or safety of the CCR surface impoundment by visual observation and, if applicable, to monitor instrumentation.

"Qualified professional engineer" means an individual who is licensed under the Professional Engineering Practice Act of 1989 [225 ILCS 325] to practice one or more disciplines of engineering and who is qualified by education, technical knowledge and experience to complete the engineering analyses and make the specific technical certifications required under this Part.

"Recognized and generally accepted engineering practices" means engineering maintenance or operation activities based on established codes, widely accepted standards, published technical reports, or a practice widely recommended throughout the industry. These practices generally detail approved ways to perform specific engineering, inspection, or mechanical integrity activities.

"Retrofit" means to remove all CCR and contaminated soils and sediments from the CCR surface impoundment, and to ensure the surface impoundment complies with the requirements in Section 845.410.

"Run-off" means any rainwater, leachate, or other liquid that drains over land from any part of a CCR surface impoundment or lateral expansion of a CCR surface impoundment.

"Run-on" means any rainwater, leachate, or other liquid that drains over land onto any part of a CCR surface impoundment or lateral expansion of a CCR surface impoundment.

"Sand and gravel pit" or "quarry" means an excavation for the extraction of aggregate, minerals or metals. The term sand and gravel pit and/or quarry does not include subsurface or surface coal mines.

"Seismic factor of safety" means the factor of safety (safety factor) determined using analysis under earthquake conditions using the peak ground acceleration for a seismic event with a 2% probability of exceedance in 50 years, equivalent to a return period of approximately 2,500 years, based on the U.S. Geological Survey (USGS) seismic hazard

maps for seismic events with this return period for the region where the CCR surface impoundment is located.

"Seismic impact zone" means an area having a 2% or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10 g in 50 years.

"Slope protection" means engineered or non-engineered measures installed on the upstream or downstream slope of the CCR surface impoundment to protect the slope against wave action or erosion, including rock riprap, wooden pile, concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines.

"Solid waste management" or "management" means the systematic administration of the activities that provide for the collection, source separation, storage, transportation, processing, treatment, or disposal of solid waste.

"Static factor of safety" means the factor of safety (safety factor) determined using analysis under the long-term, maximum storage pool loading condition, the maximum surcharge pool loading condition, and the end-of-construction loading condition.

"Structural components" means liners, leachate collection and removal systems, final covers, run-on and run-off systems, inflow design flood control systems, and any other component used in the construction and operation of the CCR surface impoundment that is necessary to ensure the integrity of the surface impoundment and ensure that the contents of the surface impoundment are not released into the environment.

"Temporary accumulation" means an accumulation on the land that is neither permanent nor indefinite. To demonstrate that the accumulation on the land is temporary, all CCR must be removed from the pile at the site. The entity engaged in the activity must have a record in place, such as a contract, purchase order, facility operation and maintenance, or fugitive dust control plan, documenting that all the CCR in the pile will be completely removed according to a specific timeline.

"Unstable area" means a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of that area, including structural components of some or all the CCR surface impoundment that are responsible for preventing releases from the surface impoundment. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and karst terrains.

"Uppermost aquifer" means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary. Upper limit is measured at a point nearest to the natural ground surface to which the aquifer rises during the wet season.

"Waste boundary" means a vertical surface located at the hydraulically downgradient limit of the CCR surface impoundment. The vertical surface extends down into the uppermost aquifer.

"Wetlands" means those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Section 845.130 Surface Impoundment Identification

The owner or operator of a CCR surface impoundment must place on, or immediately adjacent to, the CCR surface impoundment a permanent identification marker at least six feet high showing the identification number of the CCR surface impoundment assigned by the Agency, the name associated with the CCR surface impoundment and the name of the owner or operator of the CCR surface impoundment. The owner or operator must maintain the marker at all times an operating permit is required under this Part.

Section 845.140 Right of Inspection

The owner or operator of a CCR surface impoundment must allow the Agency and its duly authorized representatives to perform inspections in accordance with the Agency's authority under the Act, including:

a) Entering, at reasonable times, the facility where CCR surface impoundments are located or where any activity is to be conducted under a permit issued under this Part;

b) Having access to and copying at reasonable times any records required to be kept under the terms and conditions of a permit of this Part;

c) Inspecting at reasonable times, including during any hours of operation:

1) Equipment constructed or operated under a permit issued under this Part;

2) Equipment or monitoring methodology; or

3) Equipment required to be kept, used, operated, calibrated and maintained under a permit issued under this Part;

d) Obtaining and removing, at reasonable times, samples of any raw or finished water, discharge or emission of pollutants;

e) Entering, at reasonable times, to use any photographic, recording, testing, monitoring or other equipment for the purpose of preserving, testing, monitoring

or recording any raw or finished water, activity, discharge or emission authorized by a permit.

Section 845.150 Incorporations by Reference

a) For purposes of this Part, the Board incorporates the following material by reference:

1) Non-Regulatory Government Publications and Publications of Recognized Organizations and Associations:

Association for the Advancement of Cost Engineering (AACE), 726 East Park Avenue #180, Fairmont, WV 26554, (304) 296-8444, web.aacei.org.

"Cost Estimate Classification System — As Applied in Engineering, Procurement, and Construction for the Process Industries", TCM Framework: 7.3 – Cost Estimating and Budgeting. March 6, 2009, AACE International Recommended Practice No. 18R-97.

NTIS. National Technical Information Service, 5285 Port Royal Road, Springfield VA 22161, (703) 605-6000, www.ntis.gov.

"Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", USEPA Publication No. SW-846, as amended by Updates I, II, IIA, IIB, III, IIIA, and IIIB (Doc. No. 955-001-00000-1) (available online at https://www.epa.gov/hw-sw846/sw-846-compendium).

2) Code of Federal Regulations, Available from the Superintendent of Documents, U.S. Government Publishing Office, Washington, DC 20401, (202) 783-3238, https://www.ecfr.gov, https:/www.govinfo.gov/app/collection/cfr, or https://www.federalregister.gov:

40 CFR 257.53 (2019) (Definition of "beneficial use of CCR")

40 CFR 257.103(f)(1)(x) (85 Fed. Reg. 53563-64 (Aug. 28, 2020)) (Preparation of Semi-Annual Progress Reports)

b) This Section incorporates no later editions or amendments.

Section 845.160 Severability

If any provision of this Part or its application to any person or under any circumstances is adjudged invalid, that adjudication must not affect the validity of this Part as a whole or of any portion not adjudged invalid.

Section 845.170 Inactive Closed CCR Surface Impoundments

a) Among the provisions of this Part, only the following apply to inactive closed CCR surface impoundments:

1) All of Subpart A: General Provisions;

2) The following Sections of Subpart B (Permitting):

A) Section 845.200;

B) Section 845.210;

C) Section 845.220(a), (c), and (f)(1);

D) Section 845.230(c) and (d)(4);

E) Section 845.250;

F) Section 845.270;

G) Section 845.280;

H) Section 845.290;

3) The following Section of Subpart G (Closure and Post-Closure Care): Section 845.780(b), (d), and (e); and

4) All of Subpart I (Financial Assurance).

b) When a prior release from an inactive closed CCR surface impoundment has caused an exceedance of the groundwater quality standards in 35 Ill. Adm. Code 620, and the owner or operator has not completed remediation of the release before completing closure, the owner or operator must initiate or continue corrective action under an operating permit issued under this Part.

c) When a release from an inactive closed CCR surface impoundment causes an exceedance of the groundwater quality standards in 35 Ill. Adm. Code 620, and the Agency has not concurred with an alternative source demonstration, the owner or operator of an inactive closed CCR surface impoundment must initiate an assessment of corrective measures that prevents further releases, remediates any releases, and restores the affected area. The owner or operator of the inactive

closed CCR surface impoundment must develop a corrective action plan and obtain a construction permit consistent with subsection (a)(2) before performing any corrective action to remediate any releases and to restore the affected area, including the final cover system, groundwater monitoring system, groundwater collection trench, extraction wells, slurry walls, or any construction related to corrective action.

SUBPART B: PERMITTING

Section 845.200 Permit Requirements and Standards of Issuance

a) Permit Requirements

1) No person may construct, install, or modify a CCR surface impoundment or related treatment or mitigation facilities, including corrective action measures under Subpart F, without a construction permit issued by the Agency under this Part.

2) Except as provided in Section 845.230(d), no person may operate a CCR surface impoundment without an operating permit issued by the Agency under this Part. For purposes of this Part, a CCR surface impoundment starts operation upon initial receipt of CCR.

3) No person may perform corrective action at a CCR surface impoundment without obtaining a construction permit for corrective action and modifying the facility's operating permit, or modifying the facility's operating permit when the approved corrective action does not require the modification of the CCR surface impoundment or the installation or modification of related treatment or mitigation facilities.

4) Except as provided in Section 22.59(e) of the Act, no person may close a CCR surface impoundment without obtaining a construction permit for closure issued by the Agency under this Part.

5) A CCR surface impoundment must maintain an operating permit until:

A) The completion of post-closure care when the CCR surface impoundment is closed with a final cover system; or

B) The completion of groundwater monitoring under Section 845.740(b) when the CCR surface impoundment is closed by removal.

6) The Agency may issue a joint construction and operating permit.

b) Standards for Issuance

1) Except as provided in subsection (b)(2), the Agency may not issue any construction or operating permit required by this Part unless the applicant submits adequate proof that the CCR surface impoundment will be constructed, modified or operated so as not to cause a violation of the Act or Board rules.

2) The existence of a violation of the Act, Board regulation, or Agency regulation will not prevent the issuance of a construction or operating permit under this Part if:

A) The applicant has been granted a variance or an adjusted standard from the regulation by the Board;

B) The permit application is for construction, installation, or operation of equipment to alleviate or correct a violation; or

C) The permit application is for construction, installation, or operation of equipment necessary to restore, protect or enhance the environment.

3) *In granting permits, the Agency may impose reasonable conditions specifically related to the applicant's past compliance history with the Act as necessary to correct, detect, or prevent noncompliance. The Agency may impose such other conditions as may be necessary to accomplish the purpose of the Act and as are not inconsistent with this Part.* [415 ILCS 5/39(a)]

4) *In making its determinations on permit applications under this* Part*, the Agency may consider prior adjudications of noncompliance with the Act by the applicant that involved a release of a contaminant into the environment*. [415 ILCS 5/39(a)]

Section 845.210 General Provisions

a) All permit applications must be made on the forms prescribed by the Agency and must be mailed or delivered to the address designated by the Agency on the forms. The Agency must provide a dated, signed receipt upon request. The Agency's record of the date of filing must be deemed conclusive unless a contrary date is proved by a dated, signed receipt.

b) Required Signatures of Owners or Operators

1) All permit applications must contain the name, address, email address and telephone number of the operator, or duly authorized agent, and the

property owner to whom all inquiries and correspondence must be addressed.

2) All permit applications must be signed by the owner, operator or a duly authorized agent of the operator.

3) An application submitted by a corporation must be signed by a principal executive officer of at least the level of vice president, or his or her duly authorized representative, if that representative is responsible for the overall operation of the facility described in the application form. In the case of a partnership or a sole proprietorship, the application must be signed by a general partner or the proprietor, respectively. In the case of a publicly owned facility, the application must be signed by either the principal executive officer, ranking elected official, or other duly authorized employee.

c) Legal Description. All permit applications must contain a legal description of the facility boundary and a description of the boundaries of all units included in the facility.

d) Previous Assessments, Investigations, Plans and Programs

1) The Agency may approve the use of any hydrogeologic site investigation or characterization, groundwater monitoring well or system, or groundwater monitoring plan, bearing the seal and signature of an Illinois Licensed Professional Geologist or Licensed Professional Engineer, completed before April 21, 2021 to satisfy the requirements of this Part.

2) For existing CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a previously completed location restriction demonstration required by Section 845.300 (Placement Above the Uppermost Aquifer), Section 845.310 (Wetlands), Section 845.320 (Fault Areas), Section 845.330 (Seismic Impact Zones), and Section 845.340 (Unstable Areas) provided that the previously completed assessments meet the applicable requirements of those Sections.

3) For existing CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a previously completed assessment to serve as the initial assessment required by Section 845.440 (Hazard Potential Classification Assessment), Section 845.450 (Structural Stability Assessment) and Section 845.460 (Safety Factor Assessment) provided that the previously completed assessment:

A) Was not completed more than five years ago; and

B) Meets the applicable requirements of those Sections.

4) For inactive closed CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a post-closure care plan previously approved by the Agency.

e) The Agency must mail all notices of final action by certified mail, postmarked with a date stamp and with return receipt requested. Final action must be deemed to have taken place on the postmarked date that the notice is mailed.

f) Violation of any permit condition or failure to comply with the Act or regulations promulgated under the Act must be grounds for enforcement action as provided in the Act, including revocation of a permit.

g) Issuance of a permit under this Part does not relieve the applicant of the obligation to obtain other permits required by law.

h) The owner or operator must place in the facility's operating record all permit applications submitted to the Agency and all permits issued under this Part (see Section 845.800(d)(1)).

i) Agency Listserv

1) For each facility subject to this Part, the Agency must create and maintain a listserv. Each listserv must include the email addresses of all interested persons who notify the Agency in writing—either directly under subsection (i)(2) or through the facility owner or operator under Section 845.220(a)(9) or 845.240(f)(4)—of their respective email addresses and that they would like to receive emails of notices concerning the facility.

2) The Agency's webpage must specify how interested persons may notify the Agency in writing of their respective email addresses and that they would like to be added to the Agency's listserv for a facility subject to this Part.

3) When this Part requires that the Agency email a notice to the listserv for a facility, the Agency must do so within the timeframe specified, concurrently with other required means of disseminating the notice, or otherwise in a timely manner. When this Part requires an owner or operator to request that the Agency email a notice to the listserv for the facility, the Agency must do so within two business days after receiving the request from the owner or operator.

Section 845.220 Construction Permits

a) All construction permit applications must contain the following information and documents.

1) Design and Construction Plans (Construction History)

A) Identifying Information

i) The name and address of the person or persons owning or operating the CCR surface impoundment;

ii) The name associated with the CCR surface impoundment; and

iii) The identification number of the CCR surface impoundment if one has been assigned by the Agency.

B) A statement of the purpose for which the CCR surface impoundment is being used, how long the CCR surface impoundment has been in operation, and the types of CCR that have been placed in the CCR surface impoundment.

C) The name and size in acres of the watershed within which the CCR surface impoundment is located.

D) A description of the physical and engineering properties of the foundation and abutment materials on which the CCR surface impoundment is constructed.

E) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment; the method of site preparation and construction of each zone of the CCR surface impoundment; and the approximate dates of construction of each successive stage of construction of the CCR surface impoundment.

F) At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR surface impoundment, detailed dimensional drawings of the CCR surface impoundment, including a plan view and cross-sections of the length and width of the CCR surface impoundment, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely

affect operation of the CCR surface impoundment due to malfunction or mis-operation.

G) A description of the type, purpose, and location of existing instrumentation.

H) Area-capacity curves for the CCR surface impoundment.

I) A description of each spillway and diversion design features and capacities and calculations used in their determination.

J) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

K) Any record or knowledge of structural instability of the CCR surface impoundment.

2) Narrative Description of the Facility. The permit application must contain a written description of the facility with supporting documentation describing the procedures and plans that will be used at the facility to comply with the requirements of this Part. The descriptions must include, but are not limited to, the following information:

A) The types of CCR expected in the CCR surface impoundment, including a chemical analysis of each type of expected CCR;

B) An estimate of the maximum capacity of each surface impoundment in gallons or cubic yards;

C) The rate at which CCR and non-CCR waste streams currently enter the CCR surface impoundment in gallons per day and dry tons;

D) The estimated length of time the CCR surface impoundment will receive CCR and non-CCR waste streams; and

E) An on-site transportation plan that includes all existing and planned roads in the facility that will be used during the operation of the CCR surface impoundment.

3) Site Location Map. All permit applications must contain a site location map on the most recent United States Geological Survey (USGS) quadrangle of the area from the 7 ½ minute series (topographic), or on another map whose scale clearly shows the following information:

A) The facility boundaries and all adjacent property, extending at least 1000 meters (3280 feet) beyond the boundary of the facility;

B) All surface waters;

C) The prevailing wind direction;

D) The limits of all 100-year floodplains;

E) All-natural areas designated as a Dedicated Illinois Nature Preserve under the Illinois Natural Areas Preservation Act [525 ILCS 30];

F) All historic and archaeological sites designated by the National Historic Preservation Act (16 USC 470 et seq.) and the Illinois Historic Sites Advisory Council Act [20 ILCS 3410]; and

G) All areas identified as critical habitat under the Endangered Species Act of 1973 (16 USC 1531 et seq.) and the Illinois Endangered Species Protection Act [520 ILCS 10].

4) Site Plan Map. The application must contain maps, including cross-sectional maps of the site boundaries, showing the location of the facility. The following information must be shown:

A) The entire facility, including any proposed and all existing CCR surface impoundment locations;

B) The boundaries, both above and below ground level, of the facility and all CCR surface impoundments or landfills containing CCR included in the facility;

C) All existing and proposed groundwater monitoring wells; and

D) All main service corridors, transportation routes, and access roads to the facility.

5) A narrative description of the proposed construction of, or modification to, a CCR surface impoundment and any projected changes in the volume or nature of the CCR or non-CCR waste streams.

6) Plans and specifications fully describing the design, nature, function and interrelationship of each individual component of the facility.

7) A new groundwater monitoring program or any modification to an existing groundwater monitoring program that includes but is not limited to the following information:

A) A hydrogeologic site investigation meeting the requirements of Section 845.620, if applicable;

B) Design and construction plans of a groundwater monitoring system meeting the requirements of Section 845.630; and

C) A proposed groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data (see Sections 845.640 and 845.650).

8) The signature and seal of a qualified professional engineer.

9) Certification that the owner or operator of the CCR surface impoundment completed the public notification and public meetings required under Section 845.240, a summary of the issues raised by the public, a summary of any revisions, determinations, or other considerations made in response to those issues, and a list of interested persons in attendance who would like to be added to the Agency's listserv for the facility.

b) New Construction. In addition to the requirements in subsection (a), all construction permit applications to build a new CCR surface impoundment, lateral expansion of a CCR surface impoundment, or retrofit an existing CCR surface impoundment must also contain the following information and documents:

1) Plans and specifications that demonstrate the proposed CCR surface impoundment will meet the location standards in the following Sections:

A) Section 845.300 (Placement Above the Uppermost Aquifer);

B) Section 845.310 (Wetlands);

C) Section 845.320 (Fault Areas);

D) Section 845.330 (Seismic Impact Zones); and

E) Section 845.340 (Unstable Areas and Floodplains).

2) Plans and specifications that demonstrate the proposed CCR surface impoundment will meet the following design criteria:

A) The CCR surface impoundment will have a liner meeting the liner requirements of Section 845.400(b) or (c);

B) The CCR surface impoundment will have a leachate collection system meeting the requirements of Section 845.420; and

C) The CCR surface impoundment, if not incised, will be constructed with slope protection, as required by Section 845.430.

3) CCR fugitive dust control plan (see Section 845.500(b)).

4) Preliminary written closure plan (see Section 845.720(a)).

5) Initial written post-closure care plan, if applicable (see Section 845.780(d)).

c) Corrective Action Construction. In addition to the requirements in subsection (a), all construction permit applications that include any corrective action performed under Subpart F must also contain the following information and documents:

1) Corrective action plan (see Section 845.670);

2) Groundwater modeling, including:

A) The results of groundwater contaminant transport modeling and calculations showing how the corrective action will achieve compliance with the applicable groundwater standards;

B) All modeling inputs and assumptions;

C) Description of the fate and transport of contaminants with the selected corrective action over time; and

D) Capture zone modeling, if applicable;

3) Any necessary licenses and software needed to review and access both the models and the data contained within the models required by subsection (c)(2);

4) Corrective action groundwater monitoring program, including identification of revisions to the groundwater monitoring system for corrective action; and

5) Any interim measures necessary to reduce the contaminants leaching from the CCR surface impoundment, and/or potential exposures to human or ecological receptors, including an analysis of the factors specified in Section 845.680(a)(3).

d) Closure Construction. In addition to the requirements in subsection (a), all construction permit applications for closure of the CCR surface impoundment under Subpart G must contain the following information and documents:

1) Closure prioritization category , if applicable (see Section 845.700(g));

2) Final closure plan (see Section 845.720(b)), including the closure alternatives analysis required by Section 845.710;

3) Groundwater modeling, including:

A) The results of groundwater contaminant transport modeling and calculations showing how the closure will achieve compliance with the applicable groundwater standards;

B) All modeling inputs and assumptions;

C) Description of the fate and transport of contaminants, with the selected closure over time;

D) Capture zone modeling, if applicable; and

E) Any necessary licenses and software needed to review and access both the model and the data contained within the model.

4) Proposed schedule to complete closure; and

5) Post-closure care plan specified in Section 845.780(d), if applicable.

e) *Owners or operators of CCR surface impoundments who submitted a closure plan to the Agency before May 1, 2019, and who complete closure before July 30, 2021, shall not be required to obtain a construction permit for closure under subsection (d)*. [415 ILCS 5/22.59(e)]

f) A single construction permit application may be submitted for new construction, corrective action, and closure if the construction is related to the same multi-phased project. The permit application for a project with multiple phases must contain all information required by subsections (a), (b), (c), and (d), as applicable.

g) Duration of Construction Permits

1) For any construction permit that is not for the closure or retrofit of the CCR surface impoundment, the construction permit must be issued for fixed terms not to exceed 3 years.

2) For any construction permit for the closure or retrofit of a CCR surface impoundment, the construction permit must be issued for an initial fixed term expiring within the timeframe approved by the Agency in the construction permit or five years, whichever is less. The Agency may renew a construction permit for closure or retrofit in two-year increments under Section 845.760(b).

Section 845.230 Operating Permits

The operating permit applications must contain the following information and documents:

a) Initial operating permit for a new CCR surface impoundment and any lateral expansion of a CCR surface impoundment.

1) A demonstration that the CCR surface impoundment, as built, meets the location standards in the following Sections:

A) Section 845.300 (Placement Above the Uppermost Aquifer);

B) Section 845.310 (Wetlands);

C) Section 845.320 (Fault Areas);

D) Section 845.330 (Seismic Impact Zones); and

E) Section 845.340 (Unstable Areas and Floodplains);

2) Certification from a qualified professional engineer that the composite liner, or if applicable, the alternative composite liner, has been constructed in accordance with the requirements of Section 845.400(b) or (c);

3) Certification from a qualified professional engineer that the leachate collection system has been constructed in accordance with the requirements of Section 845.420, if applicable;

4) Evidence that the permanent markers required by Section 845.130 have been installed;

5) Documentation that the CCR surface impoundment, if not incised, will be operated and maintained with one of the forms of slope protection specified in Section 845.430;

6) Initial hazard potential classification assessment and accompanying certification (see Section 845.440(a)(2));

7) Initial Emergency Action Plan and accompanying certification (see Section 845.520(e));

8) Initial structural stability assessment and accompanying certification (see Section 845.450(c));

9) Initial safety factor assessment and accompanying certification (see Section 845.460(b));

10) Fugitive dust control plan and accompanying certification (see Section 845.500(b)(7));

11) Initial inflow design flood control system plan and accompanying certification (see Section 845.510(c)(3));

12) Proposed groundwater monitoring program, including a minimum of eight independent samples for each background and downgradient well (see Section 840.650(b));

13) Preliminary written closure plan (see Section 845.720(a));

14) Initial written post-closure care plan, if applicable (see Section 845.780(d));

15) An analysis of the chemical constituents found within the CCR to be placed in the CCR surface impoundment;

16) An analysis of the chemical constituents of all waste streams, chemical additives, and sorbent materials entering or contained in the CCR surface impoundment; and

17) A certification that the owner or operator meets the financial assurance requirements of Subpart I.

b) Renewal Operating Permit

1) Documentation that the CCR surface impoundment, if not incised, is being operated and maintained with one of the forms of slope protection specified in Section 845.430;

2) Emergency Action Plan certification if the plan was amended (see Section 845.520);

3) Fugitive dust control plan certification if the plan was amended (see Section 845.500(b)(7));

4) Any significant changes to the design and construction plans compiled under subsection (d)(2)(A) or Section 845.220(a)(1);

5) A statement that the groundwater monitoring has been conducted under an Agency approved groundwater monitoring program;

6) Written preliminary closure plan, if amended (see Section 845.720(a)); and

7) Written post-closure care plan, if amended (see Section 845.780(d)).

c) Post-Closure Care Operating Permit

The owner or operator of a CCR surface impoundment conducting post-closure care under Section 845.780 must maintain an operating permit until the completion of post-closure care. Any changes to the post-closure care plan, groundwater monitoring system, groundwater sampling and analysis program, and groundwater monitoring program must be submitted to the Agency in an operating permit application.

d) Initial Operating Permit for Existing, Inactive and Inactive Closed CCR Surface Impoundments

1) The owner or operator of an existing, inactive or inactive closed CCR surface impoundment who has not completed post-closure care must submit an initial operating permit application to the Agency by October 31, 2021;

2) The initial operating permit application for existing or inactive CCR surface impoundments that have not completed an Agency approved closure before July 30, 2021, must contain the following information and documents on forms prescribed by the Agency:

A) The history of construction specified in Section 845.220(a)(1);

B) An analysis of the chemical constituents found within the CCR to be placed in the CCR surface impoundment;

C) An analysis of the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained in the CCR surface impoundment;

D) A demonstration that the CCR surface impoundment, as built, meets, or an explanation of how the CCR surface impoundments fails to meet, the location standards in the following Sections:

i) Section 845.300 (Placement Above the Uppermost Aquifer);

ii) Section 845.310 (Wetlands);

iii) Section 845.320 (Fault Areas);

iv) Section 845.330 (Seismic Impact Zones); and

v) Section 845.340 (Unstable Areas);

E) Evidence that the permanent markers required by Section 845.130 have been installed;

F) Documentation that the CCR surface impoundment, if not incised, will be operated and maintained with one of the forms of slope protection specified in Section 845.430;

G) Initial Emergency Action Plan and accompanying certification (see Section 845.520(e));

H) Fugitive dust control plan and accompanying certification (see Section 845.500(b)(7));

I) Groundwater Monitoring Information:

i) A hydrogeologic site characterization (see Section 845.620);

ii) Design and construction plans of a groundwater monitoring system (see Section 845.630);

iii) A groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data (see Section 845.640); and

iv) Proposed groundwater monitoring program that includes a minimum of eight independent samples for each background and downgradient well (see Section 845.650(b));

J) Preliminary written closure plan (see Section 845.720(a));

K) Initial written post-closure care plan, if applicable (see Section 845.780(d));

L) The certification required by Section 845.400(h), or a statement that the CCR surface impoundment does not have a liner that meets the requirements of Section 845.400(b) or (c);

M) History of known exceedances of the groundwater protection standards in Section 845.600, and any corrective action taken to remediate the groundwater;

N) A certification that the owner or operator meets the financial assurance requirements of Subpart I;

O) Hazard potential classification assessment and accompanying certification (see Section 845.440(a)(2));

P) Structural stability assessment and accompanying certification (see Section 845.450(c));

Q) Safety factor assessment and accompanying certification (see Section 845.460(b));

R) Inflow design flood control system plan and accompanying certification (see Section 845.510(c)(3));

S) Safety and health plan (see Section 845.530); and

T) For CCR surface impoundments required to close under 845.700, the proposed closure priority categorization required by Section 845.700(g).

3) The initial operating permit application for an existing or inactive CCR surface impoundment where an Agency approved closure has been completed before July 30, 2021, and where the impoundment is not an inactive closed CCR surface impoundment, must contain the following information and documents on forms prescribed by the Agency:

A) The history of construction specified in Section 845.220(a)(1);

B) Evidence that the permanent markers required by Section 845.130 have been installed;

C) Documentation that the CCR surface impoundment, if not incised, will be operated and maintained with one of the forms of slope protection specified in Section 845.430;

D) Emergency Action Plan certification (see Section 845.520(e));

E) Groundwater monitoring information:

i) A hydrogeologic site characterization meeting the requirements of Section 845.620;

ii) Design and construction plans of a groundwater monitoring system meeting the requirements of Section 845.630;

iii) A groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data (see Section 845.640); and

iv) Proposed groundwater monitoring program that includes a minimum of eight independent samples for each background and downgradient well (see Section 845.650(b));

F) Written post-closure care plan, if applicable (see Section 845.780(d));

G) History of known exceedances of the groundwater protection standards in Section 845.600, and any corrective action plan taken to remediate the groundwater.

4) The initial operating permit application for inactive closed CCR surface impoundments must contain the following information:

A) Evidence that the permanent markers required by Section 845.130 have been installed;

B) Groundwater monitoring program;

C) Written post-closure care plan (see Section 845.780(d)); and

D) History of known exceedances of the groundwater quality standards in 35 Ill. Adm. Code 620, whether the owner or operator has obtained a groundwater management zone, and any corrective action taken to remediate the groundwater.

e) Operating permits must be issued for fixed terms not to exceed five years.

Section 845.240 Pre-Application Public Notification and Public Meeting

a) At least 30 days before the submission of a construction permit application, the owner or operator of the CCR surface impoundment must hold at least two public

meetings to discuss the proposed construction, with at least one meeting to be held after 5:00 p.m. in the evening. Any public meeting held under this Section must be located at a venue that is accessible to persons with disabilities, and the owner or operator must provide reasonable accommodations upon request.

b) The owner or operator must prepare and circulate a notice explaining the proposed construction project and any related activities and the time and place of the public meeting. At least 30 days before the public meeting, the owner or operator of the CCR surface impoundment must:

1) Mail or hand-deliver the notice to the Agency and all residents within a one-mile radius from the facility boundary;

2) Post the notice to the owner's or operator's publicly accessible Internet site under Section 845.810;

3) Post the notice in conspicuous locations throughout villages, towns, or cities within 10 miles of the facility, or use appropriate broadcast media (such as radio or television);

4) Request that the Agency email the notice to the Agency's listserv for the facility; and

5) Include in the notice the owner's and operator's contact information, the internet address where the information in Section 845.240(e) will be posted, and the date on which the information will be posted to the site.

c) When a proposed construction project or any related activity is located in an area with a significant proportion of non-English speaking residents, the notification must be circulated, or broadcast, in both English and the appropriate non-English language, and the owner or operator must provide translation services during the public meetings required by Section 845.240(a), if requested by non-English speaking members of the public.

d) The owner or operator of the CCR surface impoundment must prepare documentation recording the public meeting and place the documentation in the facility's operating record as required by Section 845.800(d)(2).

e) At least 30 days before a public meeting, the owner or operator of the CCR surface impoundment must post on the owner's or operator's publicly accessible internet site all documentation relied upon in making a tentative construction permit application.

f) At the public meeting, the owner or operator of the CCR surface impoundment must:

1) Present its decision-making process for the construction permit application, including, when applicable, the corrective action alternatives and the closure alternatives considered. The presentation must include a comparison of projected groundwater impacts for each alternative considered and an objective comparison of the pros and cons of each alternative considered;

2) Include a question/answer portion of the meeting to allow the public to ask questions. There must be representatives from the owner or operator present who are qualified and knowledgeable enough to answer the questions posed by the public.

3) If there are questions posed by the public at the hearing that cannot be answered in person or if there are subsequent questions posed by the public following the meeting, the owner or operator of the facility must respond to those questions in writing within a reasonable timeframe and post the response on the facility's CCR website required by Section 845.810; and

4) Explain that the Agency is creating a listserv for the facility, compile a list of interested persons in attendance—and their respective email addresses—who would like to be added to the listserv, and transmit that list to the Agency with the permit application.

g) Within 14 days after the public meetings required by Section 845.240, the owner or operator must distribute a general summary of the issues raised by the public, as well as a response to those issues or comments raised by the public. If these comments resulted in a revision, change in a decision, or other considerations or determination, a summary of these revisions, changes and considerations must be included in the summary. The summary must be distributed to any attendee who requests a copy at the public meeting.

h) This Section does not apply to applications for minor modifications as described in Section 845.280(d).

Section 845.250 Tentative Determination and Draft Permit

Following the receipt of a complete application for a construction permit, operating permit, or joint construction and operating permit, the Agency must prepare a tentative determination.

a) The tentative determination must include at least the following:

1) A statement regarding whether the permit is to be issued or denied; and

2) If the determination is to issue the permit, a draft permit and a brief description of any conditions contained in the permit.

b) Upon tentative determination to issue or deny the permit:

1) If the determination is to issue the permit, the Agency must notify the applicant in writing of the content of the tentative determination and draft permit and of its intent to circulate public notice of issuance in accordance with Section 845.260;

2) If the determination is to deny the permit, the Agency must notify the applicant in writing of the tentative determination and of its intent to circulate public notice of denial, in accordance with Section 845.260. In the case of denial, notice to the applicant must include a statement of the reasons for denial, as required by Section 39(a) of the Act.

c) The documents supporting the Agency's tentative decision to issue or deny a permit must be made part of the Agency's record.

Section 845.260 Draft Permit Public Notice and Participation

a) The Agency must post a notification that it has received a permit application on the Agency's webpage and must email the notice to the Agency's listserv for the applicant's facility.

b) Public Notice of Draft Permit

1) Not earlier than 15 days following the Agency's notification to the applicant of its tentative decision under Section 845.250 to issue or deny the permit application, the Agency must circulate public notice of the completed application for the permit in a manner designed to inform interested and potentially interested persons of the construction, modification, operation or closure of a CCR surface impoundment and of the proposed determination to issue or deny the permit.

2) The contents of public notice of completed applications for permits must include at least the following:

A) Name, address, and telephone number of the Agency;

B) Name and address of the applicant;

C) Brief description of the applicant's activities or operations that result in the construction, operation, modification or closure of a CCR surface impoundment;

D) A statement of the tentative determination to issue or deny the permit;

E) A brief description of the procedures for the formulation of final determinations, including the procedures for submitting comments and the expiration date of the comment period;

F) Address and telephone number of Agency premises at which interested persons may obtain further information and request a copy of the permit application and related documents;

G) A translation of the public notice into the appropriate language or languages will be made if the Agency determines that a project is located within one mile of a significant population of non-English speaking residents;

H) A brief description of how members of the public can request a public hearing under Section 845.260(d); and

I) A brief description of how members of the public can request being added to the Agency's listserv for the facility.

3) Procedures for the circulation of public notice required under this Section must include at least the following concurrent actions:

A) Posting on the Agency's webpage and all the Agency's social media outlets;

B) Mailing the notice to the clerk of the nearest city, town or village requesting further posting in conspicuous locations throughout the city, town or village;

C) Requiring the applicant to post the notice near the entrance to the applicant's premises; and

D) Emailing the notice to the Agency's listserv for the facility.

c) Public Comment Period

1) The Agency must accept written comments from interested persons on the draft permit determination for 45 days following the circulation of the public notice under subsection (b).

2) All comments must be submitted to the Agency and to the applicant.

3) The Agency must keep all timely submitted comments and consider them in the formulation of its final determination with respect to the permit application.

4) The period for comment may be extended at the discretion of the Agency.

d) Public Hearing

1) The Agency must hold a public hearing on the issuance or denial of a draft permit whenever the Agency determines that there exists a significant degree of public interest in the proposed permit.

2) Within the 45-day public comment period, any person, including the applicant, may submit to the Agency a request for a public hearing, which must include the reasons why a hearing is warranted.

3) Hearings held under this Section must be held in the geographical area in which the CCR surface impoundment is located. When determining the hearing location, consideration must be given to facilitating attendance of interested or affected persons and organizations and to accessibility of hearing sites to public transportation.

e) Notice of Public Hearing

1) The Agency must issue notice of a public hearing not less than 30 days before the date of the hearing, under the procedures for the circulation of public notice in subsection (b)(3).

2) The contents of the public notice for the public hearing must include at least the following:

A) Name, address, and telephone number of the Agency;

B) Name and address of each applicant whose application will be considered at the hearing;

C) Brief description of the applicant's activities or operations that result in the construction, operation, modification or closure of a CCR surface impoundment;

D) Information regarding the time and location of the hearing;

E) The purpose of the hearing;

F) A concise statement of the issues to be considered at the hearing;

G) Address and telephone number of premises at which interested persons may obtain further information and request a copy of the draft permit and related documents; and

H) A statement that the hearing will be conducted in accordance with this Section.

I) A translation of the public notice into the appropriate language or languages will be made if the Agency determines that a project is located within one mile of a significant population of non-English speaking residents.

f) When the Agency receives written comments or holds a public hearing under this Section, the Agency must prepare a responsiveness summary that includes:

1) An identification of the public participation activity conducted;

2) Description of the matter on which the public was consulted;

3) An estimate of the number of persons present at the hearing;

4) A summary of all significant comments, criticisms, and suggestions, whether written or oral, submitted during the public comment period, at the hearing, or during the time the hearing record was open;

5) The Agency's response to all significant comments, criticisms, and suggestions; and

6) A statement of Agency action, including, when applicable, the issuance or denial of the permit.

Section 845.270 Final Permit Determination and Appeal

a) The Agency must not make a final permit determination until the public participation process in Section 845.260 has concluded.

b) After the consideration of any comments that may have been received, the Agency may either issue or deny the permit.

c) The Agency must provide a notice of the issuance or denial of the permit to the applicant, to any person who provides comments or an email address to the Agency during the public notice period or a public hearing, and to any person on the Agency's listserv for the facility. The Agency must post its final permit determination and, if a public hearing was held, the responsiveness summary, to the Agency's website. The notice must briefly indicate any significant changes that were made from the terms and conditions of the draft permit.

d) In the case of denial, the Agency must inform the applicant of the reasons for denial, as required by Section 39(a) of the Act.

e) Appeal

1) If the Agency refuses to grant, or grants with conditions, a permit under this Part, the applicant may petition the Board to appeal the Agency's final decision under Section 40 of the Act.

2) *If the Agency grants or denies a permit under this Part, a third party, other than the permit applicant or Agency, may appeal the Agency's decision as provided under federal law for CCR surface impoundment permits.* [415 ILCS 5/40(g)]

3) All appeals must be filed with the Board within 35 days after the final action is served on the applicant.

Section 845.280 Transfer, Modification and Renewal

a) No permit is transferable from one person to another except as approved by the Agency. Approval must be granted only if a new owner or operator seeking transfer of a permit can demonstrate the ability to comply with all applicable financial requirements of Subpart I.

b) Agency Initiated Modification. The Agency may modify a permit under the following conditions:

1) Discovery of a typographical or calculation error;

2) Discovery that a determination or condition was based upon false or misleading information;

3) An order of the Board issued in an action brought under Title VII, VIII, IX or X of the Act; or

4) Promulgation of new statutes or regulations affecting the permit.

c) The owner or operator of a CCR surface impoundment may initiate modification to its permit by application submittal to the Agency at any time after the permit is approved and before the permit expires.

d) The Agency may make minor modifications to a permit without following the public notice procedures of Section 845.260. Minor modifications may only:

1) Correct typographical errors;

2) Require more frequent monitoring or reporting by the permittee, including the installation of additional groundwater monitoring wells;

3) Allow for a change in ownership or operational control of a facility when the Agency determines that no other change in the permit is necessary, provided that a written agreement containing a specific date for transfer of permit responsibility, coverage, and liability between the current and new permittees has been submitted to the Agency;

4) Change the construction schedule, which does not impact the scheduled date of completion; or

5) Require electronic reporting requirements.

e) An application for renewal of a permit must be filed with the Agency at least 180 days before the expiration date of the existing permit unless the Agency grants a waiver of this requirement. The Agency may grant a waiver of the 180-day requirement only if:

1) The permittee submits a written request to the Agency at least 60 days before the expiration of the permit;

2) The permittee's written request includes the reasonably justifiable causes for not meeting the 180-day requirement; and

3) The permittee's written request includes a date by which the permittee will submit the renewal application.

f) Any Agency decision to deny a waiver request must be made within 21 days after receipt of the waiver request (see subsection (e)(1)).

g) The terms and conditions of an expiring permit remain effective and enforceable against the permittee until the Agency takes final action on the pending permit renewal application, only if the permittee has submitted a timely application under subsection (e) and the Agency, through no fault of the permittee, does not issue a new permit by the expiration date of the previous permit.

Section 845.290 Construction Quality Assurance Program

a) The following must be constructed according to a Construction Quality Assurance (CQA) program:

1) The construction of a new CCR surface impoundment, or the lateral expansion of an existing CCR surface impoundment;

2) The retrofit of an existing CCR surface impoundment;

3) Installation of a groundwater collection system and discharge system;

4) Installation of the groundwater monitoring system; and

5) Installation of the final cover system.

b) The CQA program must meet the following requirements:

1) The owner or operator of the CCR surface impoundment must designate a CQA officer who is a qualified professional engineer.

2) At the end of each week of construction, until construction is complete, a summary report must be prepared either by the CQA officer or under the supervision of the CQA officer. The report must include descriptions of the weather, locations where construction occurred during the previous week, materials used, results of testing, inspection reports, and procedures used to perform the inspections. The CQA officer must review and approve the report. The owner or operator of the CCR surface impoundment must place the weekly reports in the facility's operating record (see Section 845.800(d)(3)).

3) The CQA officer must certify the following, when applicable:

A) The bedding material contains no undesirable objects;

B) The final closure plan or corrective action plan approved by the construction permit has been followed;

C) The anchor trench and backfill are constructed to prevent damage to a geosynthetic membrane;

D) All tears, rips, punctures, and other damage are repaired;

E) All geosynthetic membrane seams are properly constructed and tested in accordance with the manufacturer's specifications;

F) Any groundwater collection system is constructed to intersect the water table;

G) Any groundwater collection system is properly constructed to slope toward extraction points, and the extraction equipment is properly designed and installed;

H) Appropriate operation and maintenance plans for the groundwater collection system and extraction and discharge equipment are provided;

I) Proper filter material consisting of uniform granular fill, to avoid clogging, is used in construction;

J) The filter material, as placed, possesses structural strength adequate to support the maximum loads imposed by the overlying materials and equipment used at the facility;

K) CCR stabilization; and

L) Site restoration, if any.

4) The CQA officer must supervise and be responsible for all inspections, testing and other activities required to be implemented as part of the CQA program under this Section.

5) The CQA officer must be present to provide supervision and assume responsibility for performing all inspections of the following activities, when applicable:

A) Compaction of the subgrade and foundation to design parameters;

B) Application of final cover, including installation of the geomembrane; and

C) Installation of the groundwater collection system and discharge system.

6) If the CQA officer is unable to be present as required by subsection (b)(5), the CQA officer must provide the following in writing:

A) The reasons for his or her absence;

B) A designation of a person who must exercise professional judgment in carrying out the duties of the CQA officer-in-absentia; and

C) A signed statement that the CQA officer assumes full responsibility for all inspections performed and reports prepared by the designated CQA officer-in-absentia during the absence of the CQA officer.

7) The CQA program must ensure, at a minimum, that construction materials and operations meet design specifications.

SUBPART C: LOCATION RESTRICTIONS

Section 845.300 Placement Above the Uppermost Aquifer

a) Existing and new CCR surface impoundments, and all lateral expansions of CCR surface impoundments, must be constructed with a base that is located at least 1.52 meters (five feet) above the upper limit of the uppermost aquifer, or must demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR surface impoundment and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table).

b) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of subsection (a).

c) The owner or operator of an existing CCR surface impoundment must complete the demonstration required by subsection (a) and submit the completed demonstration, along with a qualified professional engineer's certification, to the Agency in the facility's initial operating permit application.

d) The owner or operator of a new CCR surface impoundment or a lateral expansion of a CCR surface impoundment must submit plans and specifications in a construction permit application that demonstrate the CCR surface impoundment will be constructed under subsection (a). Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the CCR surface impoundment or lateral expansion was constructed in accordance with the requirements in subsection (a) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.310 Wetlands

a) Existing and new CCR surface impoundments, and all lateral expansions of CCR surface impoundments, must not be located in wetlands unless the owner or operator demonstrates the following:

1) When applicable under section 404 of the Clean Water Act, Interagency Wetlands Policy Act of 1989 [20 ILCS 830] and Rivers, Lakes, and Streams Act [615 ILCS 5], or other applicable State wetlands laws, a clear and objective rebuttal of the presumption that an alternative to the CCR surface impoundment is reasonably available that does not involve wetlands.

2) The construction and operation of the CCR surface impoundment will not cause or contribute to any of the following:

A) A violation of any applicable State or federal water quality standard;

B) A violation of any applicable toxic effluent standard or prohibition under section 307 of the Clean Water Act;

C) Jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of a critical habitat, protected under the Endangered Species Act of 1973 (16 USC 1531 et seq.) and the Illinois Endangered Species Protection Act [520 ILCS 10]; and

D) A violation of any requirement under the Marine Protection, Research, and Sanctuaries Act of 1972 (16 USC 1431 and 33 USC 1401) for the protection of a marine sanctuary.

3) The CCR surface impoundment will not cause or contribute to significant degradation of wetlands by addressing all the following factors:

A) Erosion, stability, and migration potential of native wetland soils, muds and deposits used to support the CCR surface impoundment;

B) Erosion, stability, and migration potential of dredged and fill materials used to support the CCR surface impoundment;

C) The volume and chemical nature of the CCR;

D) Impacts on fish, wildlife, and other aquatic resources and their habitat from release of CCR;

E) The potential effects of catastrophic release of CCR to the wetland and the resulting impacts on the environment; and

F) Any additional factors, as necessary, to demonstrate that ecological resources in the wetland are sufficiently protected.

4) To the extent required under section 404 of the Clean Water Act or applicable State wetlands laws, steps have been taken to attempt to achieve no net loss of wetlands (as defined by acreage and function) by first avoiding impacts to wetlands to the maximum extent reasonable as required by subsections (a)(1) through (3), then minimizing unavoidable impacts to the maximum extent reasonable, and, finally, offsetting remaining unavoidable wetland impacts through all appropriate and reasonable compensatory mitigation actions (e.g., restoration of existing degraded wetlands or creation of man-made wetlands); and

5) Sufficient information is available to make a reasoned determination with respect to the demonstrations in subsections (a)(1) through (4).

b) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of subsection (a).

c) The owner or operator of an existing CCR surface impoundment must complete the demonstration required by subsection (a) and submit the completed demonstration, along with the qualified professional engineer's certification, to the Agency with the facility's initial operating permit application.

d) The owner or operator of a new CCR surface impoundment or a lateral expansion of a CCR surface impoundment must submit plans and specifications in a construction permit application that demonstrate the CCR surface impoundment will be constructed under subsection (a). Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the CCR surface impoundment or lateral expansion was constructed in accordance with the requirements in subsection (a) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.320 Fault Areas

a) Existing and new CCR surface impoundments, and all lateral expansions of CCR surface impoundments, must not be located within 60 meters (200 feet) of the outermost damage zone of a fault that has had displacement in Holocene time unless the owner or operator demonstrates that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the CCR surface impoundment.

b) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of subsection (a).

c) The owner or operator of an existing CCR surface impoundment must complete the demonstration required by subsection (a) and submit the completed demonstration, along with the qualified professional engineer's certification, to the Agency with the facility's initial operating permit application.

d) The owner or operator of a new CCR surface impoundment or a lateral expansion of a CCR surface impoundment must submit plans and specifications in a construction permit application that demonstrate the CCR surface impoundment will be constructed under subsection (a). Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the CCR surface impoundment or lateral expansion was constructed in accordance with the requirements in subsection (a) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.330 Seismic Impact Zones

a) Existing and new CCR surface impoundments, and all lateral expansions of CCR surface impoundments, must not be located in seismic impact zones unless the owner or operator demonstrates that all structural components, including liners, leachate collection and removal systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site.

b) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of subsection (a).

c) The owner or operator of an existing CCR surface impoundment must complete the demonstration required by subsection (a) and submit the completed demonstration, along with the qualified professional engineer's certification, to the Agency with the facility's initial operating permit application.

d) The owner or operator of a new CCR surface impoundment or a lateral expansion of a CCR surface impoundment must submit plans and specifications in a construction permit application that demonstrate the CCR surface impoundment will be constructed under subsection (a). Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the CCR surface impoundment or lateral expansion was constructed in accordance with the requirements of subsection (a) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.340 Unstable Areas and Floodplains

a) An existing or new CCR surface impoundment, or any lateral expansion of a CCR surface impoundment, must not be located in an unstable area unless the owner or operator demonstrates that recognized and generally accepted engineering practices have been incorporated into the design of the CCR surface impoundment to ensure that the integrity of the structural components of the CCR surface impoundment will not be disrupted.

b) The owner or operator must consider all the following factors, at a minimum, when determining whether an area is unstable:

1) On-site or local soil conditions, including liquefaction, that may result in significant differential settling;

2) On-site or local geologic or geomorphologic features; and

3) On-site or local human-made features or events (both surface and subsurface).

c) An existing or new CCR surface impoundment, or any lateral expansion of a CCR surface impoundment, must not be located in a floodplain unless the owner or operator demonstrates that recognized and generally accepted engineering practices have been incorporated into the design of the CCR surface impoundment to ensure that the CCR surface impoundment will not restrict the flow of the base flood, reduce the temporary water storage capacity of a floodplain, or result in washout of CCR, so as to pose a hazard to human life, wildlife, or land or water resources. For purposes of this subsection (c):

1) Base flood means a flood that has a 1 percent or greater chance of recurring in any year or a flood of a magnitude equaled or exceeded once in 100 years on average within the time of historical river level records.

2) Floodplain means the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands, which are inundated by the base flood.

3) Washout means the carrying away of CCR by waters of the base flood.

d) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of subsections (a) and (c).

e) The owner or operator of an existing CCR surface impoundment must complete the demonstration required by subsections (a) and (c) of this Section and submit the completed demonstration, along with a qualified professional engineer's certification, to the Agency with the facility's initial operating permit application.

f) The owner or operator of a new CCR surface impoundment, or a lateral expansion of a CCR surface impoundment, must submit plans and specifications in a construction permit application that demonstrate the CCR surface impoundment will be constructed under subsections (a)and (c). Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the CCR surface impoundment or lateral expansion was constructed in accordance with the requirements in subsections (a) and (c) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.350 Failure to Meet Location Standards

a) An owner or operator of an existing CCR surface impoundment who fails to demonstrate compliance with the requirements of this Subpart is subject to the requirements of Section 845.700.

b) An owner or operator of a new CCR surface impoundment, or any lateral expansion of a CCR surface impoundment, who fails to make the demonstration showing compliance with the requirements of this Subpart is prohibited from placing CCR in the CCR surface impoundment.

SUBPART D: DESIGN CRITERIA

Section 845.400 Liner Design Criteria for Existing CCR Surface Impoundments

a) An existing CCR surface impoundment is considered to be an existing lined surface impoundment if it has been constructed with either a composite liner that meets the requirements of subsection (b) or an alternative composite liner that meets the requirements of subsection (c).

b) Composite Liner

1) A composite liner must consist of two components: the upper component consisting of, at a minimum, a 30-mil geomembrane liner, and the lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} centimeters per second (cm/sec). The geomembrane liner components consisting of high-density polyethylene (HDPE) must be at least 60 mil. The geomembrane liner or upper liner component must be installed in direct and uniform contact with the compacted soil or lower liner component.

2) The composite liner must be:

A) Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the CCR or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation;

B) Constructed of materials that provide appropriate shear resistance of the upper and lower component interface to prevent sliding of the upper component, including on slopes;

C) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift; and

D) Installed to cover all surrounding earth likely to be in contact with the CCR or leachate.

c) Alternative Composite Liner

1) An alternative composite liner must consist of two components: the upper component consisting of, at a minimum, a 30-mil geomembrane liner, and a lower component, that is not a geomembrane, with a liquid flow rate no greater than the liquid flow rate of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. The geomembrane liner components consisting of high-density polyethylene (HDPE) must be at least 60 mil. If the lower component of the alternative liner is compacted soil, the geomembrane liner must be installed in direct and uniform contact with the compacted soil.

2) The liquid flow rate through the lower component of the alternative composite liner must be no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. The hydraulic conductivity for the two feet of compacted soil used in the comparison must be no greater than 1×10^{-7} cm/sec. The hydraulic conductivity of any alternative to the two feet of compacted soil must be determined using recognized and generally accepted methods.

3) The liquid flow rate comparison must be made using the following equation, which is derived from Darcy's Law for gravity flow through porous media.

$$Q/A = q = k ((h/t)+1)$$

Where:
Q = flow rate (cubic centimeters/second)
A = Surface area of the liner (squared centimeters)
q = flow rate per unit area (cubic centimeters/ second/squared centimeter)
k = hydraulic conductivity of the liner (centimeters /second)
h = hydraulic head above the liner (centimeters); and
t = thickness of the liner (centimeters)

4) The alternative composite liner must meet the requirements specified in subsection (b).

d) The hydraulic conductivity of the compacted soil must be determined using recognized and generally accepted methods.

e) The owner or operator of an existing CCR surface impoundment that has not completed an Agency approved closure before July 30, 2021 must submit an initial operating permit application under Section 845.230 that demonstrates whether the CCR surface impoundment was constructed with either of the following:

1) A composite liner that meets the requirements of subsection (b); or

2) An alternative composite liner that meets the requirements of subsection (c).

f) A CCR surface impoundment is considered to be an unlined CCR surface impoundment if either:

1) The owner or operator of the CCR surface impoundment determines that the CCR surface impoundment is not constructed with a liner that meets the requirements of subsection (b) or (c); or

2) The owner or operator of the CCR surface impoundment fails to document whether the CCR surface impoundment was constructed with a liner that meets the requirements of subsection (b) or (c).

g) All unlined CCR surface impoundments are subject to the requirements of Section 845.700.

h) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer attesting that the CCR surface impoundment meets the requirements of subsection (a) and submit the certification to the Agency in the facility's initial operating permit application.

Section 845.410 Liner Design Criteria for New CCR Surface Impoundments and Any Lateral Expansion of a CCR Surface Impoundment

a) New CCR surface impoundments and lateral expansions of existing and new CCR surface impoundments must be designed, constructed, operated, and maintained with either a composite liner or an alternative composite liner that meets the requirements of Section 845.400(b) or (c).

b) Any liner specified in this Section must be installed to cover all surrounding earth likely to be in contact with CCR. Dikes must not be constructed so as to damage the composite liner.

c) Before construction, the owner or operator must obtain certification from a qualified professional engineer that the design of the composite liner or, if applicable, the design of an alternative composite liner complies with the requirements of this Section and submit this certification to the Agency in the facility's construction permit application.

d) Upon completion of construction, the owner or operator must obtain a certification from a qualified professional engineer that the composite liner or, if applicable, the alternative composite liner has been constructed in accordance

with the requirements of this Section and submit this certification to the Agency in the facility's initial operating permit application.

Section 845.420 Leachate Collection and Removal System

A new CCR surface impoundment must be designed, constructed, operated and maintained with a leachate collection and removal system. The leachate collection and removal system must be designed, constructed, operated, and maintained to collect and remove leachate from the leachate collection system of the CCR surface impoundment during its active life and post-closure care period.

a) The leachate collection and removal system must:

1) Be placed above the liner required by Section 845.400 or Section 845.410;

2) Have placed above it a filter layer that has a hydraulic conductivity of at least 1 x 10^{-5} cm/sec;

3) Have a bottom slope of three percent or more towards the collection pipes;

4) Be constructed of:

A) Granular drainage materials with a hydraulic conductivity of 1 x 10^{-1} cm/sec or more and a thickness of 24 inches or more above the crown of the collection pipe; or

B) Synthetic drainage materials with a transmissivity of 6 x 10^{-4} m^2/sec or more;

5) Be constructed of materials that are chemically resistant to CCR and any non-CCR waste managed in the CCR surface impoundment and the leachate expected to be generated, and of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying waste and any waste cover materials and equipment used at the CCR surface impoundment;

6) Be designed, constructed and operated with collection pipes at the base of the granular material to prevent clogging with fines during the active life and post-closure care period;

7) Have collection pipes

A) Designed such that leachate is collected at a sump and is pumped or flows out of the CCR surface impoundment;

B) With slopes that allow flow from all points within the CCR surface impoundment to the sump or drain outlet; and

C) Large enough to conduct periodic cleaning;

8) Have a protective layer or other means of deflecting the force of CCR pumped into the CCR surface impoundment;

9) Be designed and operated to minimize clogging during the active life and post-closure care period; and

10) At a minimum, the leachate collection and removal system must be operated to remove free liquids from the CCR surface impoundment at the time of closure and during post closure care.

b) The owner or operator must obtain certification from a qualified professional engineer that the design of the leachate collection system complies with the requirements of this Section and submit this certification to the Agency in the facility's construction permit application.

c) Upon completion, the owner or operator must obtain a certification from a qualified professional engineer that the leachate collection system has been constructed in accordance with the requirements of this Section and submit this certification to the Agency in the facility's initial operating permit application.

Section 845.430 Slope Maintenance

The slopes and pertinent surrounding areas of the CCR surface impoundment must be designed, constructed, operated, and maintained with one of the forms of slope protection specified in subsection (a) that meets all the performance standards of subsection (b).

a) Slope protection must consist of one of the following:

1) A vegetative cover consisting of grassy vegetation;

2) An engineered cover consisting of a single form or combination of forms of engineered slope protection measures; or

3) A combination of the forms of cover specified in subsection (a)(1) or (a)(2).

b) Any form of cover for slope protection must meet the following performance standards:

1) The cover must be installed and maintained on the slopes and pertinent surrounding areas of the CCR surface impoundment;

2) The cover must provide protection against surface erosion, wave action, and adverse effects of rapid drawdown;

3) The cover must be maintained to allow for the observation of, and access to, the slopes and pertinent surrounding areas during routine and emergency events;

4) Woody vegetation must be removed from the slopes or pertinent surrounding areas. Any removal of woody vegetation with a diameter greater than ½ inch must be directed by a person familiar with the design and operation of the CCR surface impoundment and in consideration of the complexities of removal of a tree or shrubbery, who must ensure the removal does not create a risk of destabilizing the CCR surface impoundment or otherwise adversely affect the stability and safety of the CCR surface impoundment or personnel undertaking the removal; and

5) The height of vegetation must not exceed 12 inches.

Section 845.440 Hazard Potential Classification Assessment

a) Hazard Potential Classification Assessments

1) The owner or operator of the CCR surface impoundment must conduct an initial and annual hazard potential classification assessment of the CCR surface impoundment. The owner or operator must document the hazard potential classification of each CCR surface impoundment as either a Class 1 or Class 2 CCR surface impoundment. The owner or operator must also document the basis for each hazard potential classification.

2) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the initial hazard potential classification and each annual classification was conducted in accordance with the requirements of this Section.

3) Timeframe for Submission of the Hazard Potential Classification Assessments and Certifications

A) The owner or operator of a new CCR surface impoundment must submit the initial hazard potential classification assessment certification with the initial operating permit application before the initial receipt of CCR in the surface impoundment.

B) The owner or operator of an existing CCR surface impoundment must submit the initial hazard potential classification assessment certification with its first annual inspection report required by Section 845.540(b).

C) The owner or operator of a CCR surface impoundment must submit the annual hazard potential classification assessment certification each year with the annual inspection required by Section 845.540(b).

D) The owner or operator of a CCR surface impoundment must place each hazard potential classification assessment in the facility's operating record (see Section 845.800(d)(4)).

b) The requirements of this Section apply to all CCR surface impoundments, except for those CCR surface impoundments that are incised CCR surface impoundments. If an incised CCR surface impoundment is subsequently modified (e.g., a dike is constructed) such that the CCR surface impoundment no longer meets the definition of an incised CCR surface impoundment, the CCR surface impoundment is subject to the requirements of this Section.

Section 845.450 Structural Stability Assessment

a) The owner or operator of a CCR surface impoundment must conduct initial and annual structural stability assessments and document whether the design, construction, operation, and maintenance of the CCR surface impoundment is consistent with recognized and generally accepted engineering practices for the maximum volume of CCR and CCR wastewater that can be impounded in the CCR surface impoundment. The assessment must, at a minimum, document whether the CCR surface impoundment has been designed, constructed, operated, and maintained with:

1) Stable foundations and abutments;

2) Adequate slope protection to protect against surface erosion, wave action, and adverse effects of sudden drawdown;

3) Dikes mechanically compacted to a density sufficient to withstand the range of loading conditions in the CCR surface impoundment;

4) Slope protection consistent with Section 845.430;

5) A single spillway or a combination of spillways configured as specified in subsection (a)(5)(A). The combined capacity of all spillways must be designed, constructed, operated, and maintained to adequately manage

flow during and following the peak discharge from the event specified in subsection (a)(5)(B).

A) All spillways must be either:

i) Of non-erodible construction and designed to carry sustained flows; or

ii) Earth- or grass-lined and designed to carry short-term, infrequent flows at non-erosive velocities where sustained flows are not expected.

B) The combined capacity of all spillways must adequately manage flow during and following the peak discharge from a:

i) Probable maximum flood for a Class 1 CCR surface impoundment; or

ii) 1000-year flood for a Class 2 CCR surface impoundment.

6) Hydraulic structures underlying the base of the CCR surface impoundment or passing through the dike of the CCR surface impoundment that maintain structural integrity and are free of significant deterioration, deformation, distortion, bedding deficiencies, sedimentation, and debris that may negatively affect the CCR surface impoundment; and

7) For CCR surface impoundments with downstream slopes that can be inundated by the pool of an adjacent water body, such as a river, stream or lake, downstream slopes that maintain structural stability during low pool of the adjacent water body or sudden drawdown of the adjacent water body.

b) The annual assessment described in this Section must identify any structural stability deficiencies associated with the CCR surface impoundment in addition to recommending corrective measures. If a deficiency or a release is identified during the periodic assessment, the owner or operator of the surface impoundment must submit to the Agency a construction permit application including documentation detailing proposed corrective measures and must obtain any necessary permits from the Agency as soon as feasible.

c) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the initial structural stability assessments and each annual assessment thereafter was conducted in accordance with the requirements.

d) Timeframe for Submission of Structural Stability Assessment

1) The owner or operator of a new CCR surface impoundment must submit the initial structural stability assessment certification with the initial operating permit application before the initial receipt of CCR in the surface impoundment.

2) The owner or operator of an existing CCR surface impoundment must submit the initial structural stability assessment certification with its first annual inspection report required by Section 845.540(b).

3) The owner or operator of a CCR surface impoundment must submit the annual structural stability assessment certification each year with the annual inspection required by Section 845.540(b).

4) The owner or operator of a CCR surface impoundment must place each structural stability assessment in the facility's operating record (see Section 845.800(d)(5)).

e) The requirements of this Section apply to all CCR surface impoundments, except for those CCR surface impoundments that are incised CCR surface impoundments. If an incised CCR surface impoundment is subsequently modified (e.g., a dike is constructed) such that the CCR surface impoundment no longer meets the definition of an incised CCR surface impoundment, the CCR surface impoundment is subject to the requirements of this Section.

Section 845.460 Safety Factor Assessment

a) The owner or operator of a CCR surface impoundment must conduct an initial and annual safety factor assessment for each CCR surface impoundment and document whether the calculated factors of safety for each CCR surface impoundment achieve the minimum safety factors specified in this Section for the critical cross-section of the embankment. The critical cross-section is the cross section anticipated to be the most susceptible of all cross-sections to structural failure based on appropriate engineering considerations, including loading conditions. The safety factor assessments must be supported by appropriate engineering calculations.

1) For new CCR surface impoundments, the calculated static factor of safety under the end-of-construction loading condition must equal or exceed 1.30. The assessment of this loading condition is only required for the initial safety factor assessment and is not required for subsequent assessments.

2) The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.50.

3) The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40.

4) The calculated seismic factor of safety must equal or exceed 1.00.

5) For dikes constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

b) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the initial safety factor assessment and each annual assessment thereafter was conducted in accordance with the requirements of this Section.

c) Timeframe for Submission of the Safety Factor Assessment

1) The owner or operator of a new CCR surface impoundment must submit the initial safety factor assessment certification with the initial operating permit application before the initial receipt of CCR in the surface impoundment.

2) The owner or operator of an existing CCR surface impoundment must submit the initial safety factor assessment certification with its first annual inspection report required by Section 845.540(b).

3) The owner or operator of a CCR surface impoundment must submit the annual safety factor assessment certification each year with the annual inspection required by Section 845.540(b).

4) The owner or operator of a new CCR surface impoundment must place each safety factor assessment in the facility's operating record as required by Section 845.800(d)(6).

d) Failure to Document Minimum Safety Factors

1) For new CCR surface impoundments, until the date an owner or operator of a CCR surface impoundment documents that the calculated factors of safety achieve the minimum safety factors specified in this Section, the owner or operator is prohibited from placing CCR in the CCR surface impoundment.

2) An owner or operator of the CCR surface impoundment who either fails to complete a timely safety factor assessment or fails to demonstrate minimum safety factors as required by this Section is subject to the requirements of Section 845.700.

e) The requirements of this Section apply to all CCR surface impoundments, except for those CCR surface impoundments that are incised CCR surface impoundments. If an incised CCR surface impoundment is subsequently modified (e.g., a dike is constructed) such that the CCR surface impoundment no longer meets the definition of an incised CCR surface impoundment, the CCR surface impoundment is subject to the requirements of this Section.

SUBPART E: OPERATING CRITERIA

Section 845.500 Air Criteria

a) The owner or operator of a CCR surface impoundment, or any lateral expansion of a CCR surface impoundment, must adopt measures that will effectively minimize CCR from becoming airborne at the facility, including CCR fugitive dust originating from CCR surface impoundments, roads, and other CCR management and material handling activities.

b) CCR Fugitive Dust Control Plan. The owner or operator of the CCR surface impoundment must prepare and operate in accordance with a CCR fugitive dust control plan as specified in this subsection (b). This requirement applies in addition to, not in place of, any applicable standards under the Occupational Safety and Health Act (29 USC 15), including 29 CFR 1910.1018, 29 CFR 1910.1024, 29 CFR 1910.1025, 29 CFR 1910.1027, and 1910.1053, or any other State or federal law.

1) The CCR fugitive dust control plan must identify and describe the CCR fugitive dust control measures the owner or operator will use to minimize CCR from becoming airborne at the facility. The owner or operator must select, and include in the CCR fugitive dust control plan, the CCR fugitive dust control measures that are most appropriate for site conditions, along with an explanation of how the measures selected are applicable and appropriate for site conditions. Examples of control measures that may be appropriate include: locating CCR inside an enclosure or partial enclosure; operating a water spray or fogging system; reducing fall distances at material drop points; using wind barriers, compaction, or vegetative covers; establishing and enforcing reduced vehicle speed limits; paving and sweeping roads; covering trucks transporting CCR; reducing or halting operations during high wind events; or applying a daily cover.

2) The CCR fugitive dust control plan must include procedures to log every complaint from members of the public received by the owner or operator involving CCR fugitive dust events at the facility. The owner or operator must:

A) Include for each logged complaint the date of the complaint, the date of the incident, the name and contact information of the

complainant, if given, and all actions taken to assess and resolve the complaint; and

B) Submit quarterly reports to the Agency no later than 14 days from the end of the quarter of all complaints received in that quarter, including the information required by subsection (b)(2)(A).

3) The CCR fugitive dust control plan must include a description of the procedures the owner or operator will follow to periodically assess the effectiveness of the control plan.

4) The owner or operator of a CCR surface impoundment must prepare an initial CCR fugitive dust control plan for the facility by October 31, 2021, or by initial receipt of CCR in any CCR surface impoundment at the facility if the owner or operator becomes subject to this Part after October 31, 2021.

5) Amendment of the Plan. The owner or operator of a CCR surface impoundment subject to the requirements may amend the written CCR fugitive dust control plan at any time provided the revised plan is submitted to the Agency. The owner or operator must amend the written plan whenever there is a change in conditions that would substantially affect the written plan in effect, such as the construction and operation of a new CCR surface impoundment.

6) The owner or operator must place the initial and any amendments to the fugitive dust control plan in the facility's operating record as required by Section 845.800(d)(7). The most recent fugitive dust control plan must be placed in the facility's operating record and available on the owner's or operator's CCR website before submitting a permit application under this Part.

7) The owner or operator must obtain a certification from a qualified professional engineer that the initial CCR fugitive dust control plan, or any subsequent amendment of it, meets the requirements of this Section.

c) Annual CCR Fugitive Dust Control Report. The owner or operator of a CCR surface impoundment must prepare an annual CCR fugitive dust control report that includes a description of the actions taken by the owner or operator to control CCR fugitive dust and the four quarterly fugitive dust complaint reports submitted under subsection (b)(2)(B). The annual CCR fugitive dust control report must be submitted as a part of the annual consolidated report required by Section 845.550.

Section 845.510 Hydrologic and Hydraulic Capacity Requirements for CCR Surface Impoundments

a) The owner or operator of an existing or new CCR surface impoundment or any lateral expansion of a CCR surface impoundment must design, construct, operate, and maintain an inflow design flood control system as specified in subsections (a)(1) and (2).

1) The inflow design flood control system must adequately manage flow into the CCR surface impoundment during and following the peak discharge of the inflow design flood specified in subsection (a)(3).

2) The inflow design flood control system must adequately manage flow from the CCR surface impoundment to collect and control the peak discharge resulting from the inflow design flood specified in subsection (a)(3).

3) The inflow design flood, at a minimum, is:

A) For a Class 1 CCR surface impoundment, as determined under Section 845.440(a), the probable maximum flood;

B) For a Class 2 CCR surface impoundment, as determined under Section 845.440(a), the 1000-year flood; or

C) For an incised CCR surface impoundment, the 25-year flood.

b) Discharge from the CCR surface impoundment must be handled in accordance with the surface water requirements in Section 845.110(b)(3) and 35 Ill. Adm. Code Subtitle C.

c) Inflow Design Flood Control System Plan

1) Content of the Plan. The owner or operator must prepare initial and annual inflow design flood control system plans for the CCR surface impoundment. These plans must document how the inflow design flood control system has been designed and constructed to meet the requirements of this Section. Each plan must be supported by appropriate engineering calculations.

2) Amendment of the Plan. The owner or operator of the CCR surface impoundment may amend the written inflow design flood control system plan at any time. The owner or operator must amend the written inflow design flood control system plan whenever there is a change in conditions that would substantially affect the written plan in effect.

3) The owner or operator must obtain a certification from a qualified professional engineer stating that the initial and periodic inflow design flood control system plans meet the requirements of this Section.

4) Timeframe for Plan Submission

A) The owner or operator of a new CCR surface impoundment must submit to the Agency the initial inflow design flood control system plan certification with the initial operating permit application before the initial receipt of CCR in the surface impoundment.

B) The owner or operator of an existing CCR surface impoundment must submit the initial inflow design flood control system plan certification with its first annual inspection report required by Section 845.540(b).

C) The owner or operator of a CCR surface impoundment must submit the annual inflow design flood control system plan certification each year with the annual inspection required by Section 845.540(b).

D) The owner or operator of a new CCR surface impoundment must place each inflow design flood control system plan in the facility's operating record (see Section 845.800(d)(8)).

Section 845.520 Emergency Action Plan

a) The owner or operator of a CCR surface impoundment must prepare and maintain a written Emergency Action Plan (EAP). The owner or operator must place the EAP and any amendment of the EAP in the facility's operating record (see Section 845.800(d)(9)).

b) At a minimum, the EAP must:

1) Define the events or circumstances involving the CCR surface impoundment that represent a safety emergency, along with a description of the procedures that will be followed to detect a safety emergency in a timely manner;

2) Define responsible persons, their respective responsibilities, and notification procedures for a safety emergency involving the CCR surface impoundment;

3) Provide contact information of emergency responders;

4) Include a map that delineates the downstream area that would be affected if a CCR surface impoundment fails and a physical description of the CCR surface impoundment; and

5) Include provisions for an annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR surface impoundment and the local emergency responders.

c) The owner or operator of a CCR surface impoundment must prepare an initial Emergency Action Plan for the facility by October 31, 2021, or by initial receipt of CCR in any CCR surface impoundment at the facility if the owner or operator becomes subject to this Part after October 31, 2021.

d) Amendment of the Plan

1) The owner or operator of a CCR surface impoundment may amend the written EAP at any time.

2) The owner or operator must amend the written EAP whenever there is a change in conditions that would substantially affect the EAP in effect.

3) The written EAP must be evaluated, at a minimum, every five years to ensure the information required in this Section is accurate.

e) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the written EAP, and any subsequent amendment of the EAP, meets the requirements of this Section.

f) Activation of the EAP. The EAP must be implemented once events or circumstances involving the CCR surface impoundment that represent a safety emergency are detected, including conditions identified during any structural stability assessments, annual inspections, and inspections by a qualified person. The owner or operator of the CCR surface impoundment must submit records documenting all activations of the EAP to the Agency and place the documentation in the facility's operating record as required by Section 845.800(d)(10).

g) The owner or operator of a CCR surface impoundment must document the annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR surface impoundment and the local emergency responders as required by subsection (b)(5). The owner or operator of the CCR surface impoundment must place this documentation in the facility's operating record as required by Section 845.800(d)(11).

Section 845.530 Safety and Health Plan

a) The owner or operator of the CCR surface impoundment must develop a Safety and Health Plan and ensure that employees, contract workers, and third-party contractors are informed regarding the Safety and Health Plan. The owner or

operator must conduct ongoing worker hazard analyses and ensure employees, contract workers, and third-party contractors are aware of those analyses. The plan must be updated as needed based on the worker hazard analyses, but at least annually. The plan, and all amendments to the plan, must be placed in the facility's operating record as required by Section 845.800(d)(12), and on the owner's or operator's publicly accessible internet site.

b) For worker exposure safety, in addition to all other applicable local, State and federal requirements, the owner or operator of the CCR surface impoundment, for all chemical constituents identified in the CCR under Sections 845.230(a)(15) and 845.230(d)(2)(C), must:

1) Consider the recommendations in the most recent "NIOSH Pocket Guide to Chemical Hazards", Department of Human Health and Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (available at cdc.gov/niosh/npg/default.html);

2) Implement the Occupational Safety and Health Administration regulations in Chapter 17 of Title 29 of the Code of Federal Regulations for all hazards not otherwise classified as defined in 29 CFR 1910.1200(c); and

3) Provide safety data sheets (Globally Harmonized System of Classification and Labeling of Chemicals adopted by OSHA) or create a facility-specific safety data sheet under 29 CFR 1910.1200(g).

c) The Safety and Health Plan must include a personnel training program that meets the following minimum requirements:

1) Employees, contract workers, and third-party contractors must successfully complete a training program that informs them of the hazards at the facility to ensure compliance with the requirements of this Part. The facility must maintain an outline of the training program used (or to be used) at the facility and a brief description of training program updates.

2) At a minimum, the training program must be designed to ensure that employees, contract workers, and third-party contractors understand and are able to respond effectively to the following:

A) Procedures for using, inspecting, repairing, and replacing facility emergency and monitoring equipment;

B) Communications or alarm systems;

C) Response to fires or explosions;

D) Response to a spill or release of CCR;

E) The training under the Occupational Safety and Health Standards in 29 CFR 1910.120, 29 CFR 1926.65, and the OSHA 10-hour or 30-hour construction safety training;

F) Information about chemical hazards and hazardous materials identified in subsection (b); and

G) The use of engineering controls, administrative controls, and personal protective equipment.

d) Employees, contract workers, and third-party contractors must successfully complete the program required in subsection (c) before undertaking any activity to construct, operate or close a CCR surface impoundment.

e) Employees, contract workers, and third-party contractors must take part in an annual review of the initial training required in subsection (c).

f) The owner or operator of the CCR surface impoundment must perform, at a minimum, the following hazard communication activities:

1) Post signs at the facility identifying the hazards of CCR, including dust inhalation when handling CCR;

2) Post signs at the facility identifying unstable CCR areas that may make operation of heavy equipment hazardous; and

3) Post signs at the facility where the CCR surface impoundment is located identifying safety measures and necessary precautions, including the proper use of personal protective equipment.

Section 845.540 Inspection Requirements for CCR Surface Impoundments

a) Inspections by a Qualified Person.

1) All CCR surface impoundments and any lateral expansion of a CCR surface impoundment must be examined by a qualified person as follows:

A) At intervals not exceeding seven days and after each 25-year, 24-hour storm, inspect for the following:

i) Any appearances of actual or potential structural weakness and other conditions that are disrupting, or have the potential to disrupt, the operation or safety of the CCR surface impoundment;

ii) Deterioration, malfunctions or improper operation of overtopping control systems, where present;

iii) Sudden drops in the level of the CCR surface impoundment's contents;

iv) Erosion that creates rills, gullies, or crevices six inches or deeper, other signs of deterioration including failed or eroded vegetation in excess of 100 square feet, or cracks in dikes or other containment devices; and

v) Any visible releases;

B) At intervals not exceeding seven days, inspect the discharge of all outlets of hydraulic structures that pass underneath the base of the CCR surface impoundment or through the dike, of the CCR surface impoundment, for abnormal discoloration, flow or discharge of debris or sediment; and

C) At intervals not exceeding 30 days, monitor all CCR surface impoundment instrumentation.

2) The owner or operator must prepare a report for each inspection that includes the date of the inspection, condition of the CCR surface impoundment, any repairs made to the CCR surface impoundment, and the date of the repair. The results of the inspection by a qualified person must be recorded in the facility's operating record as required by Section 845.800(d)(13).

3) The owner or operator of a CCR surface impoundment must initiate the inspections required by subsection (a) by April 30, 2021, or by initial receipt of CCR in a CCR surface impoundment if the owner or operator becomes subject to this Part after April 30, 2021. The inspections required by subsection (a) must continue until the completion of closure by removal or the completion of post-closure care.

4) If a 25-year, 24-hour storm is identified more than 48 hours before the next scheduled weekly inspection, an additional inspection must be conducted within 24 hours after the end of the identified storm event, before the scheduled seven-day inspection.

b) Annual Inspections By a Qualified Professional Engineer.

1) The CCR surface impoundment must be inspected on an annual basis by a qualified professional engineer to ensure that the design, construction,

operation, and maintenance of the CCR surface impoundment is consistent with recognized and generally accepted engineering standards. The inspection must, at a minimum, include:

A) A review of available information regarding the status and condition of the CCR surface impoundment, including files available in the operating record (e.g., CCR surface impoundment design and construction information required by Sections 845.220(a)(1) and 845.230(d)(2)(A), previous structural stability assessments required under Section 845.450, the results of inspections by a qualified person, and results of previous annual inspections);

B) A visual inspection of the CCR surface impoundment to identify signs of distress or malfunction of the CCR surface impoundment and appurtenant structures;

C) A visual inspection of any hydraulic structures underlying the base of the CCR surface impoundment or passing through the dike of the CCR surface impoundment for structural integrity and continued safe and reliable operation;

D) The annual hazard potential classification certification, if applicable (see Section 845.440);

E) The annual structural stability assessment certification, if applicable (see Section 845.450);

F) The annual safety factor assessment certification, if applicable (see Section 845.460); and

G) The inflow design flood control system plan certification (see Section 845.510(c)).

2) Inspection Report. The qualified professional engineer must prepare a report following each inspection that addresses the following:

A) Any changes in geometry of the impounding structure since the previous annual inspection;

B) The location and type of existing instrumentation and the maximum recorded readings of each instrument since the previous annual inspection;

C) The approximate minimum, maximum, and present depth and elevation of the impounded water and CCR since the previous annual inspection;

D) The storage capacity of the impounding structure at the time of the inspection;

E) The approximate volume of the impounded water and CCR at the time of the inspection;

F) Any appearances of an actual or potential structural weakness of the CCR surface impoundment, in addition to any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the CCR surface impoundment and appurtenant structures; and

G) Any other changes that may have affected the stability or operation of the impounding structure since the previous annual inspection.

3) By January 31 of each year, the inspection report must be completed and included with the annual consolidated report required by Section 845.550.

4) Frequency of Inspections. The owner or operator of the CCR surface impoundment must conduct the inspection required by subsections (b)(1) and (2) on an annual basis. The deadline for conducting a subsequent inspection is based on the date of conducting the previous inspection.

5) If a deficiency or release is identified during an inspection, the owner or operator must submit to the Agency documentation detailing proposed corrective measures and obtain any necessary permits from the Agency.

Section 845.550 Annual Consolidated Report

a) By January 31 of each year, the owner or operator of the CCR surface impoundment must prepare an annual consolidated report for the preceding calendar year that includes the following:

1) Annual CCR fugitive dust control report (see Section 845.500(c));

2) Annual inspection report (see Section 845.540(b)), including:

A) Annual hazard potential classification certification, if applicable (see Section 845.440);

B) Annual structural stability assessment certification, if applicable (see Section 845.450);

C) Annual safety factor assessment certification, if applicable (see Section 845.460); and

D) Inflow design flood control system plan certification (see Section 845.510(c)).

3) Annual Groundwater Monitoring and Corrective Action Report (see Section 845.610(e)).

b) The owner or operator of the CCR surface impoundment must submit the annual consolidated report to the Agency in addition to placing the annual consolidated report in the facility's operating record as required by Section 845.800(d)(14).

SUBPART F: GROUNDWATER MONITORING AND CORRECTIVE ACTION

Section 845.600 Groundwater Protection Standards

a) For existing CCR surface impoundments and for inactive CCR surface impoundments:

1) The groundwater protection standards at the waste boundary must be:

A) Antimony: 0.006 mg/L

B) Arsenic: 0.010 mg/L

C) Barium: 2.0 mg/L

D) Beryllium: 0.004 mg/L

E) Boron: 2 mg/L

F) Cadmium: 0.005 mg/L

G) Chloride: 200 mg/L

H) Chromium: 0.1 mg/L

I) Cobalt: 0.006 mg/L

J) Fluoride: 4.0 mg/L

K) Lead: 0.0075 mg/L

L) Lithium: 0.04 mg/L

M) Mercury: 0.002 mg/L

N) Molybdenum: 0.1 mg/L

O) pH: 6.5-9.0 units

P) Selenium: 0.05 mg/L

Q) Sulfate: 400 mg/L

R) Thallium: 0.002 mg/L

S) Total Dissolved Solids: 1200 mg/L

T) Radium 226 and 228 combined: 5 pCi/L

2) For constituents with a background concentration higher than the levels identified in subsection (a)(1), the background concentration must be the groundwater protection standard.

b) For new CCR surface impoundments, the groundwater protection standards at the waste boundary must be background for the constituents listed in subsection (a)(1), calcium, and turbidity.

c) The owner or operator of a CCR surface impoundment may not obtain alternative groundwater quality standards in 35 Ill. Adm. Code 620.450(a)(4) for the constituents in subsections (a) and (b) before the end of post-closure care under Section 845.780, when closing with a final cover system, or before the end of groundwater monitoring under Section 845.740(b), when closing by removal.

Section 845.610 General Requirements

a) All CCR surface impoundments and lateral expansions of CCR surface impoundments are subject to the groundwater monitoring and corrective action requirements of this Subpart.

b) Required Submissions and Agency Approvals for Groundwater Monitoring

1) Existing CCR Surface Impoundments. The owner or operator of an existing CCR surface impoundment must submit the following to the Agency in an initial operating permit application:

A) A hydrogeologic site characterization meeting the requirements of Section 845.620;

B) Design and construction plans of a groundwater monitoring system meeting the requirements of Section 845.630;

C) A groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data as required by Section 845.640; and

D) A monitoring program that includes a minimum of eight independent samples for each background and downgradient well as required by Section 845.650(b).

2) New CCR Surface Impoundments. The owner or operator of a new CCR surface impoundment and all lateral expansions of a CCR surface impoundment must submit the information required in subsections (b)(1)(A) through (C) in a construction permit application, and the information required in subsection (b)(1)(D) in an operating permit application.

3) All owners and operators of CCR surface impoundments must:

A) Conduct groundwater monitoring under a monitoring program approved by the Agency under this Subpart;

B) Evaluate the groundwater monitoring data for statistically significant levels over background levels for the constituents listed in Section 845.600 after each sampling event;

C) Determine compliance with the groundwater protection standards in Section 845.600 after each sampling event; and

D) Submit all groundwater monitoring data to the Agency and any analysis performed under subsections (b)(3)(B) and (b)(3)(C) within 60 days after completion of sampling, and place the groundwater monitoring data in the facility's operating record as required by Section 845.800(d)(15).

c) Once the groundwater monitoring system and the groundwater monitoring program have been established at the CCR surface impoundment as required by this Subpart, the owner or operator must conduct groundwater monitoring and, if necessary, corrective action throughout the active life and post-closure care period of the CCR surface impoundment or the time period specified in Section 845.740(b) when closure is by removal.

d) If a CCR surface impoundment has a release, the owner or operator must immediately take all necessary measures to control all sources of the release to reduce or eliminate, to the maximum extent feasible, further releases of contaminants into the environment. The owner or operator of the CCR surface impoundment must comply with all applicable requirements of Sections 845.660, 845.670, and 845.680.

e) Annual Groundwater Monitoring and Corrective Action Report

1) The owner or operator of the CCR surface impoundment must prepare and submit to the Agency an annual groundwater monitoring and corrective action report as a part of the annual consolidated report required by Section 845.550.

2) For the preceding calendar year, the annual report must document the status of the groundwater monitoring and corrective action plan for the CCR surface impoundment, summarize key actions completed, including the status of permit applications and Agency approvals, describe any problems encountered, discuss actions to resolve the problems, and project key activities for the upcoming year.

3) At a minimum, the annual groundwater monitoring and corrective action report must contain the following information, to the extent available:

A) A map, aerial image, or diagram showing the CCR surface impoundment, all background (or upgradient) and downgradient monitoring wells, including the well identification numbers, that are part of the groundwater monitoring program for the CCR surface impoundment, and a visual delineation of any exceedances of the groundwater protection standards;

B) Identification of any monitoring wells that were installed or decommissioned during the preceding year, along with a narrative description of why those actions were taken;

C) A potentiometric surface map for each groundwater elevation sampling event required by Section 845.650(b)(2);

D) In addition to all the monitoring data obtained under this Subpart, a summary including the number of groundwater samples that were collected for analysis for each background and downgradient well, and the dates the samples were collected;

E) A narrative discussion of any statistically significant increases over background levels for the constituents listed in Section 845.600; and

F) Other information required to be included in the annual report as specified in this Subpart.

4) A section at the beginning of the annual report must provide an overview of the current status of groundwater monitoring program and corrective action plan for the CCR surface impoundment. At a minimum, the summary must:

A) Specify whether groundwater monitoring data shows a statistically significant increase over background concentrations for one or more constituents listed in Section 845.600;

B) Identify those constituents having a statistically significant increase over background concentrations and the names of the monitoring wells associated with the increase;

C) Specify whether there have been any exceedances of the groundwater protection standards for one or more constituents listed in Section 845.600;

D) Identify those constituents with exceedances of the groundwater protection standards in Section 845.600 and the names of the monitoring wells associated with the exceedance;

E) Provide the date when the assessment of corrective measures was initiated for the CCR surface impoundment;

F) Provide the date when the assessment of corrective measures was completed for the CCR surface impoundment;

G) Specify whether a remedy was selected under Section 845.670 during the current annual reporting period, and if so, the date of remedy selection; and

H) Specify whether remedial activities were initiated or are ongoing under Section 845.780 during the current annual reporting period.

Section 845.620 Hydrogeologic Site Characterization

a) The owner or operator of the CCR surface impoundment must design and implement a hydrogeologic site characterization.

b) The hydrogeologic site characterization must include, but is not limited to, the following:

1) Geologic well logs/boring logs;

2) Climatic aspects of the site, including seasonal and temporal fluctuations in groundwater flow;

3) Identification of nearby surface water bodies and drinking water intakes;

4) Identification of nearby pumping wells and associated uses of the groundwater;

5) Identification of nearby dedicated nature preserves;

6) Geologic setting;

7) Structural characteristics;

8) Geologic cross-sections;

9) Soil characteristics;

10) Identification of confining layers;

11) Identification of potential migration pathways;

12) Groundwater quality data;

13) Vertical and horizontal extent of the geologic layers to a minimum depth of 100 feet below land surface, including lithology and stratigraphy;

14) A map displaying any known underground mines beneath a CCR surface impoundment;

15) Chemical and physical properties of the geologic layers to a minimum depth of 100 feet below land surface;

16) Hydraulic characteristics of the geologic layers identified as migration pathways and geologic layers that limit migration, including:

    A) Water table depth;

    B) Hydraulic conductivities;

    C) Effective and total porosities;

    D) Direction and velocity of groundwater flow; and

E) Map of the potentiometric surface;

17) Groundwater classification under 35 Ill. Adm. Code 620; and

18) Any other information requested by the Agency that is relevant to the hydrogeologic site characterization.

Section 845.630 Groundwater Monitoring Systems

a) Performance Standard. The owner or operator of a CCR surface impoundment must install a groundwater monitoring system that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples that:

1) Accurately represent the quality of background groundwater that has not been affected by leakage from a CCR surface impoundment. A determination of background quality may include sampling of wells that are not hydraulically upgradient of the CCR management area where:

A) Hydrogeologic conditions do not allow the owner or operator of the CCR surface impoundment to determine what wells are hydraulically upgradient; or

B) Sampling at other wells will provide an indication of background groundwater quality that is demonstratively as representative or more representative than that provided by the upgradient wells; and

2) Accurately represent the quality of groundwater passing the waste boundary of the CCR surface impoundment. The downgradient monitoring system must be installed at the waste boundary that ensures detection of groundwater contamination. All potential contaminant pathways must be monitored.

b) The number, spacing, and depths of monitoring system wells must be determined based upon site-specific technical information identified in the hydrogeologic site characterization conducted under Section 845.620.

c) The groundwater monitoring system must include a sufficient number of monitoring wells necessary to meet the performance standards specified in subsection (a) based on the site-specific information specified in subsection (b). The groundwater monitoring system must contain:

1) A minimum of one upgradient and three downgradient monitoring wells; and

2) Additional monitoring wells as necessary to accurately represent the quality of background groundwater that has not been affected by leakage from the CCR surface impoundment and the quality of groundwater passing the waste boundary of the CCR surface impoundment.

d) Multiunit Groundwater Monitoring System

1) The owner or operator of multiple CCR surface impoundments may install a multiunit groundwater monitoring system instead of separate groundwater monitoring systems for each CCR surface impoundment.

2) The multiunit groundwater monitoring system must be equally as capable of detecting monitored constituents at the waste boundary of the CCR surface impoundment as the individual groundwater monitoring system specified in subsections (a) through (c) for each CCR surface impoundment, based on the following factors:

A) Number, spacing, and orientation of each CCR surface impoundment;

B) Hydrogeologic setting;

C) Site history; and

D) Engineering design of the CCR surface impoundment.

e) Monitoring wells must be properly constructed in a manner consistent with the standards of 77 Ill. Adm. Code 920.170.

1) The owner or operator must document and include in the facility's operating record the design, installation, development, and decommissioning of any monitoring wells, piezometers and other measurement, sampling, and analytical devices. The qualified professional engineer must be given access to this documentation when completing the groundwater monitoring system certification required by subsection (g).

2) The monitoring wells, piezometers, and other measurement, sampling, and analytical devices must be operated and maintained so that they perform to the design specifications throughout the life of the monitoring program.

f) The owner or operator of a new CCR surface impoundment must submit a construction permit application containing documentation showing that the groundwater monitoring system is designed to meet the requirements of this Section. The owner or operator of all CCR surface impoundments must submit an operating permit application containing documentation showing that the

groundwater monitoring system has been constructed to meet the requirements of this Section.

g) The owner or operator must obtain a certification from a qualified professional engineer stating that the groundwater monitoring system has been designed and constructed to meet the requirements of this Section. If the groundwater monitoring system includes the minimum number of monitoring wells specified in subsection (c)(1), the certification must document the basis supporting this determination. The certification must be submitted to the Agency with the appropriate permit application.

Section 845.640 Groundwater Sampling and Analysis Requirements

a) The groundwater monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of groundwater quality at the background and downgradient wells required by Section 845.630. The owner or operator of the CCR surface impoundment must develop a sampling and analysis program that includes procedures and techniques for:

1) Sample collection;

2) Sample preservation and shipment;

3) Analytical procedures;

4) Chain of custody control; and

5) Quality assurance and quality control.

b) The groundwater monitoring program must include sampling and analytical methods that are appropriate for groundwater sampling and that accurately measure constituents and other monitoring parameters in groundwater samples. For purposes of this Subpart, the term "constituent" refers to both constituents and other monitoring parameters listed in Section 845.600.

c) The owner or operator must perform the following each time ground water is sampled:

1) Measure groundwater elevations in each well before purging;

2) Determine the rate and direction of groundwater flow; and

3) Measure groundwater elevations in wells that monitor the same CCR management area within a time period short enough to avoid temporal

variations in groundwater flow that could preclude accurate determination of groundwater flow rate and direction.

d) The owner or operator of the CCR surface impoundment must establish background groundwater quality in a hydraulically upgradient or background well for each of the constituents listed in Section 845.600. Background groundwater quality may be established at wells that are not located hydraulically upgradient from the CCR surface impoundment if it meets the requirements of Section 845.630(a)(1).

e) The number of samples collected when conducting monitoring (for both downgradient and background wells) must be consistent with the statistical procedures chosen under subsection (f) and the performance standards under subsection (g). The sampling procedures must be those specified by Section 845.650(a) through (c).

f) Statistical Methods

1) The owner or operator of the CCR surface impoundment must select one of the statistical methods specified in subsection (f)(1) to be used in evaluating groundwater monitoring data for each specified constituent. The statistical test chosen must be conducted separately for each constituent in each monitoring well.

A) A parametric analysis of variance followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.

B) An analysis of variance based on ranks followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.

C) A tolerance or prediction interval procedure, in which an interval for each constituent is established from the distribution of the background data and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.

D) A control chart approach that gives control limits for each constituent.

E) Another statistical test method that meets the performance standards of subsection (g).

2) The owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the selected statistical method is appropriate for evaluating the groundwater monitoring data for the CCR surface impoundment. The certification must include a narrative description of the statistical method selected to evaluate the groundwater monitoring data. The certification must be submitted to the Agency with the appropriate permit application.

3) The owner or operator of the CCR surface impoundment must submit the following to the Agency in an operating permit application:

A) Documentation of the statistical method chosen; and

B) The qualified professional engineer certification required by subsection (f)(2).

g) Any statistical method chosen under subsection (f) must comply with the following performance standards, as appropriate, based on the statistical test method used:

1) The statistical method used to evaluate groundwater monitoring data must be appropriate for the distribution of constituents. Normal distributions of data values must use parametric methods. Non-normal distributions must use non-parametric methods. If the distribution of the constituents is shown by the owner or operator of the CCR surface impoundment to be inappropriate for a normal theory test, then the data must be transformed or a distribution-free (non-parametric) theory test must be used. If the distributions for the constituents differ, more than one statistical method may be needed.

2) If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a groundwater protection standard, the test must be done at a Type I error level of at least 0.01 for each testing period. If a multiple comparison procedure is used, the Type I experiment wise error rate for each testing period must be at least 0.05; however, the Type I error of at least 0.01 for individual well comparisons must be maintained. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.

3) If a control chart approach is used to evaluate groundwater monitoring data, the specific type of control chart and its associated constituent values must be such that this approach is at least as effective as any other

approach in this Section for evaluating groundwater data. The constituent values must be determined after considering the number of samples in the background database, the data distribution, and the range of the concentration values for each constituent of concern.

4) If a tolerance interval or a prediction interval is used to evaluate groundwater monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, must be such that this approach is at least as effective as any other approach in this Section for evaluating groundwater data. These constituents must be determined after considering the number of samples in the background database, the data distribution, and the range of the concentration values for each constituent of concern.

5) The statistical method must account for data below the limit of detection with one or more statistical procedures at least as effective as any other approach in this Section for evaluating groundwater data. Any practical quantitation limit that is used in the statistical method must be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility. For the constituents identified in Section 845.600(a)(1), the practical quantitation limit must be less than the groundwater protection standards.

6) If necessary, the statistical method must include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

h) The owner or operator of the CCR surface impoundment must determine whether there is a statistically significant increase over background values for each constituent in Section 845.600.

1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the groundwater quality of each constituent at each monitoring well designated under Section 845.630(a)(2) or (d)(1) to the background value of that constituent, according to the statistical procedures and performance standards specified by subsections (f) and (g).

2) Within 60 days after completing sampling and analysis, the owner or operator must determine whether there has been a statistically significant increase over background for any constituent at each monitoring well.

i) The owner or operator must measure total recoverable metals concentrations in measuring groundwater quality. Measurement of total recoverable metals

captures both the particulate fraction and dissolved fraction of metals in natural waters. Groundwater samples must not be field filtered before analysis.

j) All groundwater samples taken under this Subpart must be analyzed by a certified laboratory using Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, incorporated by reference in Section 845.150.

Section 845.650 Groundwater Monitoring Program

a) The owner or operator of a CCR surface impoundment must conduct groundwater monitoring consistent with this Section. At a minimum, groundwater monitoring must include groundwater monitoring for all constituents with a groundwater protection standard in Section 845.600(a), calcium, and turbidity. The owner or operator of the CCR surface impoundment must submit a groundwater monitoring plan to the Agency with its operating permit application.

b) Monitoring Frequency

1) The monitoring frequency for all constituents with a groundwater protection standard in Section 845.600(a), calcium, and turbidity must be at least quarterly during the active life of the CCR surface impoundment and the post-closure care period or period specified in Section 845.740(b) when closure is by removal except as allowed in subsection (b)(4).

A) For existing CCR surface impoundments, a minimum of eight independent samples from each background and downgradient well must be collected and analyzed for all constituents with a groundwater protection standard listed in Section 845.600(a), calcium, and turbidity within 180 days after April 21, 2021.

B) For new CCR surface impoundments, and all lateral expansions of CCR surface impoundments, a minimum of eight independent samples for each background well and downgradient well must be collected and analyzed for all constituents with a groundwater protection standard listed in Section 845.600(a), calcium, and turbidity during the first 180 days of sampling.

2) The groundwater elevation monitoring frequency must be monthly.

3) Measurement of water elevation within the CCR surface impoundment must be conducted each time the groundwater elevations are measured (see subsection 845.650(b)(2)) before dewatering for closure.

4) After completion of five years of monitoring under this Part, the owner or operator of a CCR surface impoundment may ask the Agency for approval

of a semiannual monitoring frequency by demonstrating all of the following:

A) The groundwater monitoring effectiveness will not be compromised by the reduced frequency of monitoring;

B) Sufficient data has been collected to characterize groundwater;

C) The groundwater monitoring schedule currently does not show any statistically significant increasing trends; and

D) The concentrations of constituents monitored under Section 845.650(a) at the down-gradient monitoring wells are below the applicable groundwater protection standards of Section 845.600.

5) If, after an Agency approval of a semiannual monitoring frequency under subsection (b)(4), a statistically significant increasing trend is detected or an exceedance above the GWPS is detected, the monitoring must revert to a quarterly frequency.

c) The number of samples collected and analyzed for each background well and downgradient well during subsequent quarterly sampling events must be consistent with Section 845.640 and must account for any unique characteristics of the site; but must include at least one sample from each background and downgradient well.

d) If one or more constituents are detected, and confirmed by an immediate resample, to be in exceedance of the groundwater protection standards in Section 845.600 in any sampling event, the owner or operator must notify the Agency which constituent exceeded the groundwater protection standard and place the notification in the facility's operating record as required by Section 845.800(d)(16). The owner or operator of the CCR surface impoundment also must:

1) Characterize the nature and extent of the release and any relevant site conditions that may affect the remedy ultimately selected. The characterization must be sufficient to support a complete and accurate assessment of the corrective measures necessary to effectively clean up all releases from the CCR surface impoundment under Section 845.660. The owner or operator of the CCR surface impoundment must submit the characterization to the Agency and place the characterization in the facility's operating record as required by Section 845.800(d)(16). Characterization of the release includes the following minimum measures:

A) Install additional monitoring wells necessary to define the contaminant plumes;

B) Collect data on the nature and estimated quantity of material released, including specific information on the constituents listed in Section 845.600 and the levels at which they are present in the material released;

C) Install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well in accordance with subsections (a) and (b); and

D) Sample all wells in accordance with subsections (a) and (b) to characterize the nature and extent of the release.

2) Notify all persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site as indicated by sampling of wells in accordance with subsection (d)(1). The owner or operator must send notifications made under this subsection (d)(2) to the Agency and place the notifications in the facility's operating record (see Section 845.800(d)(16)).

3) Except as provided in subsection (e), within 90 days after the detected exceedance of the groundwater protection standard, initiate an assessment of corrective measures (see Section 845.660).

e) Alternative Source Demonstration (ASD). The owner or operator of a CCR surface impoundment may, within 60 days after the detected exceedance of the groundwater protection standard, submit a demonstration to the Agency that a source other than the CCR surface impoundment caused the contamination and the CCR surface impoundment did not contribute to the contamination, or that the exceedance of the groundwater protection standard resulted from error in sampling, analysis, statistical evaluation, natural variation in groundwater quality, or a change in the potentiometric surface and groundwater flow direction. Either type of ASD must include a report that contains the factual or evidentiary basis for any conclusions and a certification of accuracy by a qualified professional engineer.

1) The owner or operator must place the ASD on the facility's publicly accessible Internet site (CCR website) under Section 845.810 within 24 hours after the submission to the Agency.

2) Within two business days after receiving the ASD, the Agency must email a notice to its listserv for the facility that the ASD is available to view on the facility's CCR website.

3) Members of the public may submit to the Agency written comments on the ASD within 14 days after the Agency provides notice under subsection (e)(2).

4) The Agency must provide a written response to the owner and operator either concurring or not concurring with the ASD within 30 days after receiving the ASD. The Agency must also mail or email its response to each person who timely submitted a written public comment under subsection (e)(3) and supplied a mailing or email address.

5) If the Agency concurs with the ASD, the owner or operator must continue monitoring as required by this Section. The owner or operator must also include the ASD in the annual groundwater monitoring and corrective action report required by Section 845.610(e).

6) If the Agency does not concur with the ASD, the owner or operator must initiate the assessment of corrective measures under Section 845.660.

7) If the Agency does not concur with the ASD, the owner or operator may petition the Board for review of the Agency's non-concurrence under 35 Ill. Adm. Code 105. The filing of a petition for review under subsection (e)(7) does not automatically stay any requirements of this Part as to the owner or operator, including the 90-day deadline to initiate an assessment of corrective measures (see Section 845.660(a)(1)).

Section 845.660 Assessment of Corrective Measures

a) Unless the Agency has concurred with an alternative source demonstration made under Section 845.650(e), the owner or operator must initiate an assessment of corrective measures to prevent further releases, to remediate any releases, and to restore the affected area.

1) The assessment of corrective measures must be initiated within 90 days after finding that any constituent listed in Section 845.600 has been detected in exceedance of the groundwater protection standards in Section 845.600, at the downgradient waste boundary or immediately upon detection of a release of CCR from a CCR surface impoundment.

2) The assessment of corrective measures must be completed and submitted to the Agency within 90 days after initiation of assessment of corrective measures, unless the owner or operator demonstrates to the Agency the need for additional time to complete the assessment of corrective measures due to site-specific conditions or circumstances. The owner or operator must submit this demonstration, along with a certification from a qualified professional engineer attesting that the demonstration is accurate, to the Agency within 60 days after initiating an assessment of corrective

measures. The Agency must either approve or disapprove the demonstration within 30 days. The 90-day deadline to complete the assessment of corrective measures may be extended for no longer than 60 days. The owner or operator must also include the Agency approved demonstration in the annual groundwater monitoring and corrective action report required by Section 845.610(e), in addition to the certification by a qualified professional engineer.

b) The owner or operator of the CCR surface impoundment must continue to monitor groundwater in accordance with the monitoring program as specified in Section 845.650.

c) The assessment under subsection (a) must include an analysis of the effectiveness of potential corrective measures in meeting all the requirements and objectives of the corrective action plan, as described by Section 845.670, addressing at least the following:

1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

2) The time required to begin and complete the corrective action plan; and

3) The institutional requirements, such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the corrective action plan.

d) The owner or operator of the CCR surface impoundment must discuss the results of the corrective measures assessment, at least 30 days before the selection of remedy, in a public meeting with interested and affected parties (see Section 845.240).

e) When the owner or operator of a CCR surface impoundment is completing closure and corrective action simultaneously, the owner or operator may combine the corrective measures assessment required by this Section and the closure alternatives analysis required by Section 845.710 into one assessment of alternatives.

Section 845.670 Corrective Action Plan

a) The owner or operator must prepare a semi-annual report describing the progress in selecting a remedy and developing a corrective action plan. The semi-annual report must be submitted to the Agency and placed in the operating record as required by Section 845.800(d)(17).

b) Within one year after completing the assessment of corrective measures as specified in Section 845.660, and after completion of the public meeting in Section 845.660(d), the owner or operator of the CCR surface impoundment must submit, in a construction permit application to the Agency, a corrective action plan that identifies the selected remedy. This requirement applies in addition to, not in place of, any applicable standards under any other State or federal law.

c) The corrective action plan must meet the following requirements:

1) Be based on the results of the corrective measures assessment conducted under Section 845.660;

2) Identify a selected remedy that at a minimum, meets the standards listed in subsection (d);

3) Contain the corrective action alternatives analysis specified in subsection (e); and

4) Contain proposed schedules for implementation, including an analysis of the factors in subsection (f);

d) The selected remedy in the corrective action plan must:

1) Be protective of human health and the environment;

2) Attain the groundwater protection standards specified in Section 845.600;

3) Control the sources of releases to reduce or eliminate, to the maximum extent feasible, further releases of constituents listed in Section 845.600 into the environment;

4) Remove from the environment as much of the contaminated material that was released from the CCR surface impoundment as is feasible, taking into account factors such as avoiding inappropriate disturbance of sensitive ecosystems; and

5) Comply with standards for management of wastes as specified in Section 845.680(d).

e) Corrective Action Alternatives Analysis. In selecting a remedy that meets the standards of subsection (d), the owner or operator of the CCR surface impoundment must consider the following evaluation factors:

1) The long- and short-term effectiveness and protectiveness of each potential remedy, along with the degree of certainty that the remedy will prove successful based on consideration of the following:

A) Magnitude of reduction of existing risks;

B) Magnitude of residual risks in terms of likelihood of further releases due to CCR remaining following implementation of a remedy;

C) The type and degree of long-term management required, including monitoring, operation, and maintenance;

D) Short-term risks that might be posed to the community or the environment during implementation of a remedy, including potential threats to human health and the environment associated with excavation, transportation, and re-disposal of contaminants;

E) Time until groundwater protection standards in Section 845.600 are achieved;

F) The potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, re-disposal, containment, or changes in groundwater flow;

G) The long-term reliability of the engineering and institutional controls, including an analysis of any off-site, nearby destabilizing activities; and

H) Potential need for replacement of the remedy.

2) The effectiveness of the remedy in controlling the source to reduce further releases based on consideration of each of the following potential factors:

A) The extent to which containment practices will reduce further releases; and

B) The extent to which treatment technologies may be used.

3) The ease or difficulty of implementing each potential remedy based on consideration of the following types of factors:

A) Degree of difficulty associated with constructing the technology;

B) Expected operational reliability of the technologies;

C) Need to coordinate with and obtain necessary approvals and permits from other agencies;

D) Availability of necessary equipment and specialists; and

E) Available capacity and location of needed treatment, storage, and disposal services.

4) The degree to which community concerns are addressed by each potential remedy.

f) The owner or operator must specify, as part of the corrective action plan, a schedule for implementing, of and completing, remedial activities. The schedule must require the completion of remedial activities within a reasonable time, taking into consideration the factors in this subsection (f). The owner or operator of the CCR surface impoundment must consider the following factors in determining the schedule of remedial activities:

1) Extent and nature of contamination, as determined by the characterization required under Section 845.650(d);

2) Reasonable probabilities of remedial technologies achieving compliance with the groundwater protection standards established by Section 845.600 and other objectives of the remedy;

3) Availability of treatment or disposal capacity for CCR managed during implementation of the remedy;

4) Potential risks to human health and the environment from exposure to contamination before completion of the remedy;

5) Resource value of the aquifer, including:

A) Current and future uses, including potential residential, agricultural, commercial industrial and ecological uses;

B) Proximity and withdrawal rate of users;

C) Groundwater quantity and quality;

D) The potential impact to the subsurface ecosystem, wildlife, other natural resources, crops, vegetation, and physical structures caused by exposure to CCR constituents;

E) The hydrogeologic characteristic of the facility and surrounding land; and

F) The availability of alternative water supplies; and

6) Other relevant factors.

Section 845.680 Implementation of the Corrective Action Plan

a) Within 90 days after the Agency's approval of the corrective action plan submitted under Section 845.670, the owner or operator must initiate corrective action. Based on the schedule approved by the Agency for implementation and completion of corrective action, the owner or operator must:

1) Establish and implement a corrective action groundwater monitoring program that:

A) At a minimum, meets the requirements of the monitoring program under Section 845.650;

B) Documents the effectiveness of the corrective action remedy; and

C) Demonstrates compliance with the groundwater protection standard under subsection (c).

2) Implement the corrective action remedy approved by the Agency under Section 845.670; and

3) Take any interim measures necessary to reduce the contaminants leaching from the CCR surface impoundment, and/or potential exposures to human or ecological receptors. Interim measures must, to the greatest extent feasible, be consistent with the objectives of, and contribute to the performance of, any remedy that may be required by Section 845.670. The following factors must be considered by an owner or operator in determining whether interim measures are necessary:

A) Time required to develop and implement a final remedy;

B) Actual or potential exposure of nearby populations or environmental receptors to any of the constituents listed in Section 845.600;

C) Actual or potential contamination of sensitive ecosystems or current or potential drinking water supplies;

D) Further degradation of the groundwater that may occur if remedial action is not initiated expeditiously;

E) Weather conditions that may cause any of the constituents listed in Section 845.600 to migrate or be released;

F) Potential for exposure to any of the constituents listed in Section 845.600 as a result of an accident or failure of a container or handling system; and

G) Other situations that may pose threats to human health and the environment.

b) If the Agency or an owner or operator of the CCR surface impoundment determines, at any time, that compliance with the requirements of Section 845.670(d) is not being achieved through the remedy selected, the owner or operator must implement other methods or techniques that could feasibly achieve compliance with the requirements. These methods or techniques must receive approval by the Agency before implementation.

c) Corrective action must be considered complete when:

1) The owner or operator of the CCR surface impoundment demonstrates compliance with the groundwater protection standards established by Section 845.600 has been achieved at all points within the plume of contamination that lies beyond the waste boundary;

2) Compliance with the groundwater protection standards has been achieved by demonstrating that concentrations of constituents listed in Section 845.600 have not exceeded the groundwater protection standards for a period of three consecutive years, using the statistical procedures and performance standards in Section 845.640(f) and (g); and

3) All actions required to complete the remedy have been satisfied.

d) All CCR managed under a remedy approved by the Agency under Section 845.670, or an interim measure required under subsection (a)(3), must be managed in a manner that complies with this Part.

e) Upon completion of the corrective action plan, the owner or operator must submit to the Agency a corrective action completion report and certification.

1) The corrective action completion report must contain supporting documentation, including:

A) Any engineering and hydrogeology reports, including, monitoring well completion reports and boring logs, all CQA reports, certifications, and designations of CQA officers-in-absentia required by Section 845.290;

B) A written summary of the implementation of the corrective action plan as stated in the construction permit and this Part;

C) Groundwater monitoring data demonstrating compliance with subsection (c);

D) Any remedial actions completed under subsection(d);

E) Documentation showing compliance with the selected remedy requirements of Section 845.670(b); and

F) Any other information relied upon by the qualified professional engineer in making the closure certification.

2) The corrective action completion certification must include a statement from a qualified professional engineer attesting that the corrective action plan has been completed in compliance with the requirements of subsection (c).

3) The owner or operator must place the corrective action completion report and certification in the facility's operating record as required by Section 845.800(d)(18).

SUBPART G: CLOSURE AND POST-CLOSURE CARE

Section 845.700 Required Closure or Retrofit of CCR Surface Impoundments

a) Required Closure. The owner or operator of the following CCR surface impoundments must stop placing CCR or non-CCR waste streams in the CCR surface impoundment and must initiate closure of the CCR surface impoundment:

1) An existing CCR surface impoundment that has not demonstrated compliance with any of the following location restrictions:

A) Uppermost aquifer location (see Section 845.300);

B) Wetlands (see Section 845.310);

C) Fault areas (see Section 845.320);

D) Seismic impact zones (see Section 845.330); or

E) Unstable areas and floodplains (see Section 845.340).

2) The owner or operator of any CCR surface impoundment that has failed to complete the initial or any subsequent annual safety factor assessment required by Section 845.460 or that has failed to document the calculated factors of safety for the CCR surface impoundment to achieve the minimum safety factors specified in Section 845.460(a).

b) Required Closure or Retrofit. The owner or operator of an existing unlined CCR surface impoundment, as determined under Section 845.400(f), must stop placing CCR and non-CCR waste streams into that CCR surface impoundment and either retrofit or close the CCR surface impoundment in accordance with the requirements of Subpart G. The owner or operator of a CCR surface impoundment electing to retrofit must submit, in accordance with the schedule in subsection (h), the written preliminary retrofit plan under subsection 845.770(a)(3) and a construction permit application to retrofit under Section 845.770;

c) Beginning on April 21, 2021, the owner or operator of the CCR surface impoundment required to close under subsection (a), or electing to close under subsection (b), must immediately take steps to categorize the CCR surface impoundment under subsection (g) and to comply with the closure alternatives analysis requirements in Section 845.710. Within 30 days after April 21, 2021, the owner or operator must send the category designation, including a justification for the category designation, for each CCR surface impoundment to the Agency for review. The owner or operator of the CCR surface impoundment must submit a construction permit application containing a final closure plan under the schedule in subsection (h).

d) Timeframes for Closure

1) Except as provided in subsection (d)(2), the owner or operator must stop placing CCR and non-CCR waste streams in the impoundment and initiate closure within six months after failing to complete any of the demonstrations listed in subsection (a).

2) For CCR surface impoundments required to close under subsection (a)(1) or electing to close under subsection (b):

A) If, on April 21, 2021, the owner or operator of a CCR surface impoundment has not satisfied an alternative closure requirement of 40 CFR 257.103 that allows for the continued receipt of CCR or non-CCR waste streams, the owner or operator must not place CCR or non-CCR waste streams into the CCR surface impoundment after April 21, 2021.

B) If, by November 30, 2020, the owner or operator of a CCR surface impoundment has submitted a complete demonstration to USEPA

seeking an alternative deadline to stop receiving waste or complete closure under 40 CFR 257.103(f), the deadline to stop receiving waste will be tolled until USEPA issues a decision. If USEPA determines that a submission is incomplete, an owner or operator must immediately stop receiving waste and comply with all applicable deadlines of Section 845.700(d)(1).

C) If USEPA disapproves the requested alternative deadline to stop receiving waste and complete closure, the owner or operator of the CCR surface impoundment must immediately stop receiving waste and initiate closure within six months after the USEPA denial of the extension and will be subject to Section 845.760(a).

D) If, USEPA approves a demonstration that alternative disposal capacity is infeasible under 40 CFR 257.103(f)(1), the owner or operator must stop placing CCR or non-CCR waste streams into the CCR surface impoundment by the end of the initial time extension approved under 40 CFR 257.103 or once alternative capacity becomes available, whichever is sooner. In no case may the owner or operator of the CCR surface impoundment place CCR or non-CCR waste streams into an eligible CCR surface impoundment after October 15, 2024, or into any other CCR surface impoundment subject to closure under Section 845.700(a) or (b) after October 15, 2023.

E) If USEPA approves a demonstration for permanent cessation of coal-fired power boilers by a certain date under 40 CFR 257.103(f)(2), the owner or operator must:

i) For CCR surface impoundments that are 40 acres or smaller, stop operation of the coal-fired boiler and complete closure by October 17, 2023; or

ii) For CCR surface impoundments that are larger than 40 acres, stop operation of the coal-fired boiler and complete closure by October 17, 2028.

F) The USEPA's decision to approve or deny the demonstration requesting an alternative deadline to initiate closure must, within 30 days be submitted to the Agency and placed in the facility’s operating record as required by Section 845.800(d)(19).

G) Failure to remain in compliance with any of the requirements of this Part will result in the automatic loss of authorization under subsections (d)(2)(D) and (d)(2)(E).

H) The owner or operator of the CCR surface impoundment with a USEPA-approved extension will not be given extensions of the timeframes for completion of closure under Section 845.760(c).

e) Semi-Annual Reports. The owner or operator of a CCR surface impoundment closing under the time frames in subsections (d)(2)(B) and (d)(2)(C) must prepare semi-annual reports consistent with the requirements in 40 CFR 257.103(f)(1)(x), incorporated by reference in Section 845.150, until the owner or operator has initiated closure.

f) An owner or operator of a CCR surface impoundment required to close under this Section must prepare the notification required under Section 845.730(d) that the CCR surface impoundment is closing under this Section.

g) Closure Prioritization

1) The owner or operator of a CCR surface impoundment required to close under this Section must assign the CCR surface impoundment to one of the following categories. Category 1 has the highest priority for closure. Category 7 has the lowest priority for closure.

A) Category 1 includes CCR surface impoundments that have impacted an existing potable water supply well or that have impacted groundwater quality within the setback of an existing potable water supply well.

B) Category 2 includes CCR surface impoundments that are an imminent threat to human health or the environment or have been designated by the Agency under subsection (g)(5).

C) Category 3 includes CCR surface impoundments located in areas of environmental justice concern, as determined by the Agency under subsection (g)(6).

D) Category 4 includes inactive CCR surface impoundments that have an exceedance of the groundwater protection standards in Section 845.600.

E) Category 5 includes existing CCR surface impoundments that have exceedances of the groundwater protection standards in Section 845.600.

F) Category 6 includes inactive CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600.

G) Category 7 includes existing CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600.

2) If a CCR surface impoundment can be categorized in more than one category, the owner or operator of the CCR surface impoundment must assign the CCR surface impoundment the highest priority category.

3) Whenever an owner or operator of a CCR surface impoundment has more than one CCR surface impoundment that must close under this Section, the owner or operator must close the CCR surface impoundments in order of priority.

4) If the CCR surface impoundment meets the criteria for Category 1, the owner or operator must take immediate steps to mitigate the impact to any existing potable water supply. The owner or operator of the CCR surface impoundment, must act to replace the water supply with a supply of equal or better quality and quantity within 30 days after notice that the impact has occurred.

5) The Agency may designate a CCR surface impoundment as a Category 2 surface impoundment when:

A) The CCR surface impoundment has failed to document that the calculated factors of safety for the CCR surface impoundment achieve the minimum safety factors specified in Section 845.460(a);

B) The CCR surface impoundment has not demonstrated compliance with the location restrictions in Subpart C;

C) The owner or operator has been enjoined under Section 43 of the Act;

D) An exceedance of the groundwater protection standards in Section 845.600 has migrated off-site; or

E) The Agency finds that an emergency condition exists creating an immediate danger to public health or welfare, or the environment.

6) For purposes of, and only for, this Part, areas of environmental justice concern are identified as any area that meets either of the following:

A) Any area within one mile of a census block group where the number of low-income persons is twice the statewide average, where low income means the number or percent of a census block

group's population in households where the household income is less than or equal to twice the federal poverty level; or

B) Any area within one mile of a census block group where the number of minority persons is twice the statewide average, where minority means the number or percent of individuals in a census block group who list their racial status as a race other than white alone or list their ethnicity as Hispanic or Latino.

7) For purposes of subsection (g)(6), if any part of a facility falls within one mile of the census block group, the entire facility, including all its CCR surface impoundments, must be considered an area of environmental justice concern.

8) The Agency may designate a CCR surface impoundment as another Category when site-specific conditions contradict the designations provided by the owner or operator in subsection (c) and the categories in subsection (g)(1).

h) Application Schedule

1) Category 1, Category 2, Category 3, and Category 4 CCR surface impoundment owners or operators must submit either a construction permit application containing a final closure plan or a construction permit application to retrofit the CCR surface impoundment in accordance with the requirements of this Part by February 1, 2022.

2) Category 5 CCR surface impoundment owners or operators must submit either a construction permit application containing a final closure plan or a construction permit application to retrofit the CCR surface impoundment in accordance with the requirements of this Part by August 1, 2022.

3) Category 6 and Category 7 CCR surface impoundment owners or operators must submit either a construction permit application containing a final closure plan or a construction permit application to retrofit the CCR surface impoundment in accordance with the requirements of this Part by August 1, 2023.

4) Owners or operators consolidating one or more CCR surface impoundments for closure must meet the application schedule of the highest priority CCR surface impoundment.

5) If the Agency denies a construction permit application submitted under this Section, the owner and operator must submit a revised construction permit application addressing all deficiencies identified by the Agency. The revised construction permit application for closure must be submitted

to the Agency within 90 days after the Agency's denial if the Agency's denial is not appealed under Section 845.270. If the Agency's denial is appealed and upheld, the owner or operator must submit a revised construction permit application for closure within 90 days after a final decision by the Board is rendered. The owner or operator of the CCR surface impoundment must discuss the owner's or operator's proposed response to all deficiencies identified by the Agency in a public meeting with interested and affected parties held under Section 845.240.

Section 845.710 Closure Alternatives

a) Closure of a CCR surface impoundment, or any lateral expansion of a CCR surface impoundment, must be completed either by leaving the CCR in place and installing a final cover system or through removal of the CCR and decontamination of the CCR surface impoundment, as described in Sections 845.720 through 845.760.

b) Before selecting a closure method, the owner or operator of each CCR surface impoundment must complete a closure alternatives analysis. The closure alternatives analysis must examine the following for each closure alternative:

1) The long- and short-term effectiveness and protectiveness of the closure method, including identification and analyses of the following factors:

A) The magnitude of reduction of existing risks;

B) The magnitude of residual risks in terms of likelihood of future releases of CCR;

C) The type and degree of long-term management required, including monitoring, operation, and maintenance;

D) The short-term risks that might be posed to the community or the environment during implementation of a closure, including potential threats to human health and the environment associated with excavation, transportation, and re-disposal of contaminants;

E) The time until closure and post-closure care or the completion of groundwater monitoring under Section 845.740(b) is completed;

F) The potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, re-disposal, containment or changes in groundwater flow;

G) The long-term reliability of the engineering and institutional controls, including an analysis of any off-site, nearby destabilizing activities; and

H) Potential need for future corrective action of the closure alternative.

2) The effectiveness of the closure method in controlling future releases based on analyses of the following factors:

A) The extent to which containment practices will reduce further releases; and

B) The extent to which treatment technologies may be used.

3) The ease or difficulty of implementing a potential closure method based on analyses of the following types of factors:

A) Degree of difficulty associated with constructing the technology;

B) Expected operational reliability of the technologies;

C) Need to coordinate with and obtain necessary approvals and permits from other agencies;

D) Availability of necessary equipment and specialists; and

E) Available capacity and location of needed treatment, storage, and disposal services.

4) The degree to which the concerns of the residents living within communities where the CCR will be handled, transported and disposed of are addressed by the closure method.

c) In the closure alternatives analysis, the owner or operator of the CCR surface impoundment must:

1) Analyze complete removal of the CCR as one closure alternative, along with the modes for transporting the removed CCR, including by rail, barge, low-polluting trucks, or a combination of these transportation modes;

2) Identify whether the facility has an onsite landfill with remaining capacity that can legally accept CCR, and, if not, whether constructing an onsite landfill is possible; and

3) Include any other closure method in the alternatives analysis if requested by the Agency.

d) The analysis for each alternative completed under this Section must:

1) Meet or exceed a class 4 estimate under the AACE Classification Standard, incorporated by reference in Section 845.150, or a comparable classification practice as provided in the AACE Classification Standard;

2) Contain the results of groundwater contaminant transport modeling and calculations showing how the closure alternative will achieve compliance with the applicable groundwater protection standards;

3) Include a description of the fate and transport of contaminants with the closure alternative over time, including consideration of seasonal variations; and

4) Assess impacts to waters in the State.

e) At least 30 days before submission of a construction permit application for closure, the owner or operator of the CCR surface impoundment must discuss the results of the closure alternatives analysis in a public meeting with interested and affected parties (see Section 845.240).

f) After completion of the public meeting under subsection (e), the owner or operator of a CCR surface impoundment must select a closure method and submit a final closure plan to the Agency under Section 845.720(b). All materials demonstrating completion of the closure alternatives analysis specified in this Section must be submitted with the final closure plan.

g) The selected closure method must meet the requirements and standards of this Part, ensure the protection of human health and the environment, and achieve compliance with the groundwater protection standards in Section 845.600.

Section 845.720 Closure Plan

a) Preliminary Written Closure Plan

1) Content of the Preliminary Closure Plan. The owner or operator of a new CCR surface impoundment or an existing CCR surface impoundment not required to close under Section 845.700 must prepare a preliminary written closure plan that describes the steps necessary to close the CCR surface impoundment at any point during the active life of the CCR surface impoundment consistent with recognized and generally accepted engineering practices. The preliminary written closure plan must include, at a minimum, the following:

A) A narrative description of how the CCR surface impoundment will be closed in accordance with this Part.

B) If closure of the CCR surface impoundment will be accomplished through removal of CCR from the CCR surface impoundment, a description of the procedures to remove the CCR and decontaminate the CCR surface impoundment in accordance with Section 845.740.

C) If closure of the CCR surface impoundment will be accomplished by leaving CCR in place, a description of the final cover system, designed in accordance with Section 845.750, and the methods and procedures to be used to install the final cover. The closure plan must also discuss how the final cover system will achieve the performance standards specified in Section 845.750.

D) An estimate of the maximum inventory of CCR ever on-site over the active life of the CCR surface impoundment.

E) An estimate of the largest area of the CCR surface impoundment ever requiring a final cover (see Section 845.750), at any time during the CCR surface impoundment's active life.

F) A schedule for completing all activities necessary to satisfy the closure criteria in this Section, including an estimate of the year in which all closure activities for the CCR surface impoundment will be completed. The schedule should provide sufficient information to describe the sequential steps that will be taken to close the CCR surface impoundment, including identification of major milestones such as coordinating with and obtaining necessary approvals and permits from other agencies, the dewatering and stabilization phases of CCR surface impoundment closure, or installation of the final cover system, and the estimated timeframes to complete each step or phase of CCR surface impoundment closure. When preparing the preliminary written closure plan, if the owner or operator of a CCR surface impoundment estimates that the time required to complete closure will exceed the timeframes specified in Section 845.760(a), the preliminary written closure plan must include the site-specific information, factors and considerations that would support any time extension sought under Section 845.760(b).

2) The owner or operator of the CCR surface impoundment must submit the preliminary written closure plan to the Agency with its initial operating permit application. The owner or operator of the CCR surface

impoundment must submit the most recently amended preliminary closure plan to the Agency with each operating permit renewal application. The owner or operator must place preliminary and amended preliminary written closure plans in the facility's operating record as required by Section 845.800(d)(20).

3) Amendment of a Preliminary Written Closure Plan.

A) The owner or operator may amend the preliminary written closure plan at any time.

B) The owner or operator must amend the preliminary written closure plan whenever:

i) There is a change in the operation of the CCR surface impoundment that would substantially affect the written closure plan in effect; or

ii) Before closure activities have started, unanticipated events necessitate a revision of the written closure plan.

C) The owner or operator must amend the closure plan at least 60 days before a planned change in the operation of the facility or CCR surface impoundment, or within 60 days after an unanticipated event requires the need to revise an existing written closure plan.

4) The owner or operator of the CCR surface impoundment must obtain and submit with its initial and renewal operating permit applications a written certification from a qualified professional engineer that the initial and any amendment of the preliminary written closure plan meets the requirements of this Part.

b) Final Closure Plan

1) The owner or operator of a CCR surface impoundment must submit to the Agency, as a part of a construction permit application for closure, a final closure plan. The plan must be submitted before the installation of a final cover system or removal of CCR from the surface impoundment for the purpose of closure.

2) Except as otherwise provided in Section 22.59 of the Act, the owner or operator of a CCR surface impoundment must not close a CCR surface impoundment without a construction permit issued under this Part.

3) The final closure plan must identify the proposed selected closure method, and must include the information required in subsection (a)(1) and the closure alternatives analysis specified in Section 845.710.

4) If a final written closure plan revision is necessary after closure activities have started for a CCR surface impoundment, the owner or operator must submit a request to modify the construction permit within 60 days following the triggering event.

5) The owner or operator of the CCR surface impoundment must obtain and submit with its construction permit application for closure a written certification from a qualified professional engineer that the final written closure plan meets the requirements of this Part.

Section 845.730 Initiation of Closure

Initiation of closure activities. Except as provided for in this Section, the owner or operator of a CCR surface impoundment must initiate closure of the CCR surface impoundment within the applicable timeframes specified in either subsection (a) or (b). For purposes of this Section, closure of the CCR surface impoundment has been initiated if the owner or operator has stopped placing waste in the CCR surface impoundment and has submitted to the Agency a construction permit application under Section 845.220(d).

a) Known Final Receipt. The owner or operator must initiate closure of the CCR surface impoundment within 30 days after the date on which the CCR surface impoundment either:

1) Receives the known final placement of waste, either CCR or any non-CCR waste stream; or

2) Removes the known final volume of CCR from the CCR surface impoundment for the purpose of beneficial use of CCR.

b) Temporarily Idled CCR Surface Impoundments.

1) Except as provided by subsection (b)(2), the owner or operator must initiate closure of a CCR surface impoundment that has not received CCR or any non-CCR waste stream, or is no longer removing CCR for the purpose of beneficial use, within two years after the last receipt of waste or within two years after the last removal of CCR material for the purpose of beneficial use.

2) Notwithstanding subsection (b)(1), the owner or operator of the CCR surface impoundment may secure an additional two years to initiate closure of the idle surface impoundment if the Agency approves the owner's or operator's written demonstration that the CCR surface

impoundment will continue to accept wastes or will start removing CCR for the purpose of beneficial use. The documentation must be supported by, at a minimum, the information specified in this subsection (b)(2). The owner or operator may obtain two-year extensions, provided the owner or operator continues to be able to demonstrate that there is reasonable likelihood that the CCR surface impoundment will accept wastes in the foreseeable future or will remove CCR from the surface impoundment for the purpose of beneficial use. The owner or operator must place each Agency approved demonstration, if more than one time extension is sought, in the facility's operating record as required by Section 845.800(d)(21) before the end of any two-year period.

A) Information documenting that the CCR surface impoundment has remaining storage or disposal capacity or that the CCR surface impoundment can have CCR removed for the purpose of beneficial use; and

B) Information demonstrating that that there is a reasonable likelihood that the CCR surface impoundment will resume receiving CCR or non-CCR waste streams in the foreseeable future or that CCR can be removed for the purpose of beneficial use. The narrative must include a best estimate as to when the CCR surface impoundment will resume receiving CCR or non-CCR waste streams. The situations listed in this subsection (b)(2)(B) are examples of situations that would support a determination that the CCR surface impoundment will resume receiving CCR or non-CCR waste streams in the foreseeable future.

i) Normal plant operations include periods during which the CCR surface impoundment does not receive CCR or non-CCR waste streams, such as the alternating use of two or more CCR surface impoundments whereby, at any point in time, one CCR surface impoundment is receiving CCR while CCR is being removed from a second CCR surface impoundment after its dewatering.

ii) The CCR surface impoundment is dedicated to a coal-fired boiler surface impoundment that is temporarily idled (e.g., CCR is not being generated) and there is a reasonable likelihood that the coal-fired boiler will resume operations in the future.

iii) The CCR surface impoundment is dedicated to an operating coal-fired boiler (i.e., CCR is being generated); however, no CCR is being placed in the CCR surface impoundment because the CCR is being entirely diverted to beneficial

uses, but there is a reasonable likelihood that the CCR surface impoundment will again be used in the foreseeable future.

iv) The CCR surface impoundment currently receives only non-CCR waste streams and those non-CCR waste streams are not generated for an extended period of time, but there is a reasonable likelihood that the CCR surface impoundment will again receive non-CCR waste streams in the future.

3) In order to obtain additional time extensions to initiate closure of a CCR surface impoundment beyond the two years provided by subsection (b)(1), the owner or operator of the CCR surface impoundment must submit the demonstration required by subsection (b)(2) to the Agency for review and approval. The written documentation must include the following statement signed by the owner or operator or an authorized representative:

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this demonstration and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

c) The timeframes specified in subsections (a) and (b) do not apply to an owner or operator of a CCR surface impoundment closing the CCR surface impoundment as required by Section 845.700:

d) By the date the owner or operator initiates closure of a CCR surface impoundment, the owner or operator must prepare a notification of intent to close a CCR surface impoundment. The notification must be placed in the facility's operating record as required by Section 845.800(d)(21).

Section 845.740 Closure by Removal

a) Closure by Removal of CCR. An owner or operator may elect to close a CCR surface impoundment by removing all CCR and decontaminating all areas affected by releases of CCR from the CCR surface impoundment. CCR removal and decontamination of the CCR surface impoundment are complete when all CCR and CCR residues, containment system components such as the impoundment liner and contaminated subsoils, and CCR impoundment structures and ancillary equipment have been removed. Closure by removal must be

completed before the completion of a groundwater corrective action under Subpart F.

b) After closure by removal has been completed, the owner or operator must continue groundwater monitoring under Subpart F for three years after the completion of closure or for three years after groundwater monitoring does not show an exceedance of the groundwater protection standard established under Section 845.600, whichever is longer.

c) The owner or operator of a CCR surface impoundment removing CCR during closure must responsibly handle and transport the CCR consistent with this subsection.

1) Transportation

A) Manifests

i) When transporting CCR off-site by motor vehicle, manifests must be carried as specified in 35 Ill. Adm. Code 809. For purposes of this Part, coal combustion fly ash that is removed from a CCR surface impoundment is not exempt from the manifest requirement.

ii) When transporting CCR off-site by any other mode or method, including trains or barges, manifests must be carried specifying, at a minimum, the following information: the volume of the CCR; the location from which the CCR was loaded onto the mode of transportation and the date the loading took place; and the location where the CCR is being taken and the date it will be delivered.

B) The owner or operator of a CCR surface impoundment from which CCR is removed and transported off-site must develop a CCR transportation plan, which must include:

i) Identification of the transportation method selected, including whether a combination of transportation methods will be used;

ii) The frequency, time of day, and routes of CCR transportation;

iii) Any measures to minimize noise, traffic, and safety concerns caused by the transportation of the CCR;

iv) Measures to limit fugitive dust from any transportation of CCR;

v) Installation and use of a vehicle washing station;

vi) A means of covering the CCR for any mode of CCR transportation, including conveyor belts; and

vii) A requirement that, for transport by motor vehicle, the CCR is transported by a permitted special waste hauler under 35 Ill. Adm. Code 809.201.

2) The owner or operator of a CCR surface impoundment must develop and implement onsite dust controls, which must include:

A) A water spray or other commercial dust suppressant to suppress dust in CCR handling areas and haul roads; and

B) Handling of CCR to minimize airborne particulates and offsite particulate movement during any weather event or condition.

3) The owner or operator of a CCR surface impoundment must provide the following public notices:

A) Signage must be posted at the property entrance warning of the hazards of CCR dust inhalation; and

B) When CCR is transported off-site, a written notice explaining the hazards of CCR dust inhalation, the transportation plan, and tentative transportation schedule must be provided to units of local government through which the CCR will be transported.

4) The owner or operator of the surface impoundment must take measures to prevent contamination of surface water, groundwater, soil and sediments from the removal of CCR, including the following:

A) CCR removed from the surface impoundment may only be temporarily stored, and must be stored in a lined landfill, CCR surface impoundment, enclosed structure, or CCR storage pile.

B) CCR storage piles must:

i) Be tarped or constructed with wind barriers to suppress dust and to limit stormwater contact with storage piles;

ii) Be periodically wetted or have periodic application of dust suppressants;

iii) Have a storage pad, or a geomembrane liner, with a hydraulic conductivity no greater than 1 x 10^{-7} cm/sec, that is properly sloped to allow appropriate drainage;

iv) Be tarped over the edge of the storage pad where possible;

v) Be constructed with fixed and mobile berms, where appropriate, to reduce run-on and run-off of stormwater to and from the storage pile, and minimize stormwater-CCR contact; and

vi) Have a groundwater monitoring system that is consistent with the requirements of Section 845.630 and approved by the Agency.

C) The owner or operator of the CCR surface impoundment must incorporate general housekeeping procedures such as daily cleanup of CCR, tarping of trucks, maintaining the pad and equipment, and good practices during unloading and loading.

D) The owner or operator of the CCR must minimize the amount of time the CCR is exposed to precipitation and wind.

E) The discharge of stormwater runoff that has contact with CCR must be covered by an individual National Pollutant Discharge Elimination System (NPDES) permit. The owner or operator must develop and implement a Stormwater Pollution Prevention Plan (SWPPP) in addition to any other requirements of the facility's NPDES permit. Any construction permit application for closure must include a copy of the SWPPP.

d) At the end of each month during which CCR is being removed from a CCR surface impoundment, the owner or operator must prepare a report that:

1) Describes the weather, precipitation amounts, the amount of CCR removed from the CCR surface impoundment, the amount and location of CCR being stored on-site, the amount of CCR transported offsite, the implementation of good housekeeping procedures required by subsection (c)(4)(C), and the implementation of dust control measures; and

2) Documents worker safety measures implemented. The owner or operator of the CCR surface impoundment must place the monthly report in the facility's operating record as required by Section 845.800(d)(23).

e) Upon completion of CCR removal and decontamination of the CCR surface impoundment under subsection (a), the owner or operator of the CCR surface impoundment must submit to the Agency a completion of CCR removal and decontamination report and a certification from a qualified professional engineer that CCR removal and decontamination of the CCR surface impoundment has been completed in accordance with this Section. The owner or operator must place the CCR removal and decontamination report and certification in the facility's operating record as required by Section 845.800(d)(32).

f) Upon completion of groundwater monitoring required under subsection (b), the owner or operator of the CCR surface impoundment must submit to the Agency a completion of groundwater monitoring report and a certification from a qualified professional engineer that groundwater monitoring has been completed in accordance with this Section. The owner or operator must place the groundwater monitoring report and certification in the facility's operating record as required by Section 845.800(d)(24).

Section 845.750 Closure with a Final Cover System

Closure Performance Standard When Leaving CCR in Place:

a) The owner or operator of a CCR surface impoundment must ensure that, at a minimum, the CCR surface impoundment is closed in a manner that will:

1) Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;

2) Preclude the probability of future impoundment of water, sediment, or slurry;

3) Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system during the closure and post-closure care period;

4) Minimize the need for further maintenance of the CCR surface impoundment; and

5) Be completed in the shortest amount of time consistent with recognized and generally accepted engineering practices.

b) Drainage and Stabilization of CCR Surface Impoundments. The owner or operator of a CCR surface impoundment or any lateral expansion of a CCR

surface impoundment must meet the requirements of this subsection (b) before installing the final cover system required by subsection (c).

1) Free liquids must be eliminated by removing liquid wastes or solidifying the remaining wastes and waste residues.

2) Remaining wastes must be stabilized sufficiently to support the final cover system.

c) Final Cover System. If a CCR surface impoundment is closed by leaving CCR in place, the owner or operator must install a final cover system that is designed to minimize infiltration and erosion, and, at a minimum, meets the requirements of this subsection (c). The final cover system must consist of a low permeability layer and a final protective layer. The design of the final cover system must be included in the preliminary and final written closure plans required by Section 845.720 and the construction permit application for closure submitted to the Agency.

1) Standards for the Low Permeability Layer. The low permeability layer must have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a hydraulic conductivity no greater than 1×10^{-7} cm/sec, whichever is less. The low permeability layer must be constructed in accordance with the standards in either subsection (c)(1)(A) or (c)(1)(B), unless the owner or operator demonstrates that another low permeability layer construction technique or material provides equivalent or superior performance to the requirements of either subsection (c)(1)(A) or (c)(1)(B) and is approved by the Agency.

A) A compacted earth layer constructed in accordance with the following standards:

i) The minimum allowable thickness must be 0.91 meter (three feet); and

ii) The layer must be compacted to achieve a hydraulic conductivity of 1×10^{-7} cm/sec or less and minimize void spaces.

B) A geomembrane constructed in accordance with the following standards:

i) The geosynthetic membrane must have a minimum thickness of 40 mil (0.04 inches) and, in terms of hydraulic flux, must be equivalent or superior to a three-foot layer of soil with a hydraulic conductivity of 1×10^{-7} cm/sec;

ii) The geomembrane must have strength to withstand the normal stresses imposed by the waste stabilization process; and

iii) The geomembrane must be placed over a prepared base free from sharp objects and other materials that may cause damage.

2) Standards for the Final Protective Layer. The final protective layer must meet the following requirements, unless the owner or operator demonstrates that another final protective layer construction technique or material provides equivalent or superior performance to the requirements of this subsection (c)(2) and is approved by the Agency.

A) Cover the entire low permeability layer;

B) Be at least three feet thick, be sufficient to protect the low permeability layer from freezing, and minimize root penetration of the low permeability layer;

C) Consist of soil material capable of supporting vegetation;

D) Be placed as soon as possible after placement of the low permeability layer; and

E) Be covered with vegetation to minimize wind and water erosion.

3) The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

4) The owner or operator of the CCR surface impoundment must obtain and submit with its construction permit application for closure a written certification from a qualified professional engineer that the design of the final cover system meets the requirements of this Section.

d) This subsection specifies the allowable uses of CCR in the closure of CCR surface impoundments closing under Section 845.700. Notwithstanding the prohibition on further placement in Section 845.700, CCR may be placed in these surface impoundments, but only for purposes of grading and contouring in the design and construction of the final cover system, if:

1) The CCR placed was generated at the facility and is located at the facility at the time closure was initiated;

2) CCR is placed entirely above the elevation of CCR in the surface impoundment, following dewatering and stabilization (see subsection (b));

3) The CCR is placed entirely within the perimeter berms of the CCR surface impoundment; and

4) The final cover system is constructed with either:

A) A slope not steeper than 5% grade after allowance for settlement; or

B) At a steeper grade, if the Agency determines that the steeper slope is necessary, based on conditions at the site, to facilitate run-off and minimize erosion, and that side slopes are evaluated for erosion potential based on a stability analysis to evaluate possible erosion potential. The stability analysis, at a minimum, must evaluate the site geology; characterize soil shear strength; construct a slope stability model; establish groundwater and seepage conditions, if any; select loading conditions; locate critical failure surface; and iterate until minimum factor of safety is achieved.

Section 845.760 Completion of Closure Activities

a) Except as provided for in subsection (b), the owner or operator must complete closure of existing and new CCR surface impoundments, and any lateral expansion of a CCR surface impoundment, within the timeframe approved by the Agency in the final closure plan, or within five years of obtaining a construction permit for closure, whichever is less.

b) Extensions of Closure Timeframes

1) The timeframes for completing closure of a CCR surface impoundment specified under subsection (a) may be extended if the owner or operator has demonstrated to the Agency that it was not feasible to complete closure of the CCR surface impoundment within the required timeframes due to factors beyond the facility's control.

2) The demonstration must include a narrative explaining the basis for additional time.

3) The owner or operator must submit the demonstration to the Agency with a renewal construction permit application for closure.

4) Factors that may support a demonstration include:

A) Complications stemming from the climate and weather, such as unusual amounts of precipitation or a significantly shortened construction season;

B) Time required to dewater a surface impoundment due to the volume of CCR contained in the CCR surface impoundment or the characteristics of the CCR in the surface impoundment;

C) Statement that the geology and terrain surrounding the CCR surface impoundment will affect the amount of material needed to close the CCR surface impoundment; or

D) Time required or delays caused by the need to coordinate with and obtain necessary approvals and permits from the Agency or other agencies.

c) Maximum Time Extensions

1) CCR surface impoundments of 40 acres or smaller that are not closing by removal may extend the time to complete closure by no longer than two years.

2) CCR surface impoundments larger than 40 acres that are not closing by removal may extend the timeframe to complete closure of the CCR surface impoundment multiple times, in two-year increments. For each two-year extension sought, the owner or operator must substantiate the factual circumstances demonstrating the need for the extension. No more than a total of five two-year extensions may be obtained for any CCR surface impoundment.

3) CCR surface impoundments that are closing by removal may extend the time to complete closure multiple times, in two-year increments. For each two-year extension sought, the owner or operator must substantiate the factual circumstances demonstrating the need for the extension. In no instance may the time allowed for closure by removal be extended beyond the completion of a groundwater corrective action as required by Section 845.680(c)(1).

d) In order to obtain an additional time extension to complete closure of a CCR surface impoundment beyond the times provided by subsection (a), the owner or operator of the CCR surface impoundment must include with the demonstration required by subsection (b) the following statement signed by the owner or operator or an authorized representative:

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this demonstration and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that

there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

e) Upon completion of all closure activities required by this Part and approved in the final closure plan, the owner or operator of the CCR surface impoundment must submit to the Agency a closure report and a closure certification.

1) The closure report must contain supporting documentation, including:

A) Engineering and hydrogeology reports, including monitoring well completion reports and boring logs, all CQA reports, certifications, and designations of CQA officers-in-absentia required by Section 845.290;

B) Photographs, including time, date and location information of the photographs, of the final cover system and groundwater collection system, if applicable, and any other photographs relied upon to document construction activities;

C) A written summary of closure requirements and completed activities as stated in the closure plan and this Part; and

D) Any other information relied upon by the qualified professional engineer in making the closure certification.

2) The closure certification must include a statement from a qualified professional engineer that closure has been completed in accordance with the Agency-approved final closure plan and the requirements of this Section.

3) The owner or operator must place the closure report and certification in the facility's operating record as required by Section 845.800(d)(24).

f) Within 30 days after the Agency's approval of the closure report and closure certification submitted under subsection (e), the owner or operator must prepare a notification of closure of the CCR surface impoundment. The notification must include the certification by a qualified professional engineer required by subsection (e)(2). The owner or operator must place the notification in the facility's operating record as required by Section 845.800(d)(25).

g) If an owner or operator of a CCR surface impoundment has completed closure of the CCR surface impoundment before April 21, 2021, the owner or operator must notify the Agency of the completed closure by September 30, 2021, if that notification has not previously been submitted.

h) Deed Notations

1) Following closure of a CCR surface impoundment, the owner or operator must record a notation on the deed to the property, or some other instrument that is normally examined during title search.

2) The notation on the deed must in perpetuity notify any potential purchaser of the property that:

A) The land has been used as a CCR surface impoundment; and

B) Its use is restricted under the post-closure care requirements as provided by Section 845.780(d)(1)(C) or groundwater monitoring requirements in Section 845.740(b).

3) Within 30 days after recording a notation on the deed to the property, the owner or operator must submit to the Agency a notification stating that the notation has been recorded. The owner or operator must place the notification in the facility's operating record as required by 845.800(d)(26).

Section 845.770 Retrofitting

Retrofit of a CCR surface impoundment must be completed in accordance with the requirements of this Section.

a) To retrofit an existing CCR surface impoundment, the owner or operator must:

1) First remove all CCR, including any liners except as specified in subsection (a)(4), as necessary, and contaminated soils and sediments from the CCR surface impoundment;

2) Comply with the requirements in Sections 845.410 and 845.420; and

3) Within 30 days after April 21, 2021, the owner or operator electing to retrofit a CCR surface impoundment under this Section must submit a written preliminary retrofit plan to the Agency and post the written preliminary retrofit plan in the facility's operating record as required by Section 845.800(d)(27). The written preliminary retrofit plan must include a prioritization categorization under Section 845.700(g) and the expected construction permit application date under Section 845.700(h); and

4) An owner or operator may request the Agency to approve the use of an existing competent geomembrane liner as a supplemental liner by submitting visual inspection, and analytical testing results to demonstrate that the existing liner is not contaminated with CCR constituents.

b) A CCR surface impoundment undergoing a retrofit remains subject to all other requirements of this Part, including the requirement to conduct any necessary corrective action.

c) Written Retrofit Plan

1) Content of the Plan. The owner or operator must prepare a written retrofit plan that describes the steps necessary to retrofit the CCR surface impoundment consistent with recognized and generally accepted engineering practices. The written retrofit plan must include, at a minimum, all the following information:

A) A narrative description of the specific measures that will be taken to retrofit the CCR surface impoundment in accordance with this Section.

B) A description of the procedures to remove all CCR, liners as necessary, and contaminated soils and sediments from the CCR surface impoundment.

C) An estimate of the maximum amount of CCR and other contaminated materials that will be removed as part of the retrofit operation.

D) An estimate of the largest area of the CCR surface impoundment that will be affected by the retrofit operation.

E) A schedule for completing all activities necessary to satisfy the retrofit criteria in this Section, including an estimate of the year in which retrofit activities of the CCR surface impoundment will be completed.

2) The owner or operator must submit the written retrofit plan with the construction permit application and must obtain a construction permit before retrofitting a CCR surface impoundment.

3) Amendment of a Written Retrofit Plan.

A) The owner or operator may submit a permit modification application to amend the initial or any subsequent written retrofit plan at any time.

B) The owner or operator must seek to amend the written retrofit plan whenever:

i) There is a change in the operation of the CCR surface impoundment that would substantially affect the written retrofit plan in effect; or

ii) unanticipated events necessitate a revision of the written retrofit plan either before or after retrofit activities have started.

C) The owner or operator must seek to amend the retrofit plan at least 60 days before a planned change in the operation of the facility or CCR surface impoundment, or within 60 days after an unanticipated event requires the revision of an existing written retrofit plan. If a written retrofit plan needs to be revised after retrofit activities have started for a CCR surface impoundment, the owner or operator must submit a request to modify the construction permit within 60 days following the triggering event.

4) The owner or operator of the CCR surface impoundment must obtain a written certification from a qualified professional engineer that the activities outlined in the written retrofit plan, including any amendment of the plan, meet the requirements of this Section.

d) By the date the owner or operator submits a construction permit application to the Agency to retrofit a CCR surface impoundment, the owner or operator must prepare a notification of intent to retrofit a CCR surface impoundment. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by Section 845.800(d)(28).

e) When activities related to retrofitting the CCR surface impoundment include the removal of CCR from the surface impoundment, the handling and removal of CCR must be performed in a manner consistent with the requirements of Section 845.740.

f) Deadline for Completion of Activities Related to the Retrofit of a CCR Surface Impoundment. Any CCR surface impoundment that is being retrofitted must complete all retrofit activities within the timeframe approved by the Agency in the retrofit plan, or within five years after obtaining a construction permit, whichever is less. The same procedures specified for the extension closure timeframes in Section 845.760(b) apply to extension of retrofit timeframes.

g) Upon completion of all retrofit activities required by this Part and approved by the Agency in a construction permit, the owner or operator of the CCR surface impoundment must submit to the Agency a retrofit completion report and certification.

1) The retrofit completion report must contain supporting documentation, including:

A) Engineering and hydrogeology reports, including monitoring well completion reports and boring logs, all CQA reports, certifications, and designations of CQA officers-in-absentia required by Section 845.290;

B) Photographs, including time, date and location information of the photographs, of the liner system and leachate collection system, and any other photographs relied upon to document construction activities;

C) A written summary of retrofit requirements and completed activities as stated in the construction permit and this Part; and

D) Any other information relied upon by the qualified professional engineer in making the closure certification.

2) The retrofit certification must include a statement from a qualified professional engineer that retrofit has been completed in accordance with the retrofit plan specified in subsection (c) and the requirements of this Part.

3) The owner or operator must place the retrofit completion report and certification in the facility's operating record as required by Section 845.800(d)(29).

h) Within 30 days after the Agency's approval of the retrofit completion report and certification submitted under subsection (g), the owner or operator must prepare a notification of completion of retrofit activities. The notification must include the certification by a qualified professional engineer as required by subsection (g)(2). The owner or operator has completed the notification when it has been placed in the facility's operating record as required by Section 845.800(d)(30).

i) At any time after the initiation of a CCR surface impoundment retrofit, the owner or operator may stop the retrofit and seek to initiate closure of the CCR surface impoundment in accordance with the requirements of this Subpart G. The owner or operator of the CCR surface impoundment must obtain an approved construction permit for closure.

Section 845.780 Post-Closure Care Requirements

a) Applicability

1) Except as provided by subsection (a)(2), this Section applies to the owners or operators of CCR surface impoundments who have completed an Agency approved closure.

2) An owner or operator of a CCR surface impoundment that elects to close a CCR surface impoundment by removing CCR as provided by Section 845.740 is not subject to the post-closure care criteria of this Section.

b) Post-closure Care Maintenance Requirements. Following closure of the CCR surface impoundment, the owner or operator must conduct post-closure care for the CCR surface impoundment, which must consist of at least the following:

1) Maintaining the integrity and effectiveness of the final cover system, including making repairs to the final cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover;

2) If the CCR surface impoundment is subject to the design criteria of Section 845.420, maintaining the integrity and effectiveness of the leachate collection and removal system and operating the leachate collection and removal system in accordance with the requirements of Section 845.420; and

3) Maintaining the groundwater monitoring system and monitoring the groundwater in accordance with the requirements of Subpart F.

c) Post-closure Care Period

1) Except as provided by subsection (c)(2), the owner or operator of the CCR surface impoundment must conduct post-closure care for 30 years.

2) At the end of the 30-year post-closure care period, the owner or operator of the CCR surface impoundment must continue to conduct post-closure care until the groundwater monitoring data shows the concentrations are:

A) Below the groundwater protection standards in Section 845.600; and

B) Not increasing for those constituents over background, using the statistical procedures and performance standards in Section 845.640(f) and (g), provided that:

i) Concentrations have been reduced to the maximum extent feasible; and

ii) Concentrations are protective of human health and the environment.

d) Written Post-closure Care Plan

1) Content of the Plan. The owner or operator of a CCR surface impoundment must prepare a written post-closure care plan that includes, at a minimum, the information specified in this subsection (d)(1).

A) A description of the monitoring and maintenance activities required in subsection (b) for the CCR surface impoundment and the frequency at which these activities will be performed;

B) The name, address, telephone number, and email address of the person or office to contact about the facility during the post-closure care period; and

C) A description of the planned uses of the property during the post-closure care period. Post-closure use of the property must not disturb the integrity of the final cover, liners, or any other component of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements of this Part. Any other disturbance is allowed if the owner or operator of the CCR surface impoundment demonstrates that disturbance of the final cover, liner, or other component of the containment system, including any removal of CCR, will not increase the potential threat to human health or the environment. The demonstration must be certified by a qualified professional engineer and must be submitted to the Agency.

2) Deadline to Prepare the Initial Written Post-closure Care Plan. The owner or operator of a CCR surface impoundment must submit to the Agency an initial written post-closure care plan consistent with the requirements specified in subsection (d)(1), with its initial operating permit application.

3) Amendment of a Written Post-closure Care Plan.

A) The owner or operator may submit an operating permit modification application to amend the initial or any subsequent written post-closure care plan developed under subsection (d)(1) at any time.

B) The owner or operator must seek to amend the written closure care plan whenever:

i) There is a change in the operation of the CCR surface impoundment that would substantially affect the written post-closure care plan in effect; or

ii) unanticipated events necessitate a revision of the written post-closure care plan, after post-closure activities have started.

C) The owner or operator must seek to amend the written post-closure care plan at least 60 days before a planned change in the operation of the facility or CCR surface impoundment, or within 60 days after an unanticipated event requires the need to revise an existing written post-closure care plan. If a written post-closure care plan is revised after post-closure activities have started for a CCR surface impoundment, the owner or operator must submit a request to modify the operating permit within 30 days following the triggering event.

4) The owner or operator of the CCR surface impoundment must obtain a written certification from a qualified professional engineer that the initial, and any amendment of the, written post-closure care plan meets the requirements of this Section.

e) Upon the completion of the post-closure care period, the owner or operator of the CCR surface impoundment must submit a request to the Agency to terminate post-closure care. The request must include a certification by a qualified professional engineer verifying that post-closure care has been completed in accordance with the post-closure care plan specified in subsection (d) and the requirements of this Section.

f) Notification of Completion of Post-closure Care Period. Within 30 days after the Agency's approval of the owner's or operator's request to terminate post-closure care, the owner or operator must prepare a notification of completion of post-closure care and must place the notification in the facility's operating record as required by Section 845.800(d)(31).

SUBPART H: RECORDKEEPING

Section 845.800 Facility Operating Record

a) Each owner or operator of a CCR surface impoundment subject to the requirements of this Part must maintain files of all information required by this Section in a written operating record at the facility.

b) Unless specified otherwise, each file must be retained for at least three years past the date the Agency approved the owner's or operator's request to terminate post-

closure care, when closure is with a final cover system, or the completion of groundwater monitoring under Section 845.740(b), when closure is by removal.

c) An owner or operator of more than one CCR surface impoundment subject to the provisions of this Part may comply with the requirements of this Section in one recordkeeping system provided the system identifies each file by the name and identification number of each CCR surface impoundment. The files may be maintained on microfilm, on a computer, on computer disks, on a storage system accessible by a computer, on magnetic tape disks, or on microfiche.

d) Unless otherwise required below, the owner or operator of a CCR surface impoundment must place the following information, as it becomes available, in the facility's operating record:

1) Copies of all permit applications and permits issued under this Part;

2) Documentation recording the public meetings held under Section 845.240;

3) Weekly CQA reports under Section 845.290(b);

4) Hazard potential classification assessments for CCR surface impoundments (see Section 845.440(a)(3)(D));

5) Structural stability assessments for CCR surface impoundments (see Section 845.450(d)(4));

6) Safety factor assessments for CCR surface impoundments (see Section 845.460(c)(4));

7) The CCR fugitive dust control plan and any subsequent amendment of the plan (see Section 845.500(b)(6)), except that only the most recent fugitive dust control plan must be maintained in the facility's operating record, irrespective of the time requirement specified in subsection (b);

8) Inflow design flood control system plans for CCR surface impoundments (see Section 845.510(c)(4)(D));

9) Emergency Action Plan (see Section 845.520(a)), except that only the most recent EAP must be maintained in the facility's operating record irrespective of the time requirement specified in subsection (b);

10) Documentation prepared by the owner or operator recording all activations of the EAP (see Section 845.520(f));

11) Documentation prepared by the owner or operator recording the annual face-to-face meeting or exercise between representatives of the owner or

operator of the CCR surface impoundment and the local emergency responders (see Section 845.520(g));

12) Safety and Health Plan (see Section 845.530(a));

13) Documentation recording the results of each inspection and instrumentation monitoring by a qualified person (see Section 845.540(a)(2));

14) Annual consolidated report (see Section 845.550), which contains the following:

A) The annual CCR fugitive dust control report (see Section 845.500(c));

B) The annual inspection report (see Section 845.540(b)(3)); and

C) The annual groundwater monitoring and corrective action report (see Section 845.610(e));

15) All groundwater monitoring data submitted to the Agency and any analysis performed (see Section 845.610(b)(3)(D));

16) Within 30 days after detecting one or more monitored constituents above the groundwater protection standard, the notifications required by Section 845.650(d) and (e);

17) The semi-annual report describing the progress in selecting and designing the remedy (see Section 845.670(a));

18) Within 30 days after completing the corrective action plan, the notification required by Section 845.680(e);

19) USEPA-approved or denied demonstration as required by Section 845.700(d)(2)(F);

20) The preliminary written closure plan and any amendment of the plan (see Section 845.720(a)) except that only the most recent closure plan must be maintained in the facility's operating record, irrespective of the time requirement specified in subsection (b);

21) The written demonstrations, including the certification required by Section 845.730(b)(3), for a time extension for initiating closure (see Section 845.730(b)(2));

22) The notification of intent to close a CCR surface impoundment (see Section 845.730(d));

23) The monthly reports for closure by removal (see Section 845.740(d));

24) The closure report and certification (see Section 845.760(e)(3)), or the completion of groundwater monitoring report and certification (see Section 845.740(f));

25) The notification of completion of closure of a CCR surface impoundment (see Section 845.760(f));

26) The notification recording a notation on the deed (see Section 845.760(h));

27) The preliminary written retrofit plan for a CCR surface impoundment (see Section 845.770(a)(3));

28) The notification of intent to initiate retrofit of a CCR surface impoundment (see Section 845.770(d));

29) The retrofit completion report and certification (see Section 845.770(g)(3));

30) The notification of completion of retrofit activities (see Section 845.770(h));

31) The notification of completion of post-closure care period (see Section 845.780(f));

32) The completion of CCR removal and decontamination report and certification (see Section 845.740(e)); and

33) The most current cost estimates (see Section 845.940(d)).

Section 845.810 Publicly Accessible Internet Site Requirements

a) Each owner or operator of a CCR surface impoundment subject to the requirements of this Part must maintain a publicly accessible Internet site (CCR website) containing the information specified in this Section. The owner's or operator's website must be titled "Illinois CCR Rule Compliance Data and Information".

b) An owner or operator of more than one CCR surface impoundment subject to the provisions of this Part may comply with the requirements of this Section by using the same Internet site for multiple CCR surface impoundments, provided the CCR

website clearly delineates information by the name and identification number of each CCR surface impoundment.

c) Unless otherwise required in this Section, the information required to be posted to the CCR website must be made available to the public on the CCR website until 3 years after post-closure care (when closure is with a final cover system) or the completion of groundwater monitoring under Section 845.740(b) (when closure is by removal).

d) Unless otherwise required in this Section, the information must be posted to the CCR website within 14 days after placing the pertinent information required by Section 845.800 in the operating record.

e) The owner or operator must place all the information specified under Section 845.800(d) on the owner's or operator's CCR website.

f) The owner or operator must place all the information specified in Section 845.240(e) on the owner's or operator's CCR website at least 30 days before the public meeting.

g) The owner or operator must notify the Agency of the web address of the publicly accessible Internet site, including any change to the web address. The Agency must maintain a list of these web addresses on the Agency's website.

SUBPART I: FINANCIAL ASSURANCE

Section 845.900 General Provisions

a) This Subpart provides procedures by which the owner or operator of a CCR surface impoundment subject to this Part provides financial assurance satisfying the requirements of Section 22.59(f) of the Act.

b) The owner or operator must provide financial assurance to ensure the following:

1) Completion of closure;

2) Completion of post-closure care, if applicable; and

3) Remediation of releases from a CCR surface impoundment.

c) The owner or operator must maintain financial assurance equal to or greater than the current cost estimates always calculated under Section 845.930, except as otherwise provided by Section 845.910.

d) Financial assurance must be provided, by a trust agreement, a surety bond guaranteeing payment, a surety bond guaranteeing payment or performance, or an

irrevocable letter of credit (see Section 845.950). The owner or operator must provide financial assurance to the Agency within the timeframes in Section 845.950(c).

e) This Subpart does not apply to the State of Illinois, its agencies and institutions, any unit of local government, or any not-for-profit electric cooperative as defined in Section 3.4 of the Electric Supplier Act [220 ILCS 30].

f) The Agency is authorized to enter into contracts and agreements necessary to carry out the purposes of this Subpart and of Section 22.59(f) of the Act. Neither the State, nor the Director of the Agency, nor any State employee will be liable for any damages or injuries arising out of, or resulting from, any action taken under this Part.

g) The Agency may sue in any court of competent jurisdiction to enforce its rights under financial instruments. The filing of an enforcement action before the Board is not a condition precedent to such an Agency action, except when this Subpart or the terms of the instrument provide otherwise.

h) The Agency must have the authority to approve or disapprove any financial assurance mechanism posted or submitted under this Subpart.

i) The following Agency actions may be appealed to the Board as a permit denial under Section 845.270(e) and Section 22.59(f)(3) of the Act:

1) A refusal to accept financial assurance tendered by the owner or operator;

2) A refusal to release the owner or operator from the requirement to maintain financial assurance;

3) A refusal to release excess funds from a trust;

4) A refusal to approve a reduction in the penal sum of a bond; and

5) A refusal to approve a reduction in the amount of a letter of credit.

j) An owner or operator must notify the Agency by certified mail of the beginning of a voluntary or involuntary proceeding under Title 11 of the United States Code (Bankruptcy) naming any of the owners or operators as debtor, within 10 days after the proceeding starts.

k) An owner or operator that fulfills the requirements of Section 845.960, 845.970, 845.980, or 845.990 by obtaining a trust fund, surety bond, or letter of credit will be deemed to be without the required financial assurance in the event of bankruptcy of the trustee or issuing institution, or a suspension or revocation of the authority of the trustee institution to act as trustee or of the institution issuing

the surety bond or letter of credit to issue those instruments. The owner or operator must establish alternative financial assurance within 60 days after such an event.

Section 845.910 Upgrading Financial Assurance

a) The owner or operator must increase the total amount of financial assurance to equal or exceed the current cost estimate within 60 days after either of the following occurrences:

1) An increase in the current cost estimate; or

2) A decrease in the value of a trust fund.

b) The owner or operator of a CCR surface impoundment must make annual adjustments for inflation if required under Section 845.930 or 845.940.

Section 845.920 Release of Financial Institution and Owner or Operator

a) The Agency must release a trustee, surety, or other financial institution when:

1) An owner or operator substitutes alternative financial assurance such that the total financial assurance for the CCR surface impoundment is equal to or greater than the current cost estimate, without counting the amounts to be released; or

2) The Agency releases the owner or operator from the requirements of this Subpart under subsection (b).

b) The Agency must release an owner or operator of a CCR surface impoundment from the requirements of this Subpart under the following circumstances:

1) Completed Closure. In the Agency's approval of the closure report and certification under Section 845.760, the Agency must notify the owner or operator in writing that it is no longer required by this Subpart to maintain financial assurance for closure of the CCR surface impoundment.

2) Completed Post-Closure Care. In the Agency's approval of the owner's or operator's request to terminate post-closure care under Section 845.780, the Agency must notify the owner or operator in writing that it is no longer required by this Subpart to maintain financial assurance for post-closure care of the CCR surface impoundment.

3) Completed Corrective Action. In the Agency's approval of the corrective action completion report and certification under Section 845.680, the Agency must notify the owner or operator in writing that it is no longer

required by this Subpart to maintain financial assurance for corrective action.

Section 845.930 Cost Estimates

a) The owner or operator must prepare and submit to the Agency, for approval, written cost estimates for:

1) The total costs for closure and post-closure care;

2) Preliminary corrective action costs; and

3) The total costs of the corrective action plan for remediation of any releases from a CCR surface impoundment.

b) Written Cost Estimate for Closure and Post-closure

1) The owner or operator must have a detailed written estimate, in current dollars, of the cost of closing the CCR surface impoundment in accordance with this Part and providing post-closure care on an annual basis, when required, in accordance with this Part. The cost estimate is the total cost for closure and post-closure care.

2) The cost estimate must equal the cost of final closure and post-closure care at the point in the CCR surface impoundment's active life when the extent and manner of its operation would make closure and post-closure care the most expensive.

3) The cost estimate must be based on the assumption that the Agency will contract with a third party at the appropriate prevailing wages, under the Prevailing Wage Act [820 ILCS 130], if applicable, to implement the closure and post-closure care plans. A third party is a party who is neither a parent nor a subsidiary of the owner or operator.

4) The cost estimate may not be reduced by allowance for the salvage value of facility structures or equipment, for the resale value of land, for the sale of CCR or its beneficial reuse if permitted by the Agency under this Part, or for other assets associated with the facility at the time of partial or final closure.

5) The owner or operator must not incorporate a zero cost for CCR, if permitted by the Agency under this Part, that might have economic value.

6) The cost estimate must, at a minimum, include all costs for all activities necessary to close the CCR surface impoundment and provide post-closure care in accordance with all requirements.

7) The post-closure care portion of the cost estimate must, at a minimum, be based on the following elements:

A) Maintaining the integrity and effectiveness of the final cover system, including making repairs to the final cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover;

B) If the CCR surface impoundment is subject to the design criteria of Section 845.420, maintaining the integrity and effectiveness of the leachate collection and removal system and operating the leachate collection and removal system in accordance with the requirements of Section 845.420; and

C) Maintaining the groundwater monitoring system and monitoring the groundwater in accordance with the requirements of this Part.

c) Cost Estimate for Corrective Action

1) Preliminary Corrective Action Cost Estimate. An owner or operator of a CCR surface impoundment with a release that has caused an exceedance of the groundwater protection standard in Section 845.600, or groundwater quality standard in 35 Ill. Adm. Code 620, must provide a preliminary corrective action cost estimate that is equal to 25% of the costs calculated under subsection (b).

2) Corrective Action Cost Estimate. The owner or operator must provide to the Agency a detailed written estimate, in current dollars, of the cost of hiring a third party at the appropriate prevailing wages, under the Prevailing Wage Act, if applicable, to implement the approved corrective action plan in accordance with this Part. The corrective action cost estimate must account for the total costs of corrective action activities as described in the approved corrective action plan for the entire corrective action period.

3) The owner or operator must annually adjust the cost estimates in this subsection (c) for inflation (see Section 845.940(a)) until the approved corrective action plan is completed.

4) The owner or operator must increase the corrective action cost estimates in this subsection (c) and the amount of financial assurance provided if changes in the corrective action plan or CCR surface impoundment conditions increase the maximum costs of corrective action.

5) The owner or operator may reduce the amount of the corrective action cost estimate, upon Agency approval, if the cost estimate exceeds the maximum remaining costs of corrective action.

Section 845.940 Revision of Cost Estimates

a) During the active life of the CCR surface impoundment, the owner or operator must adjust the cost estimates for closure, post-closure care, and corrective action for inflation on an annual basis. The adjustments must occur within 60 days before the anniversary date of the establishment of the financial instruments used to comply with Section 845.950. The adjustment may be made by recalculating the maximum costs of closure, post-closure care, or corrective action in current dollars, or by using an inflation factor derived from the annual Implicit Price Deflator for Gross National Product (Deflator) as published by the U.S. Department of Commerce in its Survey of Current Business (Table 1.1.9) (see subsections (a)(1) and (a)(2)). The inflation factor is the result of dividing the latest published annual Deflator by the Deflator for the previous year.

1) The first adjustment is made by multiplying the cost estimate by the inflation factor. The result is the adjusted cost estimate.

2) Subsequent adjustments are made by multiplying the latest adjusted cost estimate by the latest inflation factor.

b) During the active life of the CCR surface impoundment, the owner or operator must revise the cost estimate within 30 days after the Agency has approved a request to modify the corrective action plan, closure plan, or post-closure care plan, if the change in the modified plan increases the cost of corrective action, closure or post-closure care. The revised cost estimate must be adjusted for inflation (see subsection (a)).

c) At least 60 days before submitting any closure plan to the Agency, the owner or operator must revise the cost estimate if the selected closure method increases the estimated closure or post-closure care costs.

d) The owner or operator must keep the most current cost estimates in the facility's operating record during the operating life of the CCR surface impoundment.

Section 845.950 Mechanisms for Financial Assurance

a) The owner or operator of a CCR surface impoundment must use any of the mechanisms listed in this subsection (a) to provide financial assurance for closure and post-closure care, and for corrective action at a CCR surface impoundment. An owner or operator of a CCR surface impoundment must also meet the requirements of subsections (b), (c), and (d). The mechanisms are as follows:

1) A trust fund (see Section 845.960);

2) A surety bond guaranteeing payment (see Section 845.970);

3) A surety bond guaranteeing performance (see Section 845.980); or

4) An irrevocable letter of credit (see Section 845.990).

b) The owner or operator of a CCR surface impoundment must ensure that the language of the mechanisms listed in subsection (a), when used for providing financial assurance for closure, post-closure, and corrective action, is consistent with the forms prescribed by the Agency and satisfies the following:

1) The amount of funds assured is sufficient to cover the costs of closure, post-closure care, and corrective action; and

2) The funds will be available in a timely fashion when needed.

c) The owner or operator of a CCR surface impoundment must provide financial assurance utilizing one or more of the mechanisms listed in subsection (a) within the following timeframes:

1) An owner or operator of an existing CCR surface impoundment must provide financial assurance to the Agency for closure and post-closure care within 60 days after April 21, 2021;

2) An owner or operator of a new CCR surface impoundment must provide financial assurance to the Agency for closure and post-closure care at least 60 days before the date of initial receipt of CCR in the CCR surface impoundment.

3) In the case of corrective action required by this Part, the owner or operator of the CCR surface impoundment must provide preliminary financial assurance for corrective action no later than when the owner or operator initiates an assessment of corrective measures under Section 845.650(d)(3). The preliminary financial assurance for corrective action must be maintained until replaced with financial assurance based on the cost estimate of the corrective action. The owner or operator of the CCR surface impoundment must provide financial assurance based on the approved corrective action plan to the Agency within 60 days after either the Agency's approval or April 21, 2021, whichever is later.

d) The owner or operator must provide continuous financial assurance coverage until the owner or operator is released from the financial assurance requirements of this Subpart under Section 845.920(b).

e) Use of Multiple Financial Assurance Mechanisms. An owner or operator may satisfy the requirements of this Subpart by establishing more than one financial mechanism per CCR surface impoundment. These mechanisms are limited to trust funds, surety bonds guaranteeing payment, and letters of credit. The mechanisms must be as specified in Sections 845.960, 845.970, and 845.990, as applicable, except that it is the combination of mechanisms, rather than the single mechanism, that must provide financial assurance for an aggregate amount at least equal to the current cost estimate for closure, post-closure care, and corrective action, except that mechanisms guaranteeing performance, rather than payment, may not be combined with other instruments. The owner or operator may use any or all the mechanisms to provide financial assurance for corrective action, closure and post-closure care.

f) Use of a Financial Assurance Mechanism for Multiple CCR Surface Impoundments in Illinois. An owner or operator may use a financial assurance mechanism specified in this Subpart to meet the requirements of this Subpart for more than one CCR surface impoundment located in Illinois. Evidence of financial assurance submitted to the Agency must include a list showing, for each CCR surface impoundment, the identification number (see Section 845.130), name, address and the amount of funds assured by the mechanism. The amount of funds available through the mechanism must be at least the sum of funds that would be available if a separate mechanism had been established and maintained for each CCR surface impoundment. The amount of funds available to the Agency must be enough to close and provide post-closure care for all of the owner's or operator's CCR surface impoundments. In directing funds available through a single mechanism for the closure and post-closure care of any single CCR surface impoundment covered by that mechanism, the Agency must direct only that amount of funds designated for that CCR surface impoundment, unless the owner or operator agrees to the use of additional funds available under that mechanism.

Section 845.960 Trust Fund

a) An owner or operator may satisfy the requirements of this Subpart by establishing a fully funded trust fund that conforms to the requirements of this Section and submitting to the Agency an original signed duplicate of the trust agreement.

b) The trustee must be an entity that has the authority to act as a trustee and of whom either of the following is true:

1) It is an entity whose trust operations are examined by the Illinois Department of Financial and Professional Regulation under the Illinois Banking Act [205 ILCS 5]; or

2) It is an entity that complies with the Corporate Fiduciary Act [205 ILCS 620].

c) The trust agreement must be on forms prescribed by the Agency. The trust agreement must be updated within 60 days after a change in the amount of the current closure, post-closure, and corrective action cost estimates covered by the agreement.

d) The trust fund must be fully funded from the date that the trust agreement becomes effective.

e) The trustee must evaluate the trust fund annually, as of the day the trust was created or on such earlier date as may be provided in the agreement. The trustee must notify the owner or operator and the Agency of the value within 30 days after the evaluation date.

f) If the owner or operator of a CCR surface impoundment establishes a trust fund after having used one or more alternative mechanisms specified in this Subpart, the trust fund must be fully funded and established according to the specifications of this Section.

g) Release of Excess Funds

1) If the value of the financial assurance is greater than the total amount of the current cost estimate, the owner or operator may submit a written request to the Agency for a release of the amount in excess of the current cost estimate.

2) Within 60 days after receiving a request from the owner or operator for a release of funds, the Agency must instruct the trustee to release to the owner or operator the funds as the Agency specifies in writing to be in excess of the current cost estimate.

h) Reimbursement for Closure, Post-closure Care, and Corrective Action Expenses

1) After initiating corrective action, closure, or post-closure care an owner or operator, or any other person authorized to perform corrective action, closure, or post-closure care, may request reimbursement for closure, post-closure care, or corrective action expenditures by submitting itemized bills to the Agency.

2) Within 60 days after receiving the itemized bills for closure, post-closure care, or correction action activities, the Agency must determine whether the expenditures are in accordance with the closure, post-closure care, or corrective action plan. The Agency must instruct the trustee to make reimbursement in amounts the Agency specifies in writing as expenditures made in accordance with the closure, post-closure care, or corrective action plan.

3) If the Agency determines, based on information available to it, that the cost of closure and post-closure care or corrective action will be greater than the value of the trust fund, it must withhold reimbursement of amounts it determines are necessary to preserve the fund in order to accomplish closure and post-closure care or corrective action until it determines that the owner or operator is no longer required to maintain financial assurance for closure and post-closure care or corrective action. If the fund is inadequate to pay all claims, the Agency must pay claims according to the following priorities:

A) Persons with whom the Agency has contracted to perform closure, post-closure care, or corrective action activities (first priority);

B) Persons who have completed closure, post-closure care, or corrective action authorized by the Agency (second priority);

C) Persons who have completed work that furthered the closure, post-closure care, or corrective action (third priority);

D) The owner or operator and related business entities (last priority).

Section 845.970 Surety Bond Guaranteeing Payment

a) An owner or operator may satisfy the requirements of this Subpart by obtaining a surety bond that conforms to the requirements of this Section and submitting the bond to the Agency.

b) The surety company issuing the bond must, at a minimum, be among those listed as acceptable sureties on federal bonds in Circular 570 of the U.S. Department of the Treasury. Circular 570 is available on the Internet from the following website: https://fiscal.treasury.gov/surety-bonds/circular-570.html.

c) The surety bond must be on forms prescribed by the Agency.

d) Any payments drawn from or made under the bond will be placed in the Coal Combustion Residual Surface Impoundment Financial Assurance Fund within the State Treasury.

e) Conditions

1) The bond must guarantee that the owner or operator will:

A) Provide closure and post-closure care in accordance with the approved closure and post-closure care plans and, if the bond is a corrective action bond, provide corrective action in accordance

with this Part; and

B) Provide alternative financial assurance, as specified in this Subpart, and obtain the Agency's written approval of the assurance provided within 90 days after receipt by both the owner or operator and the Agency of a notice from the surety that the bond will not be renewed for another term.

2) The surety will become liable on the bond obligation when, during the term of the bond, the owner or operator fails to perform as guaranteed by the bond. The owner or operator fails to perform when the owner or operator:

A) Abandons the CCR surface impoundment;

B) Is adjudicated bankrupt;

C) Fails to initiate closure of the CCR surface impoundment or post-closure care or corrective action when ordered to do so by the Board under Title VIII of the Act (Enforcement), or when ordered to do so by a court of competent jurisdiction;

D) Notifies the Agency that it has initiated closure or corrective action, or initiates closure or corrective action, but fails to close the CCR surface impoundment or provide post-closure care or corrective action in accordance with the Agency-approved closure and post-closure care or corrective action plans;

E) For a corrective action bond, fails to implement or complete corrective action at a CCR surface impoundment in accordance with Section 845.670; or

F) Fails to, within 90 days after receipt by both the owner or operator and the Agency of a notice from the surety that the bond will not be renewed for another term:

i) Provide alternative financial assurance, as specified in this Subpart; and

ii) Obtain the Agency's written approval of the assurance.

3) If the owner or operator does not establish alternative financial assurance, as specified in this Subpart, and obtain written approval of that alternative assurance from the Agency within 90 days after receipt by both the owner or operator and the Agency of a notice of nonrenewal from the surety (see subsection (g)(2)), the Agency must draw on the bond. During the last 30

days of a notice of nonrenewal, the Agency must draw on the bond if the owner or operator has failed to provide alternative financial assurance, as specified in this Section, and obtain from the Agency written approval of that assurance.

f) Penal Sum

1) The penal sum of the bond must be in an amount at least equal to the current cost estimate.

2) Whenever the current cost estimate decreases, the penal sum may be reduced to the amount of the current cost estimate following written approval by the Agency.

3) Whenever the current cost estimate increases to an amount greater than the penal sum, the owner or operator, within 90 days after the increase, must either cause the penal sum to be increased to an amount at least equal to the current cost estimate and submit evidence of that increase to the Agency or obtain other financial assurance, as specified in this Subpart, to cover the increase and submit evidence of the alternative financial assurance to the Agency.

g) Term

1) The bond must be issued for a term of at least one year and must not be cancelable during that term.

2) The surety bond must provide that, on the current expiration date and on each successive expiration date, the term of the surety bond will be automatically extended for a period of at least one year unless, at least 120 days before the current expiration date, the surety notifies both the owner or operator and the Agency by certified mail of a decision not to renew the bond. Under the terms of the surety bond, the 120 days will begin on the date when both the owner or operator and the Agency have received the notice, as evidenced by the return receipts.

3) The Agency must release the surety by providing written authorization for termination of the bond to the owner or operator and the surety when either of the following occurs:

A) An owner or operator substitutes alternative financial assurance, as specified in this Subpart; or

B) The Agency releases the owner or operator from the requirements of this Subpart in accordance with Section 845.920(b).

h) Cure of Default and Refunds

1) The Agency must release the surety if, after the surety becomes liable on the bond, the owner or operator or another person provides financial assurance for closure and post-closure care of the CCR surface impoundment or corrective action at a CCR surface impoundment; unless the Agency determines that the closure, post-closure care, or corrective action plan, or the amount of substituted financial assurance, is inadequate to provide closure and post-closure care or implement corrective action in compliance with this Part.

2) After closure and post-closure care have been completed in accordance with the plans and requirements of this Part or after the completion of corrective action at a CCR surface impoundment in accordance with this Part, the Agency must refund any unspent money that was paid into the Coal Combustion Residual Surface Impoundment Financial Assurance Fund by the surety, subject to appropriation of funds by the Illinois General Assembly.

Section 845.980 Surety Bond Guaranteeing Performance

a) An owner or operator may satisfy the requirements of this Subpart by obtaining a surety bond that conforms to the requirements of this Section and submitting the bond to the Agency.

b) The surety company issuing the bond must, at a minimum, be among those listed as acceptable sureties on federal bonds in Circular 570 of the U.S. Department of the Treasury. Circular 570 is available on the Internet from the following website: https://fiscal.treasury.gov/surety-bonds/circular-570.html.

c) The surety bond must be on forms prescribed by the Agency.

d) Any payments made under the bond will be placed in the Coal Combustion Residual Surface Impoundment Financial Assurance Fund within the State Treasury.

e) Conditions

1) The bond must guarantee that the owner or operator will:

A) Provide closure and post-closure care in accordance with the approved closure and post-closure care plans and, if the bond is a corrective action bond, provide corrective action in accordance with this Part; and

B) Provide alternative financial assurance, as specified in this Subpart, and obtain the Agency's written approval of the assurance provided within 90 days after receipt by both the owner or operator and the Agency of a notice from the surety that the bond will not be renewed for another term.

2) The surety will become liable on the bond obligation when, during the term of the bond, the owner or operator fails to perform as guaranteed by the bond. The owner or operator fails to perform when the owner or operator:

A) Abandons the CCR surface impoundment;

B) Is adjudicated bankrupt;

C) Fails to initiate closure of the CCR surface impoundment or post-closure care or corrective action when ordered to do so by the Board under Title VIII of the Act (Enforcement), or when ordered to do so by a court of competent jurisdiction;

D) Notifies the Agency that it has initiated closure or corrective action, or initiates closure or corrective action, but fails to close the CCR surface impoundment or provide post-closure care or corrective action in accordance with the Agency-approved closure and post-closure care or corrective action plans;

E) For a corrective action bond, fails to implement or complete corrective action at a CCR surface impoundment in accordance with Section 845.670; or

F) Fails to, within 90 days after receipt by both the owner or operator and the Agency of a notice from the surety that the bond will not be renewed for another term:

i) Provide alternative financial assurance, as specified in this Subpart; and

ii) Obtain the Agency's written approval of the assurance.

3) Upon failure of the owner or operator to perform as guaranteed by the bond, the surety must have the option of:

A) providing closure and post-closure care in accordance with the approved closure and post-closure care plans;

B) carrying out corrective action in accordance with the corrective action plan; or

C) paying the penal sum.

f) Penal Sum

1) The penal sum of the bond must be in an amount at least equal to the current cost estimate.

2) Whenever the current cost estimate decreases, the penal sum may be reduced to the amount of the current cost estimate following written approval by the Agency.

3) Whenever the current cost estimate increases to an amount greater than the penal sum, the owner or operator, within 90 days after the increase, must either cause the penal sum to be increased to an amount at least equal to the current cost estimate and submit evidence of that increase to the Agency or obtain other financial assurance, as specified in this Subpart, and submit evidence of the alternative financial assurance to the Agency.

g) Term

1) The bond must be issued for a term of at least one year and must not be cancelable during that term.

2) The surety bond must provide that, on the current expiration date and on each successive expiration date, the term of the surety bond will be automatically extended for a period of at least one year unless, at least 120 days before the current expiration date, the surety notifies both the owner or operator and the Agency by certified mail of a decision not to renew the bond. Under the terms of the surety bond, the 120 days will begin on the date when both the owner or operator and the Agency have received the notice, as evidenced by the return receipts.

3) The Agency must release the surety by providing written authorization for termination of the bond to the owner or operator and the surety when either of the following occurs:

A) An owner or operator substitutes alternative financial assurance, as specified in this Subpart; or

B) The Agency releases the owner or operator from the requirements of this Subpart in accordance with Section 845.920(b).

h) Cure of Default and Refunds

1) The Agency must release the surety if, after the surety becomes liable on the bond, the owner or operator or another person provides financial assurance for closure and post-closure care of the CCR surface impoundment or corrective action at a CCR surface impoundment; unless the Agency determines that the closure, post-closure care, or corrective action plan, or the amount of substituted financial assurance, is inadequate to provide closure and post-closure care or implement corrective action in compliance with this Part.

2) After closure and post-closure care have been completed in accordance with the plans and requirements of this Part or after the completion of corrective action at a CCR surface impoundment in accordance with this Part, the Agency must refund any unspent money that was paid into the Coal Combustion Residual Surface Impoundment Financial Assurance Fund by the surety, subject to appropriation of funds by the Illinois General Assembly.

i) The surety will not be liable for deficiencies in the performance of closure, post-closure care, or corrective action by the owner or operator after the Agency releases the owner or operator from the requirements of this Subpart.

Section 845.990 Letter of Credit

a) An owner or operator may satisfy the requirements of this Subpart by obtaining an irrevocable standby letter of credit that conforms to the requirements of this Section and submitting the letter to the Agency.

b) The issuing institution must be an entity that has the authority to issue letters of credit and:

1) Whose letter of credit operations are regulated by the Illinois Department of Financial and Professional Regulation under the Illinois Banking Act [205 ILCS 5]; or

2) Whose deposits are insured by the Federal Deposit Insurance Corporation.

c) Forms

1) The letter of credit must be on forms prescribed by the Agency.

2) The letter of credit must be accompanied by a letter from the owner or operator, referring to the letter of credit by number, the name and address of the issuing institution, and the effective date of the letter, and providing the following information: the name and address of the CCR surface impoundment, the identification number (see Section 845.130), and the

amount of funds assured by the letter of credit for closure and post-closure care of the CCR surface impoundment, or for corrective action at the CCR surface impoundment.

d) Any amounts drawn by the Agency under the letter of credit will be deposited in the Coal Combustion Residual Surface Impoundment Financial Assurance Fund within the State Treasury.

e) Conditions on Which the Agency Must Draw on the Letter of Credit:

1) The Agency must draw on the letter of credit if the owner or operator fails to perform closure or post-closure care in accordance with the approved closure and post-closure care plans or fails to perform corrective action at a CCR surface impoundment in accordance with this Part.

2) The Agency must draw on the letter of credit if the owner or operator:

A) Abandons the CCR surface impoundment;

B) Is adjudicated bankrupt;

C) Fails to initiate closure of the CCR surface impoundment or post-closure care or corrective action when ordered to do so by the Board under Title VIII of the Act (Enforcement), or when ordered to do so by a court of competent jurisdiction;

D) Notifies the Agency that it has initiated closure or corrective action, or initiates closure or corrective action, but fails to provide closure and post-closure care or corrective action in accordance with the Agency-approved closure and post-closure care or corrective action plans;

E) For a corrective action letter of credit, fails to implement or complete corrective action at a CCR surface impoundment in accordance with Section 845.670; or

F) Fails to, within 90 days after receipt by both the owner or operator and the Agency of a notice from the surety that the bond will not be renewed for another term:

i) Provide alternative financial assurance, as specified in this Subpart; and

ii) Obtain the Agency's written approval of the assurance.

3) If the owner or operator does not establish alternative financial assurance,

as specified in this Subpart, and obtain written approval of that alternative assurance from the Agency within 90 days after receipt by both the owner or operator and the Agency of a notice of expiration from the issuing institution (see subsection (g)(2)), the Agency must draw on the letter of credit. During the last 30 days of a notice of expiration, the Agency must draw on the letter of credit if the owner or operator has failed to provide alternative financial assurance, as specified in this Section, and obtain from the Agency written approval of that assurance.

f) Amount

1) The letter of credit must be issued in an amount at least equal to the current cost estimate.

2) Whenever the current cost estimate decreases, the amount of credit may be reduced to the amount of the current cost estimate following written approval by the Agency.

3) Whenever the current cost estimate increases to an amount greater than the amount of the credit, the owner or operator, within 90 days after the increase, must either cause the amount of the credit to be increased to an amount at least equal to the current cost estimate and submit evidence of that increase to the Agency or obtain other financial assurance, as specified in this Subpart, to cover the increase and submit evidence of the alternative financial assurance to the Agency.

g) Term

1) The letter of credit must be issued for a term of at least one year and must be irrevocable during that term.

2) The letter of credit must provide that, on the current expiration date and on each successive expiration date, the letter of credit will be automatically extended for a period of at least one year unless, at least 120 days before the current expiration date, the issuing institution notifies both the owner or operator and the Agency by certified mail of a decision not to extend the letter of credit for another term. Under the terms of the letter of credit, the 120 days will begin on the date when both the owner or operator and the Agency have received the notice, as evidenced by the return receipts.

3) The Agency must return the letter of credit to the issuing institution for termination when either of the following occurs:

A) An owner or operator substitutes alternative financial assurance, as specified in this Subpart; or

B) The Agency releases the owner or operator from the requirements of this Subpart in accordance with Section 845.920(b).

h) Cure of Default and Refunds

1) The Agency must release the financial institution if, after the Agency is allowed to draw on the letter of credit, the owner or operator or another person provides financial assurance for closure and post-closure care of the CCR surface impoundment or corrective action at a CCR surface impoundment; unless the Agency determines that the closure, post-closure care, or corrective action plan, or the amount of substituted financial assurance, is inadequate to provide closure and post-closure care or implement corrective action in compliance with this Part.

2) After closure and post-closure care have been completed in accordance with the plans and requirements of this Part or after the completion of corrective action at a CCR surface impoundment in accordance with this Part, the Agency must refund any unspent money that was drawn and paid into the Coal Combustion Residual Surface Impoundment Financial Assurance Fund by the financial institution, subject to appropriation of funds by the Illinois General Assembly.

DOCUMENT 11

Luminant

Illinois Power Generating Company
1500 Eastport Plaza Dr.
Collinsville, IL 62234

October 25, 2021

Illinois Environmental Protection Agency
DWPC – Permits MC #15
Attn: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Re: Coffeen Power Plant Ash Pond No. 2; IEPA ID # W1350150004-02

Dear Mr. LeCrone:

In accordance with 35 I.A.C. § 845.200, Illinois Power Generating Company (IPGC) is submitting an operating permit application for the Coffeen Power Plant Ash Pond No. 2 (IEPA ID # W1350150004-02). One hardcopy and one digital copy are provided with this submittal.

The permit application was prepared in accordance with 35 I.A.C. § 845.230(d)(2) (Existing, Inactive and Inactive Closed CCR Surface Impoundment that have completed an Agency approved closure before July 30, 2021). This submittal includes the completed permit forms as required by § 845.210.

Sincerely,

Cynthia Vodopivec
SVP-Environmental Health and Safety

Enclosures

Prepared for

Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, Illinois 62234

INITIAL OPERATING PERMIT

COFFEEN ASH POND 2

Prepared by

425 South Woods Mill Road, Suite 300
St. Louis, MO 63017

October 25, 2021

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1. INTRODUCTION

Illinois Power Generating Company operates the coal-fired Coffeen Power Plant located in Montgomery County, Illinois. The IEPA assigned identification number assigned to this impoundment is: W1350150004-02 for Ash Pond 2. The National Inventory of Dams (NID) number assigned for Ash Pond 2 by the Illinois Department of Natural Resources (IDNR) is IL50714.

This initial operating permit application was developed in accordance with 35 Ill. Admin. Code 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845).

This initial operating permit application is for Ash Pond 2.

1.1. Facility Information

Section 845.210(b)(1): All permit applications must contain the name, address, email address and telephone number of the operator, or duly authorized agent, and the property owner to whom all inquiries and correspondence shall be addressed.

Facility:	Coffeen Ash Pond 2 Coffeen Power Plant 134 Cips Lane Coffeen, IL 62017
Owner/Operator:	Illinois Power Generating Company 1500 Eastport Plaza Drive Collinsville, Illinois 62234

1.2. Owner Signatures

Section 845.210(b)(2): All permit applications must be signed by the owner, operator or a duly authorized agent of the operator.

The owner of the Coffeen Power Plant is a corporation.

Section 845.210(b)(3): An application submitted by a corporation must be signed by a principal executive officer of at least the level of vice president, or his or her duly authorized representative, if that representative is responsible for the overall operation of the facility described in the application form..

The signature of Cynthia Vodopivec on behalf of Illinois Power Generating Company can be found in the permit applications located in Section 3.

1.3. Legal Description

Section 845.210(c): All permit applications must contain a legal description of the facility boundary and a description of the boundaries of all units included in the facility.

A legal description has been developed in compliance with Section 845.210(c) and is included in Attachment A.

1.4. Previous Assessments

Section 845.210(d): Previous Assessments, Investigations Plans, and Programs

Previous assessments were performed in accordance with 40 CFR § 257 and are referenced within the permit application and included in the appropriate Attachments.

Section 845.210(d)(1): The Agency may approve the use of any hydrogeologic site investigation or characterization, groundwater monitoring well or system, or groundwater monitoring plan, bearing the seal and signature of an Illinois Licensed Professional Geologist or Licensed Professional Engineer, completed before April 21, 2021 to satisfy the requirements of this Part.

A previous hydrogeologic site investigation or characterization, groundwater monitoring well or system, or groundwater monitoring plan have been completed with a seal from an Illinois Licensed Professional Geologist or Licensed Professional Engineer. However, field investigations have been completed that supplement that work that will be utilized in the following sections of this report.

> *Section 845.210(d)(2): For existing CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a previously completed location restriction demonstration required by Section 845.300 (Placement Above the Uppermost Aquifer), Section 845.310 (Wetlands), Section 845.320 (Fault Areas), Section 845.330 (Seismic Impact Zones), and Section 845.340 (Unstable Areas) provided that the previously completed assessments meet the applicable requirements of those Sections.*

No previous assessments are provided for Section 845.300 (Placement Above the Uppermost Aquifer), Section 845.310 (Wetlands), Section 845.320 (Fault Areas), Section 845.330 (Seismic Impact Zones), and Section 845.340 (Unstable Areas).

> *Section 845.210(d)(3): For existing CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a previously completed assessment to serve as the initial assessment required by Section 845.440 (Hazard Potential Classification Assessment), Section 845.450 (Structural Stability Assessment) and Section 845.460 (Safety Factor Assessment) provided that the previously completed assessment: A) Was not completed more than five years ago; and B) Meets the applicable requirements of those Sections.*

No previous assessments are provided for Section 845.440 (Hazard Potential Classification Assessment), Section 845.450 (Structural Stability Assessment) and Section 845.460 (Safety Factor Assessment).

> *Section 845.210(d)(4): For inactive closed CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a post-closure care plan previously approved by the Agency.*

No post-closure care plan was previously approved by the Agency.

2. OPERATING PERMIT

2.1. Initial Operating Permit

Section 845.230(d): Initial Operating Permit for Existing, Inactive and Inactive Closed CCR Surface Impoundments

The Coffeen Ash Pond 2 as defined by IEPA is a closed inactive surface impoundment that has not completed post-closure care. Per Part 845, Illinois Power Generating Company is submitting an initial operating permit application to IEPA by October 31, 2021. The following sections contain information or references to documents required for the Operating Permit application (Section 845.230).

2.2. History of Construction

Section 845.230(d)(2)(A): The history of construction specified in Section 845.220(a)(1);

The history of construction prepared in 2016 pursuant to 40 CFR § 257.73(c) is provided in Attachment B.

2.3. Permanent Markers

Section 845.230(d)(2)(E): Evidence of permanent markers required by Section 845.130 have been installed;

Evidence of permanent markers at the Coffeen Ash Pond 2 as required by Section 845.130 is provided in Attachment E.

2.4. Slope Maintenance

Section 845.230(d)(2)(F): Documentation that the CCR surface impoundment, if not incised, will be operated and maintained with one of the forms of slope protection specified in Section 845.430;

The Coffeen Ash Pond 2 is not incised. Documentation of slope protection as required by Section 845.430 is provided in Attachment J.

2.5. Groundwater Monitoring

Section 845.230(d)(2)(I): Groundwater monitoring information:

The groundwater monitoring information for the Coffeen Ash Pond 2 is described in the following sections.

Section 845.230(d)(2)(I)(i): Hydrogeologic site characterization (see Section 845.620);

Hydrogeologic site characterization for the Coffeen Ash Pond 2 is provided in Attachment H.

Section 845.230(d)(2)(I)(ii): Design and construction plans of a groundwater monitoring system (see Section 845.630);

Design and construction plans of a groundwater monitoring system are provided in Attachment I.

Section 845.230(d)(2)(I)(iii): A groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data (see Section 845.640); and

A groundwater sampling and analysis program that meets the requirements of Section 845.640 is provided in Attachment I.

Section 845.230(d)(2)(I)(iv): Proposed groundwater monitoring program that includes a minimum of eight independent samples for each background and downgradient well (see Section 845.650(b));

A proposed groundwater monitoring program that meets the requirements of Section 845.650(b) is provided in Attachment I.

2.6. Initial Post-Closure Care Plan

Section 845.230(d)(2)(K): Initial written post-closure care plan, if applicable (see Section 845.780(d));

The Coffeen Ash Pond 2 closure was completed by capping the CCR in place. The initial post closure care plan was developed in accordance with Section 845.780 and is provided in Attachment K.

2.7. History of Groundwater Exceedances

Section 845.230(d)(2)(M): History of known exceedances of the groundwater protection standards in Section 845.600, and any corrective action taken to remediate the groundwater;

A history of known exceedances and any corrective action taken is provided in Attachment M.

2.8. Financial Assurance Requirements

Section 845.230(d)(2)(N): A certification that the owner or operator meets the financial assurance requirements of Subpart I;

A certification meeting the requirement of Section 845.230(d)(2)(N) stating that the Owner meets the financial assurance requirements of *Subpart I* is provided in Attachment N.

3. PERMIT APPLICATION

All permit applications must be made on the forms prescribed by the Agency and must be mailed or delivered to the address designated by the Agency on the forms. The permit applications (CCR-1 and CCR-2OE) are provided below.

Form CCR 1

Illinois Environmental Protection Agency
CCR Surface Impoundment Permit Application
Form CCR 1 – General Provisions

Bureau of Water ID Number: For IEPA Use Only

W1350150004

CCR Permit Number:

Initial Permit

Facility Name:

Coffeen Power Plant

SECTION 1: FACILITY, OPERATOR, AND OWNER INFORMATION (35 Ill. Adm. Code 845.210(b))

Facility, Operator, and Owner Information

1.1 Facility Name

Illinois Power Generating Company - Coffeen Power Plant

1.2 Illinois EPA CCR Permit Number (if applicable)

Initial Permit

1.3 Facility Contact Information

Name (first and last)	Title	Phone Number
Phil Morris	Senior Director - Environmental	618-343-7794

Email address

phil.morris@vistracorp.com

1.4 Facility Mailing Address

Street or P.O. box

1500 Eastport Plaza Dr

City or town	State	Zip Code
Collinsville	IL	62234

1.5 Facility Location

Street, route number, or other specific identifier

134 CIPS Lane

County name	County code (if known)	
Montgomery		

City or town	State	Zip Code
Coffeen	IL	62017

1.6 Name of Owner/Operator

Illinois Power Generating Company

Facility, Operator, and Owner Info

1.7 Owner/Operator Contact Information

Name (first and last)	Title	Phone Number
Phil Morris	Senior Director - Environmental	618-343-7794

Email address
phil.morris@vistracorp.com

1.8 Owner/Operator Mailing Address

Street or P.O. box
1500 Eastport Plaza Dr

City or town	State	Zip Code
Collinsville	IL	62234

SECTION 2: LEGAL DESCRIPTION (35 Ill. Adm. Code 845.210(c))

Legal Description

2.1 Legal Description of the facility boundary

See Attachment A.

SECTION 3: PUBLICLY ACCESSIBLE INTERNET SITE REQUIREMENTS (35 Ill. Adm. Code 845.810)

Internet Site

3.1 Web Address(es) to publicly accessible internet site(s) (CCR website)

www.luminant.com/illinois-ccr/

3.2 Is/are the website(s) titled "Illinois CCR Rule Compliance Data and Information"

☑	Yes	☐	No

SECTION 4: IMPOUNDMENT IDENTIFICATION

Impoundment Identification

4.1 List all the impoundment identification numbers for your facility and check the corresponding box to indicate that you have attached a written description for each impoundment.

W1350150004-02 (see Attachment A)	☑ Attached written description
	☐ Attached written description
	☐ Attached written description
	☐ Attached written description
	☐ Attached written description
	☐ Attached written description

☐	Attached written description
☐	Attached written description
☐	Attached written description
☐	Attached written description

SECTION 5: CHECKLIST AND CERTIFICATION STATEMENT

Checklist and Certification Statement

5.1 In Column 1 below, mark the sections of Form 1 that you have completed and are submitting with your application. For each section, specify in Column 2 any attachments that you are enclosing.

Column 1		Column 2	
Section 1: Facility, Operator, and Owner Information	☑	w/attachments	☐
Section 2: Legal Description	☑	w/attachments	☑
Section 3: Publicly Accessible Internet Site Requirement	☑	w/attachments	☐
Section 4: Impoundment Identification	☑	w/attachments	☑

5.2 **Certification Statement**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

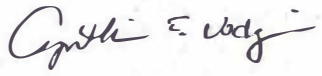
Name (print or type first and last name) of Owner/Operator

Cynthia Vodopivec

Official Title

SVP - Environmental

Signature



Date Signed

10/25/2021

Form
CCR 2OE

Illinois Environmental Protection Agency

CCR Surface Impoundment Permit Application

Form CCR 2OE – Initial Operating Permit for Existing or Inactive CCR Surface Impoundment Where an Agency-approved Closure Has Been Completed Before July 30, 2021

Bureau of Water ID Number: For IEPA Use Only

W1350150004

CCR Permit Number:

Initial Permit

Facility Name:

Coffeen Power Plant

SECTION 1: CONSTRUCTION HISTORY (35 Ill. Adm. Code 845.220 and 35 Ill. Adm. Code 845.230)

Construction History

1.1	CCR surface impoundment name.
	Ash Pond No. 2
1.2	Identification number of the CCR surface impoundment (if one has been assigned by the Agency).
	W1350150004 - 02
1.3	Describe the boundaries of the CCR surface impoundment (35 Ill. Adm. Code 845.210 (c)).
	See Attachment A
1.4	State the purpose for which the CCR surface impoundment is being used.
	See Attachment B
1.5	How long has the CCR surface impoundment been in operation?
	See Attachment B
1.6	List the types of CCR that have been placed in the CCR surface impoundment.
	See Attachment B
1.7	List the name of the watershed within which the CCR surface impoundment is located.
	See Attachment B
1.8	What is the size in acres of the watershed within which the CCR surface impoundment is located?
	See Attachment B
1.9	Check the corresponding boxes to indicate that you have attached the following:
☑	A description of the physical and engineering properties of the foundation and abutment materials on which the CCR surface impoundment is constructed.

Construction History

- [x] A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment.
- [x] A statement of the method of site preparation and construction of each zone of the CCR surface impoundment.
- [x] A statement of the approximate dates of construction of each successive stage of construction of the CCR surface impoundment.
- [x] Drawings satisfying the requirements of 35 Ill. Adm. Code 845.220(a)(1)(F).
- [x] A description of the type, purpose, and location of existing instrumentation.
- [x] Area Capacity Curves for the CCR Impoundment.
- [x] A description of each spillway and diversion design features and capacities and provide the calculations used in their determination.
- [x] The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

1.10.1 Is there any record or knowledge of structural instability of the CCR surface impoundment?

- [x] Yes
- [ ] No

1.10.2 If you answered yes to Item 1.10.1, provide detailed explanation of the structural instability.

See Attachment B

SECTION 2: ATTACHMENTS

Attachments

2.1 Check the corresponding boxes to indicate that you have attached the following:

- [x] Evidence that the permanent markers required by 35 Ill. Adm. Code 845.130 have been installed.
- [x] Documentation demonstrating that the CCR surface impoundment, if not incised, will be operated and maintained with one of the forms of slope protection specified in 35 Ill. Adm. Code 845.430.
- [ ] Emergency Action Plan and accompanying certification required by 35 Ill. Adm. Code 845.520(e).
- [x] Written post-closure care plan, if applicable (see 35 Ill. Adm. Code 845.780(d)).
- [x] History of known exceedances of the groundwater protection standards in 35 Ill. Adm. Code 845.600, and any corrective action taken to remediate the groundwater.

SECTION 3: GROUNDWATER MONITORING

3.1 Check the corresponding boxes to indicate whether you have attached the following groundwater monitoring information:

- [x] A hydrogeologic site characterization meeting the requirements of 35 Ill. Adm. Code 845.620.

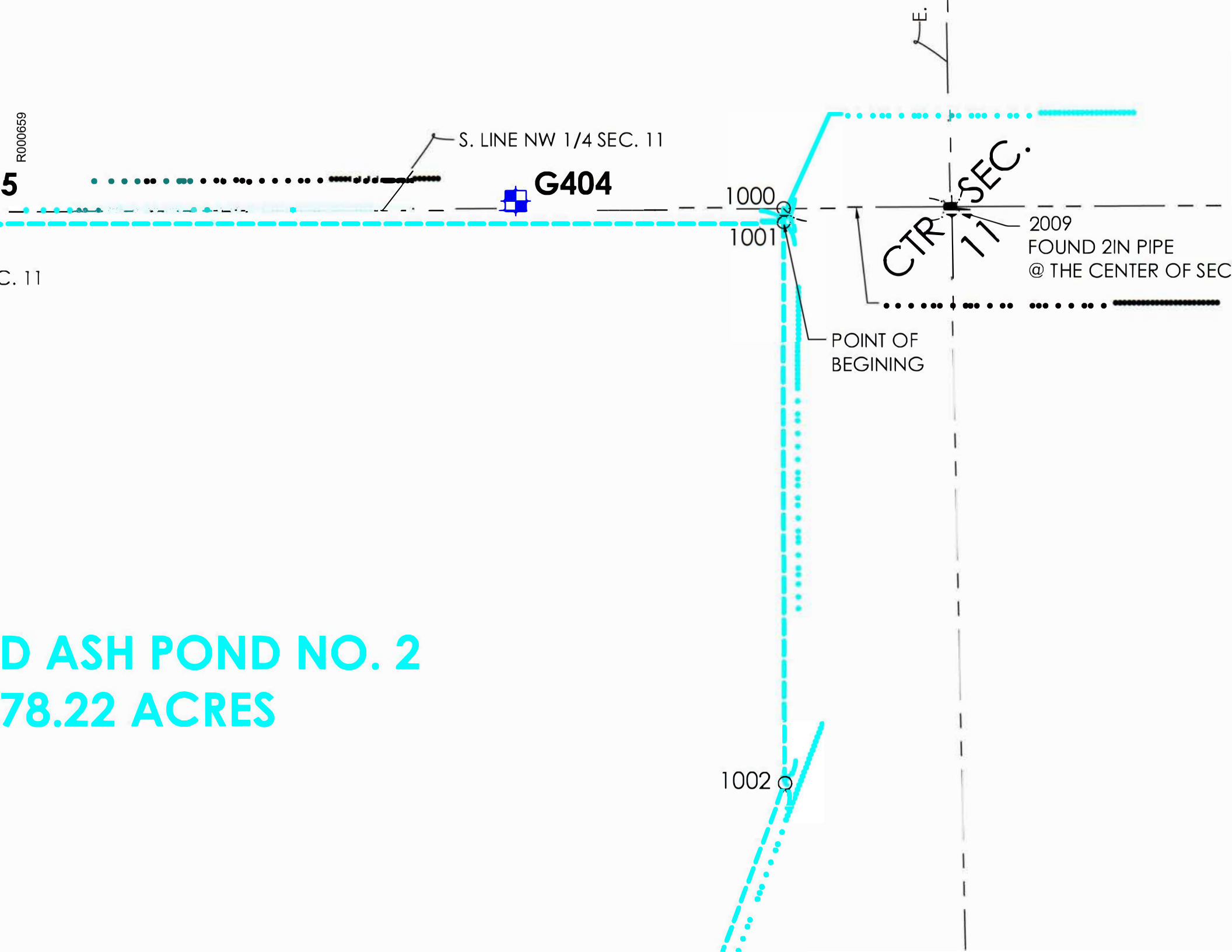
Groundwater

- [x] Design and construction plans of a groundwater monitoring system meeting the requirements of 35 Ill. Adm. Code 845.630.

- [x] A groundwater sampling and analysis program that includes section of the statistical procedures to be used for evaluating groundwater monitoring data, required by 35 Ill. Adm. Code 845.640.

- [x] Proposed groundwater monitoring program that includes a minimum of eight independent samples for each background and downgradient well, required by 35 Ill. Adm. Code 845.650(b).

ATTACHMENT A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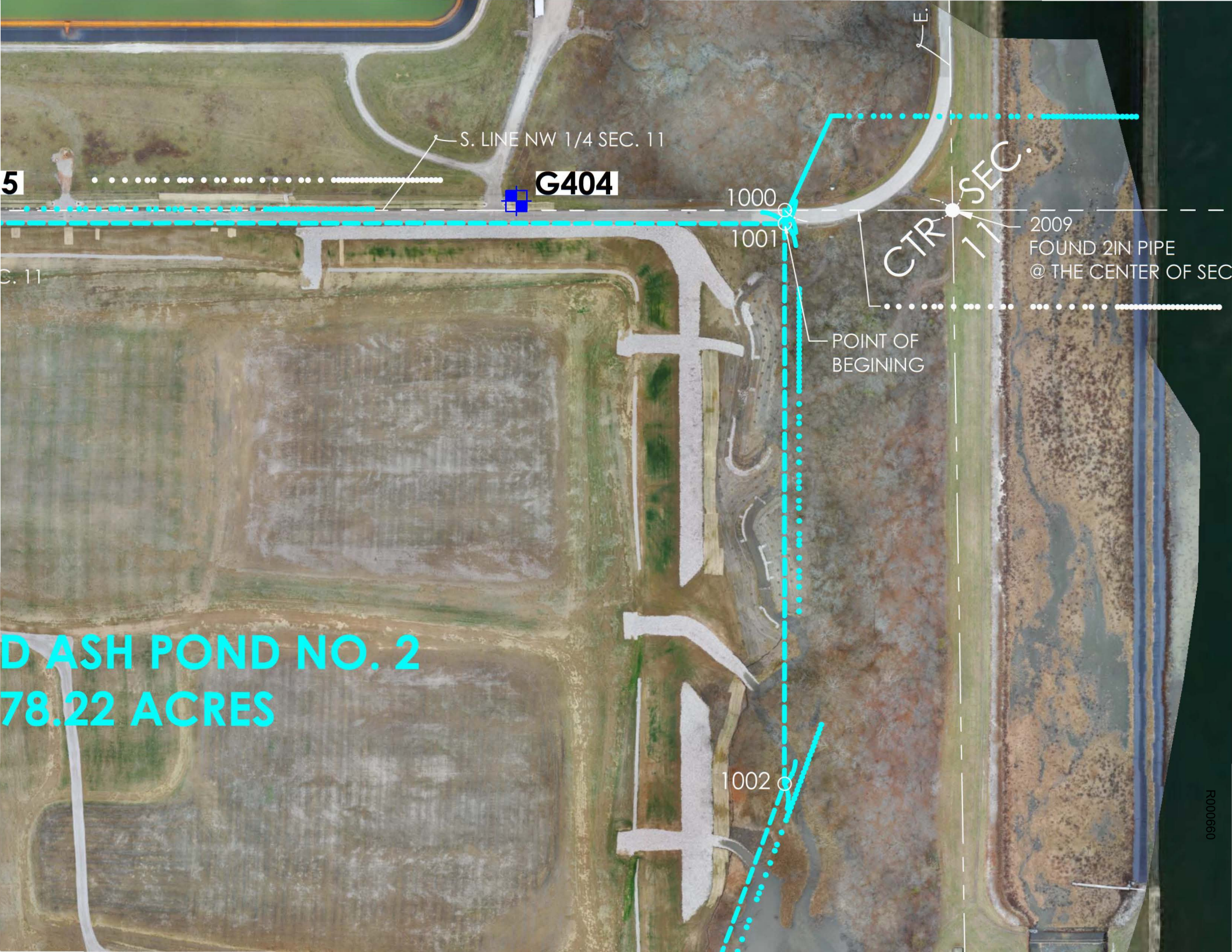
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ATTACHMENT B

AECOM

October 2016

Illinois Power Generating Company
134 CIPS Lane
Coffeen, IL 62017

RE: History of Construction
USEPA Final CCR Rule, 40 CFR § 257.73(c)
Coffeen Power Station
Coffeen, Illinois

On behalf of Illinois Power Generating Company, AECOM has prepared the following history of construction for Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond at the Coffeen Power Station in accordance with 40 CFR § 257.73(c).

BACKGROUND

40 CFR § 257.73(c)(1) requires the owner or operator of an existing coal combustion residual (CCR) surface impoundment that either (1) has a height of five feet or more and a storage volume of 20 acre-feet or more, or (2) has a height of 20 feet or more to compile a history of construction by October 17, 2016 that contains, to the extent feasible, the information specified in 40 CFR § 257.73(c)(1)(i)–(xii).

The history of construction presented herein was compiled based on existing documentation, to the extent that it is reasonably and readily available (see 80 Fed. Reg. 21302, 21380 [April 17, 2015]), and AECOM's site experience. AECOM's document review included record drawings, geotechnical investigations, construction specifications, etc. for Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond at the Coffeen Power Station.

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HISTORY OF CONSTRUCTION

§ 257.73(c)(1)(i): The name and address of the person(s) owning or operating the CCR unit; the name associated with the CCR unit; and the identification number of the CCR unit if one has been assigned by the state.

Owner: Illinois Power Generating Company

Address: 1500 Eastport Plaza Drive
Collinsville, IL 62234

CCR Units: Ash Pond No. 1
Ash Pond No. 2
GMF Pond, IDNR Dam ID No. IL50579
GMF Recycle Pond, IDNR Dam ID No. IL50578

Ash Pond No. 1 and Ash Pond No. 2 do not have a state assigned identification number.

§ 257.73(c)(1)(ii): The location of the CCR unit identified on the most recent USGS 7$^{1}/_{2}$ or 15 minute topographic quadrangle map or a topographic map of equivalent scale if a USGS map is not available.

The locations of Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond have been identified on an USGS 7-1/2 minute topographic quadrangle map in **Appendix A**.

§ 257.73(c)(1)(iii): A statement of the purpose for which the CCR unit is being used.

The following captures the purposes of the CCR units:

- Ash Pond No. 1 is being used to store and dispose of bottom ash and other-non-CCR waste and to clarify recycled process water for plant operations. Ash Pond No. 2 (inactive) was used to store and dispose of bottom ash and fly ash.
- The GMF Pond is being used to store and dispose of gypsum and to clarify recycled process water for plant operations.
- The GMF Recycle Pond was used to store and dispose of gypsum from the plant's scrubber operations prior to the in-service date of the GMF Pond in 2010. The GMF Recycle Pond currently only receives and stores clear process water from the GMF Pond.

Notice of intent to close Ash Pond No. 2 was provided in November, 2015.[1]

[1] This history of construction report was prepared on a facility-wide basis for CCR surface impoundments at the Coffeen Power Station. The inclusion of Ash Pond No. 2 in this history of construction report does not concede and should not be construed to concede that Ash Pond No. 2 is subject to the Design Criteria or all Operating Criteria in the CCR Rule.

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§ 257.73(c)(1)(iv): The name and size in acres of the watershed where the CCR unit is located.

Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond are located in the Coffeen Lake Watershed with a 12-digit Hydrologic Unit Code (HUC) of 071402030304 and a drainage area of 11,695 acres (USGS, 2016).

§ 257.73(c)(1)(v): A description of the physical and engineering properties of the foundation and abutment materials on which the CCR unit is constructed.

The foundation and abutment materials of Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond consist of native fine-grained soils of wind-blown origin (loess), with some coarse-grained layers, underlain by glacial till. The physical properties of the fine-grained soils are described as low- to medium-plasticity silty clay, sandy lean clay, or lean clay with sand, often with trace amounts of gravel; or high plasticity fat clay, often with trace amounts of sand. The clay soils vary from soft to very stiff, moist to wet, and brown to gray. The physical properties of the coarse-grained soils are described as clayey sand, silty sand, or fine to coarse sand, with trace amounts of gravel. The sand is wet and varies from loose to dense and brown to gray. A thin layer of native silty or sandy lean clay is located immediately above the glacial till deposits. The clay is very soft to medium stiff, low to medium plasticity, wet, and orange brown to gray. The physical properties of the glacial till are described as lean clay, or silty to sandy lean clay, with trace amounts of fine gravel, hard, low plasticity, moist to wet, and brown to gray. An available summary of the engineering property typical ranges of the foundation and abutment materials is presented in **Table 1** below. The engineering properties are based on previous geotechnical explorations and laboratory testing.

Ash Pond No. 1 and Ash Pond No. 2 are enclosed impoundments with embankments and do not have abutments. The GMF Pond and GMF Recycle Pond were constructed as incised impoundments enclosed by embankments.

Table 1. Summary of Foundation and Abutment Material Engineering Properties

Material	Unit Weight (pcf)	Effective (drained) Shear Strength Parameters		Total (undrained) Shear Strength Parameters	Post-Earthquake Shear Strength
		Cohesion, c′ (psf)	Friction Angle, ϕ′ (deg)	S_u/p'	S_{ur}/p'
Foundation Clay (Under Embankment)	125	0	32	S_u/p' = 0.39-0.45, Min. S_u = 700 psf	Peak Undrained
Foundation Clay (Free Field)	125	0	30	S_u/p' = 0.24-0.28, Min. S_u = 450 psf	Peak Undrained
Soft Foundation Clay	125	0	30	S_u/p' = 0.22-0.28, Min. S_u = 275 psf	S_u/p' = 0.13-0.16, Min. S_{ur} = 200 psf
Glacial Till	135	0	40	S_u/p' = 0.45-0.64, Min. S_u = 700 psf	Peak Undrained

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§ 257.73(c)(1)(vi): A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR unit; the method of site preparation and construction of each zone of the CCR unit; and the approximate dates of construction of each successive stage of construction of the CCR unit.

Physical properties for the embankment construction materials for Ash Pond No. 1, Ash Pond No. 2, GMF Pond, and GMF Recycle Pond are described as silty clay, sandy lean clay, or lean clay with sand, with trace amounts of fine gravel. The fill is soft to very stiff in consistency, low to medium plasticity, moist to wet, and brown to gray. Trace amounts of organic material and ash are present. The embankment fill generally appears to be well-compacted. An available summary of the engineering properties of the embankment construction materials is presented in **Table 2** below. The engineering properties are based on previous geotechnical explorations and laboratory testing.

Table 2. Summary of Construction Material Engineering Properties for Embankments

Material	Unit Weight (pcf)	Peak Drained Shear Strength		Peak Undrained Shear Strength	Post-Earthquake Shear Strength
		Cohesion, c' (psf)	Friction Angle, ϕ' (deg)	S_u/p'	S_{ur}/p'
Embankment Fill	135	0	31	$S_u/p' = 0.60$, Min. $S_u = 450$ psf	Peak Undrained

The GMF Pond and GMF Recycle Pond contain liner systems. The liner system within the GMF Pond consists of a 60-mil textured high density polyethylene (HDPE) geomembrane underlain by a 3-foot thick layer of compacted clay. A typical cross section profile of the GMF Pond liner system is shown on drawing C-10206 (sh. 9) presented in **Appendix B**. An available summary of the engineering properties of the GMF Pond liner construction materials from Hanson (2008) is presented in **Table 3** below. The liner system within the GMF Recycle Pond consists of a 60-mil textured HDPE geomembrane underlain by smooth-drum rolled native soil. A typical cross section profile of the GMF Recycle Pond liner system is shown on drawing C-10206 (sh. 20) presented in **Appendix B**.

Table 3. Summary of Construction Material Engineering Properties for Liner

Material	Unit Weight (pcf)	Effective (drained) Shear Strength Parameters		Total (undrained) Shear Strength Parameters	
		c' (psf)	Φ' (°)	c (psf)	Φ (°)
Clay Liner	121.2	0	28.3	1950	0

The method of site preparation and construction of Ash Pond No. 1 and Ash Pond No. 2 is not reasonably and readily available. Site preparation and construction of the GMF Pond and GMF Recycle Pond were completed in accordance with the applicable construction specification (see § 257.73(c)(1)(xi) below).

The approximate dates of construction of each successive stage of construction of Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond are provided in **Table 4** below.

Table 4. Approximate dates of construction of each successive stage of construction.

Date	Event
1964	Construction of Ash Pond No. 1
1971	Construction of Ash Pond No. 2
1978-1979	Installation of internal embankment and new recycle intake structure in Ash Pond No. 1 and abandonment of existing outfall structure
1984-1985	Closure of Ash Pond No. 2 by installing a clay cover
2000	Installation of a sheet pile wall to facilitate construction of drainage flume along the northeast corner of the Ash Pond No. 1
2009	Installation of well dewatering system in Ash Pond No. 2
2008-2010	Construction of the GMF Pond and the GMF Recycle Pond

§ 257.73(c)(1)(vii): At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit, detailed dimensional drawings of the CCR unit, including a plan view and cross sections of the length and width of the CCR unit, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation.

Drawings that contain items pertaining to the requested information for Ash Pond No. 1, Ash Pond No. 2, the GMF Pond, and the GMF Recycle Pond are listed in **Table 5** below. Items marked as "Not Available" are items not found during a review of the reasonably and readily available record documentation.

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Table 5. List of drawings containing items pertaining to the information requested in § 257.73(c)(1)(vii).

	Ash Pond No. 1	Ash Pond No. 2	GMF Pond	GMF Recycle Pond
Dimensional plan view (all zones)	B-35, S-44, S-45	B-560, A1000 (sh. 1)	C-10206 (sh. 4, 9, 10)	C-10206 (sh. 4, 19)
Dimensional cross sections	B-35, S-47 to S-50	B-561	C-10206 (sh. 9)	C-10206 (sh. 20)
Foundation Improvements	Not Applicable	Not Applicable	C-10206 (sh. 10)	C-10206 (sh. 20)
Drainage Provisions	Not Applicable	A1000 (sh. 4)	C-10206 (sh. 15, 16, 20)	C-10206 (sh. 21)
Spillways and Outlets	S-8, S-49	W1008 (sh. 2)	C-10206 (sh. 20)	C-10206 (sh. 22)
Diversion Ditches	Not Applicable	A1000 (sh. 1)	Not Applicable	Not Applicable
Instrument Locations	Plate 2, Figure 2A	Figure 2B	Not Applicable	C-10206 (sh. 19)
Slope Protection	S-49	B-561	C-10206 (sh. 9)	C-10206 (sh. 20)
Normal Operating Pool Elevation	S-8, S-49	Not Applicable	C-10201-25	Not Available
Maximum Pool Elevation	S-8	Not Applicable	C-10201-25	Not Available
Approximate Maximum Depth of CCR in 2016	15 feet	28 feet	16 feet	12 feet

All drawings referenced in **Table 5** above can be found in **Appendix B** and **Appendix C**.

Based on the review of the drawings listed above, no natural or manmade features that could adversely affect operation of these CCR units due to malfunction or mis-operation were identified.

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§ 257.73(c)(1)(viii): A description of the type, purpose, and location of existing instrumentation.

Existing instrumentation at Ash Pond No. 1 and Ash Pond No. 2 include vibrating-wire and open-standpipe piezometers. The purpose of the piezometers is to measure the phreatic surface within and around the impoundments. Two (2) open-standpipe piezometers (AP-P1 and AP-P2) were installed at Ash Pond No. 2 in 2009 and the locations are presented on Figure 2A in **Appendix C**. Two (2) open-standpipe piezometers (B-2 and B-4) were installed at Ash Pond No. 1 in 2010 and the locations are presented on Plate 2 in **Appendix C**. Twelve (12) open-standpipe and vibrating-wire piezometers were installed at Ash Pond No. 1 and Ash Pond No. 2 in 2015 and the locations are presented on Figure 2A in **Appendix C**.

The GMF Pond does not contain existing instrumentation. Existing instrumentation at the GMF Recycle Pond consists of one (1) ultrasonic level transmitter. The purpose of the ultrasonic level transmitter is to measure the water level within the GMF Recycle Pond. The location of the ultrasonic level transmitter is shown on drawing C-10206 (sh. 19) presented in **Appendix B**.

§ 257.73(c)(1)(ix): Area-capacity curves for the CCR unit.

Area-capacity curves for Ash Pond No. 2 and the GMF Recycle Pond are not reasonably and readily available. The area-capacity curves for Ash Pond No. 1 and the GMF Pond are presented in **Figures 1** and **2**, respectively, below. “Area-capacity curves”, as defined by 40 CFR § 257.53, “means graphic curves which readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.”

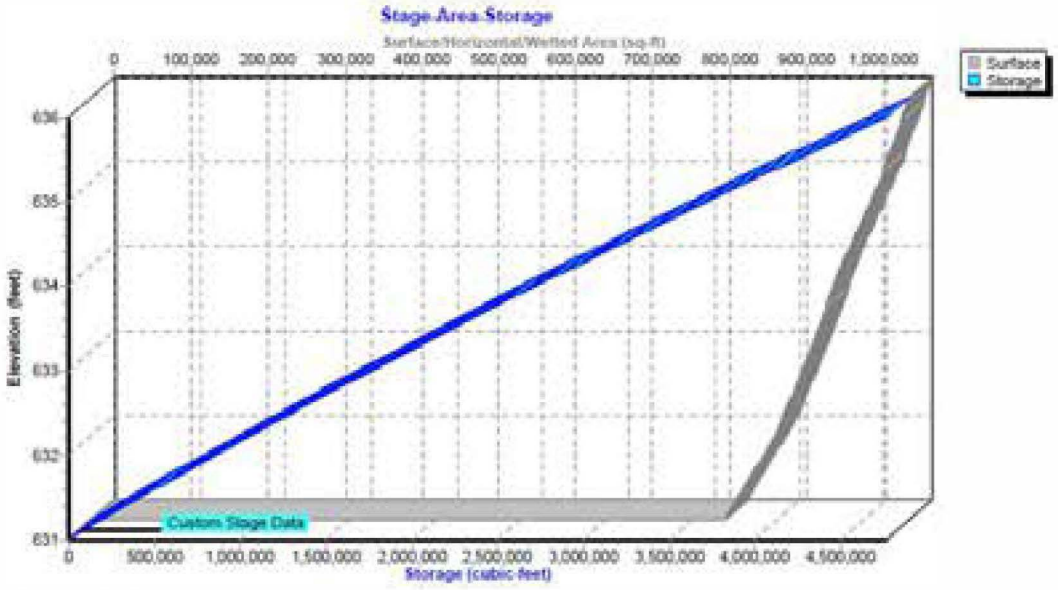

Figure 1. Area-capacity curve for Ash Pond No. 1

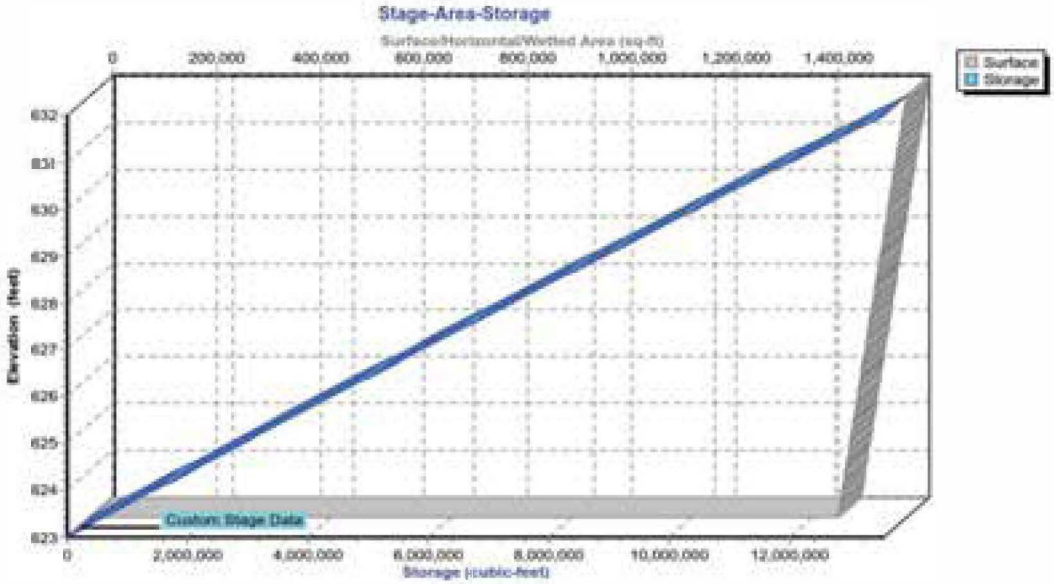

Figure 2. Area-capacity curve for GMF Pond

The area-capacity curves shown were taken from the pond modeling analysis. Actual pond capacity is limited to the approximate berm elevation listed in **Table 6** below. Any information above berm elevation should be disregarded.

§ 257.73(c)(1)(x): A description of each spillway and diversion design features and capacities and calculations used in their determination.

Ash Pond No. 1 contains a concrete intake structure that drains into a 48-inch diameter (dia.) steel pipe. The steel pipe leads to the recycle pump house. In 2016, the discharge capacity of Ash Pond No. 1 was evaluated using HydroCAD 10 software modeling a 1,000-year, 24-hour rainfall event. The results of the HydroCAD 10 analysis are presented below in **Table 6**.

Ash Pond No. 2 was closed in 1984-1985 by installing a clay cover. Non-contact stormwater is collected in ditches along the clay cover and drain off the pond cover via concrete-lined ditch outlets. CCR-contact stormwater collected within the pond is pumped into the GMF Pond via the well dewatering system at the discretion of plant personnel. The capacity of the diversion ditches and well pumps during a model rainfall event has not been evaluated.

The GMF Pond contains a 14-inch high-density polyethylene (HDPE) pipe culvert for normal flow and a weir-like spillway for high water flow. The GMF Pond also contains a 10-inch dia. HDPE siphon pipe used for dewatering. In 2016, the discharge capacity of the GMF Pond was evaluated using HydroCAD 10 software modeling a 1,000-year, 24-hour rainfall event. The results of the HydroCAD 10 analysis are presented below in **Table 6**.

The GMF Recycle Pond contains a decant structure that drains into two (2) 18-inch dia. HDPE pipes that lead to a pump house. The capacity of the decant structure during a model rainfall event has not been evaluated.

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Table 6. Results of HydroCAD 10 analyses

	Ash Pond No. 1	GMF Pond
Approximate Minimum Berm Elevation[1] (ft)	635.0	631.0
Approximate Emergency Spillway Elevation[1] (ft)	Not Applicable	624.0
Starting Pool Elevation[1] (ft)	631.0	621.2
Peak Elevation[1] (ft)	632.0	623.8
Time to Peak (hr)	24.4	24.1
Surface Area (ac)	20.4	33.4
Storage[2] (ac-ft)	19.5	88.3

Note: 1. Elevations are based on NAVD88 datum
2. Storage given is from Starting Pool Elevation to Peak Elevation.

§ 257.73(c)(1)(xi): The construction specifications and provisions for surveillance, maintenance, and repair of the CCR unit.

The construction specifications for Ash Pond No. 1 and Ash Pond No. 2 are not reasonably and readily available. The construction specifications for the GMF Pond and the GMF Recycle Pond are located in *Project Specifications, Gypsum Stack and Recycle Pond Construction* presented in **Appendix D**.

The provisions for surveillance, maintenance, and repair of Ash Pond No. 1 are located in *Operation & Maintenance Manual for #1 Ash Pond* presented in **Appendix E**. The provisions for surveillance, maintenance, and repair of Ash Pond No. 2 are not reasonably and readily available. The provisions for surveillance, maintenance, and repair of the GMF Pond and the GMF Recycle Pond are located in *Operation and Maintenance Manual, Gypsum Management Facility* presented in **Appendix F**.

The operations and maintenance plans for the CCR units identified in this report are currently being revised by Illinois Power Generating Company.

§ 257.73(c)(1)(xii): Any record or knowledge of structural instability of the CCR unit.

In March, 2009, shallow sloughing was observed along the eastern embankment of Ash Pond No. 2. The sloughing was inspected by Hanson Professional Services Inc. A dewatering

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system was installed in Ash Pond No. 2 to lower the phreatic surface within the pond. In December, 2015, additional sloughing was observed on the embankment of Ash Pond No. 2 and on the embankment of Ash Pond No. 1. The sloughing was believed to be caused by recent heavy rains and was repaired. Photos of the 2015 sloughing repair are presented in **Appendix G**.

There is no record or knowledge of structural instability at the GMF Pond and the GMF Recycle Pond at Coffeen Power Station.

LIMITATIONS

The signature of AECOM's authorized representative on this document represents that to the best of AECOM's knowledge, information and belief in the exercise of its professional judgment, it is AECOM's professional opinion that the aforementioned information is accurate as of the date of such signature. Any recommendation, opinion or decisions by AECOM are made on the basis of AECOM's experience, qualifications and professional judgment and are not to be construed as warranties or guaranties. In addition, opinions relating to environmental, geologic, and geotechnical conditions or other estimates are based on available data and that actual conditions may vary from those encountered at the times and locations where data are obtained, despite the use of due care.

Sincerely,

Claudia Prado
Program Manager

Victor Modeer, P.E., D.GE
Senior Project Manager

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REFERENCES

Hanson Professional Services Inc. (2008), *Support Document for IDNR/OWR Permit Application, Coffeen Power Generating Station Gypsum Management Facility Montgomery County, Illinois*

United States Environmental Protection Agency (USEPA). (2015). *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities; Final Rule*. 40 CFR Parts 257 and 261, 80 Fed. Reg. 21302, 21380 April 17, 2015.

United States Geological Survey (USGS). (2016). The National Map Viewer. http://viewer.nationalmap.gov/viewer/. USGS data first accessed in March of 2016.

APPENDICES

Appendix A: History of Construction Vicinity Map
Appendix B: Coffeen Power Station Drawings
Appendix C: Coffeen Power Station Boring and Piezometer Locations
Appendix D: Project Specifications, Gypsum Stack and Recycle Pond Construction (Hanson 2008)
Appendix E: Operation & Maintenance Manual for #1 Ash Pond
Appendix F: Operation and Maintenance Manual, Gypsum Management Facility Operation (2015)
Appendix G: Photos of 2015 Sloughing Repair

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Appendix A: History of Construction Vicinity Map

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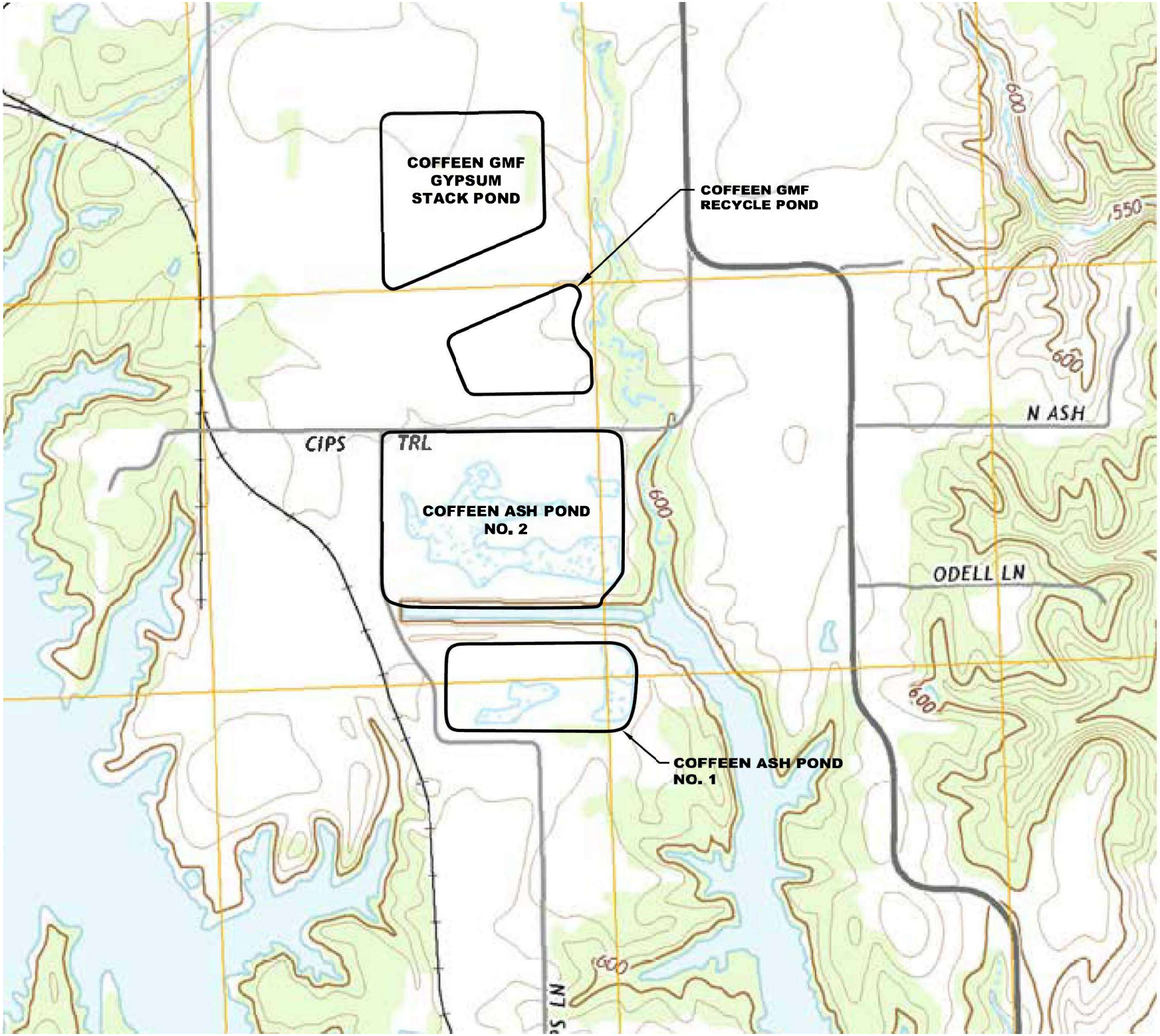

LEGEND

CCR UNITS

SOURCE:
MAP PROVIDED FROM E
USGS DIGITAL RASTER
MINUTE TOPOGRAPHIC
COFFEEN, ILLINOIS, REV



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Appendix B: Coffeen Power Station Drawings

1. "Earthwork & Grading Plan", Drawing No. B-35, Revision S, 8 September, 1995, Sargent & Lundy Engineers.
2. "Concrete Recycle Pump House – Intake Structure", Drawing No. S-8, Revision 6, 23 February, 1996, Stearns-Roger Incorporated.
3. "Civil Layout & Grading Plan Sheet 4", Drawing No. S-44, Revision 6, 23 February, 1996, Stearns-Roger Incorporated.
4. "Civil Layout & Grading Plan Sheet 5", Drawing No. S-45, Revision 9, 23 February, 1996, Stearns-Roger Incorporated.
5. "Civil Miscellaneous Sections and Details, Sheet 2", Drawing No. S-47, Revision 2, 23 February, 1996, Stearns-Roger Incorporated.
6. "Civil Ash Pond No 1 – Sections and Details", Drawing No. S-48, Revision 2, 23 February, 1996, Stearns-Roger Incorporated.
7. "Civil Miscellaneous Sections and Details, Sheet 4", Drawing No. S-49, Revision 4, 23 February, 1996, Stearns-Roger Incorporated.
8. "Civil Miscellaneous Sections and Details", Drawing No. S-50, Revision 4, 23 February, 1996, Stearns-Roger Incorporated.
9. "Ash Storage Area, Plan", Drawing No. B-560, Revision A, 9 February, 1971, Sargent & Lundy Engineers.
10. "Ash Storage Area, Sections & Details", Drawing No. B-561, Revision A, 9 February, 1971, Sargent & Lundy Engineers.
11. "Overall Site Plan, Dewatering System, Ash Pond #2", Drawing No. A1000 (sh. 1), Revision A, 12 October, 2009, Ameren Energy Resources Generating.
12. "Site Details, Dewatering System, Ash Pond #2", Drawing No. A1000 (sh. 4), Revision A, 12 October, 2009, Ameren Energy Resources Generating.
13. "Proposed Site Plan, CCB Management Facility", Drawing No. C-10206 (sh. 4), Revision 0, 5 January, 2011, Ameren Energy Generating.
14. "Groundwater Monitoring & Boring Plan, CCB Management Facility", Drawing No. C-10206 (sh. 5), Revision 0, 5 January, 2011, Ameren Energy Generating.
15. "Anchor Trench and Liner System, CCB Management Facility", Drawing No. C-10206 (sh. 9), Revision 0, 5 January, 2011, Ameren Energy Generating.
16. "Cell G1-Foundation Grade & Control Data, CCB Management Facility", Drawing No. C-10206 (sh. 10), Revision 0, 5 January, 2011, Ameren Energy Generating.
17. "Cell G1-Process Water Recovery System, CCB Management Facility", Drawing No. C-10206 (sh. 15), Revision 0, 5 January, 2011, Ameren Energy Generating.
18. "Cell G1-PWRS Drain Details, CCB Management Facility", Drawing No. C-10206 (sh. 16), Revision 0, 5 January, 2011, Ameren Energy Generating.
19. "Recycle Pond Plan & Control Data, CCB Management Facility", Drawing No. C-10206 (sh. 19), Revision 0, 5 January, 2011, Ameren Energy Generating.
20. "Recycle Pond – Process Water Transfer Channel Details, CCB Management Facility", Drawing No. C-10206 (sh. 20), Revision 0, 5 January, 2011, Ameren Energy Generating.

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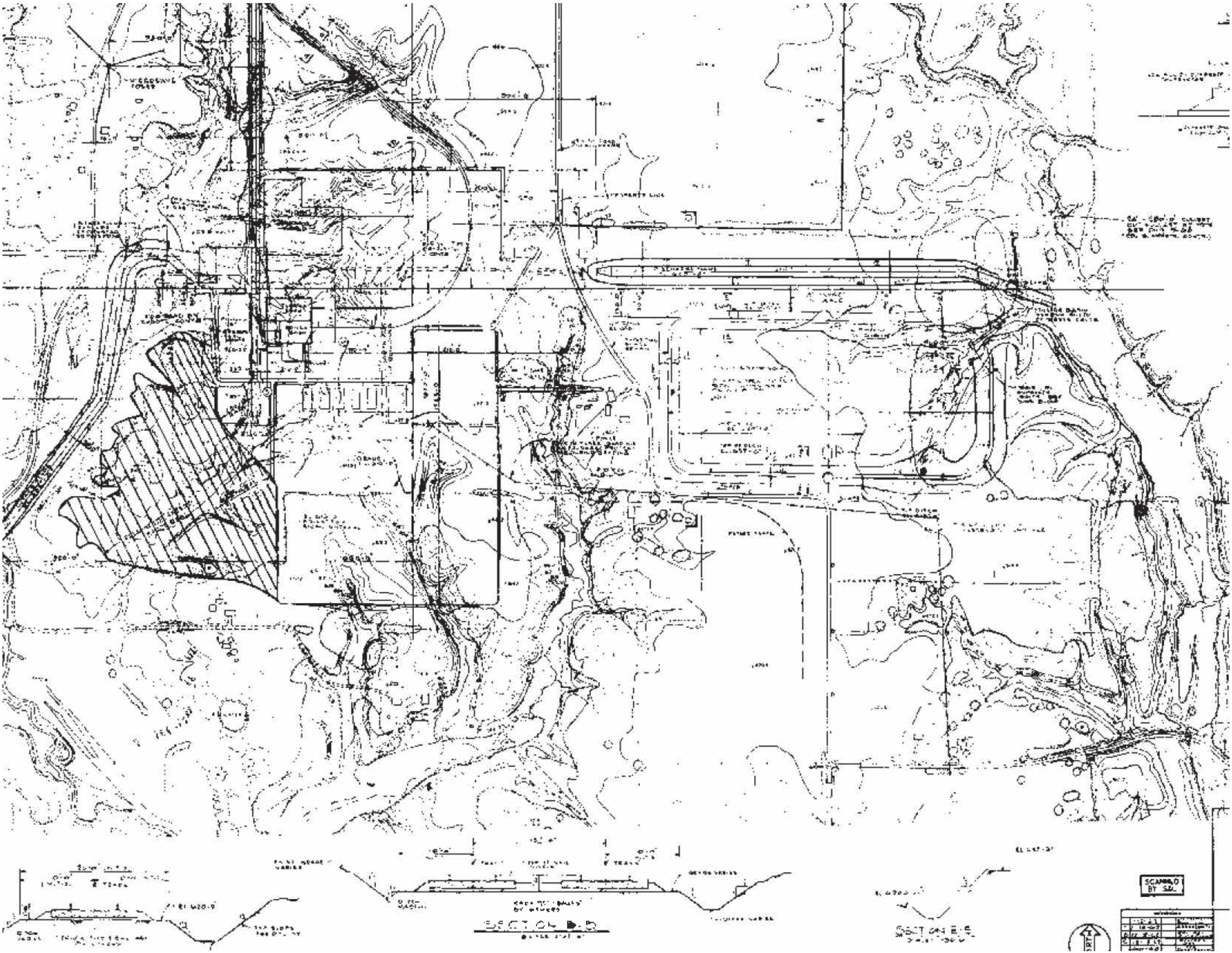
Appendix B: Coffeen Power Station Drawings (continued)

21. "Recycle Pond–Process Water Decant Sections & Details, CCB Management Facility", Drawing No. C-10206 (sh. 21), Revision 0, 5 January, 2011, Ameren Energy Generating.
22. "Recycle Pond – Emergency Spillway Sections & Details, CCB Management Facility", Drawing No. C-10206 (sh. 22), Revision 0, 5 January, 2011, Ameren Energy Generating.
23. "Ash Pond #2, Drainage Modifications", Drawing No. W1008 (sh. 2), Ameren Energy Generating.



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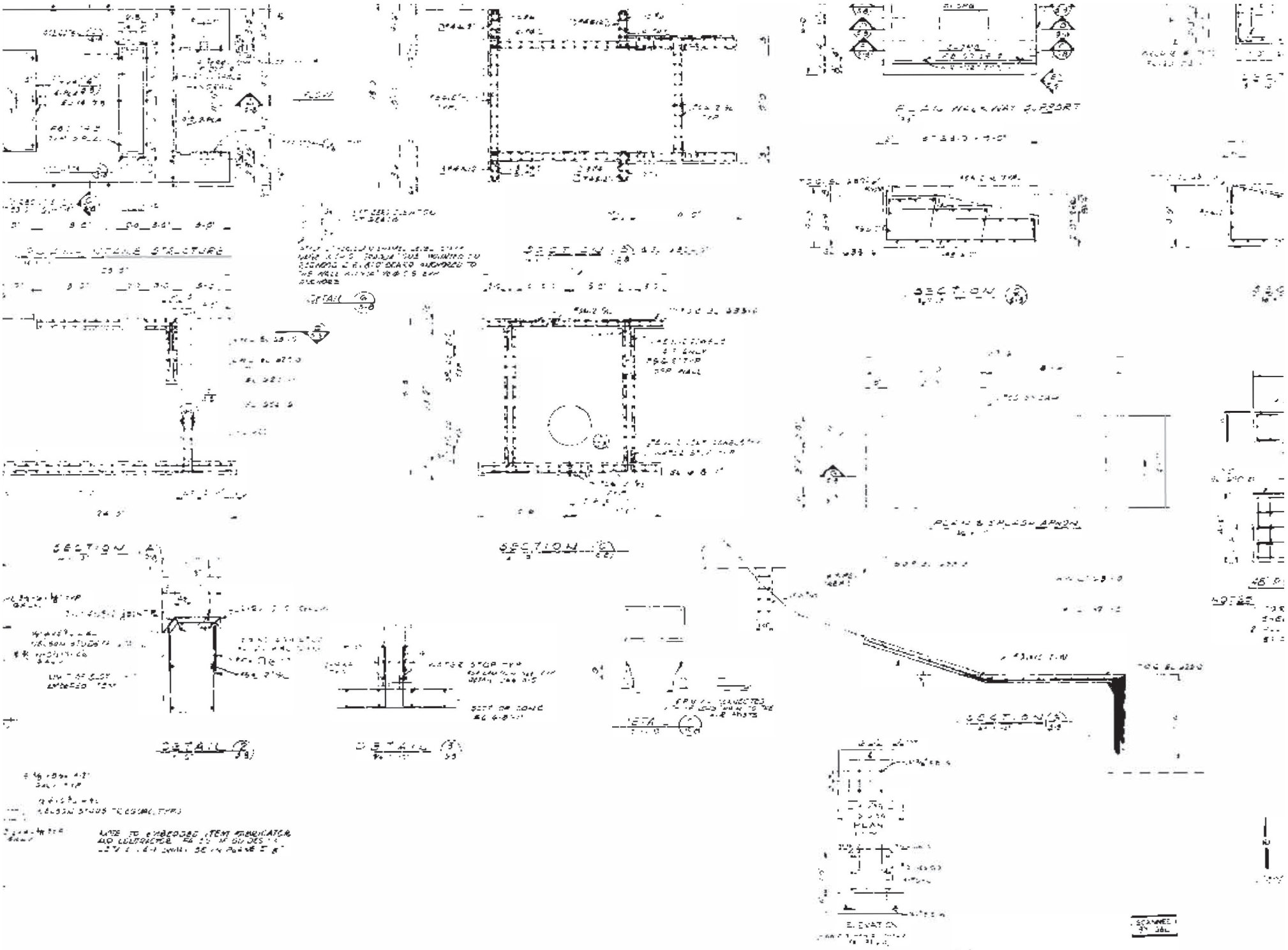

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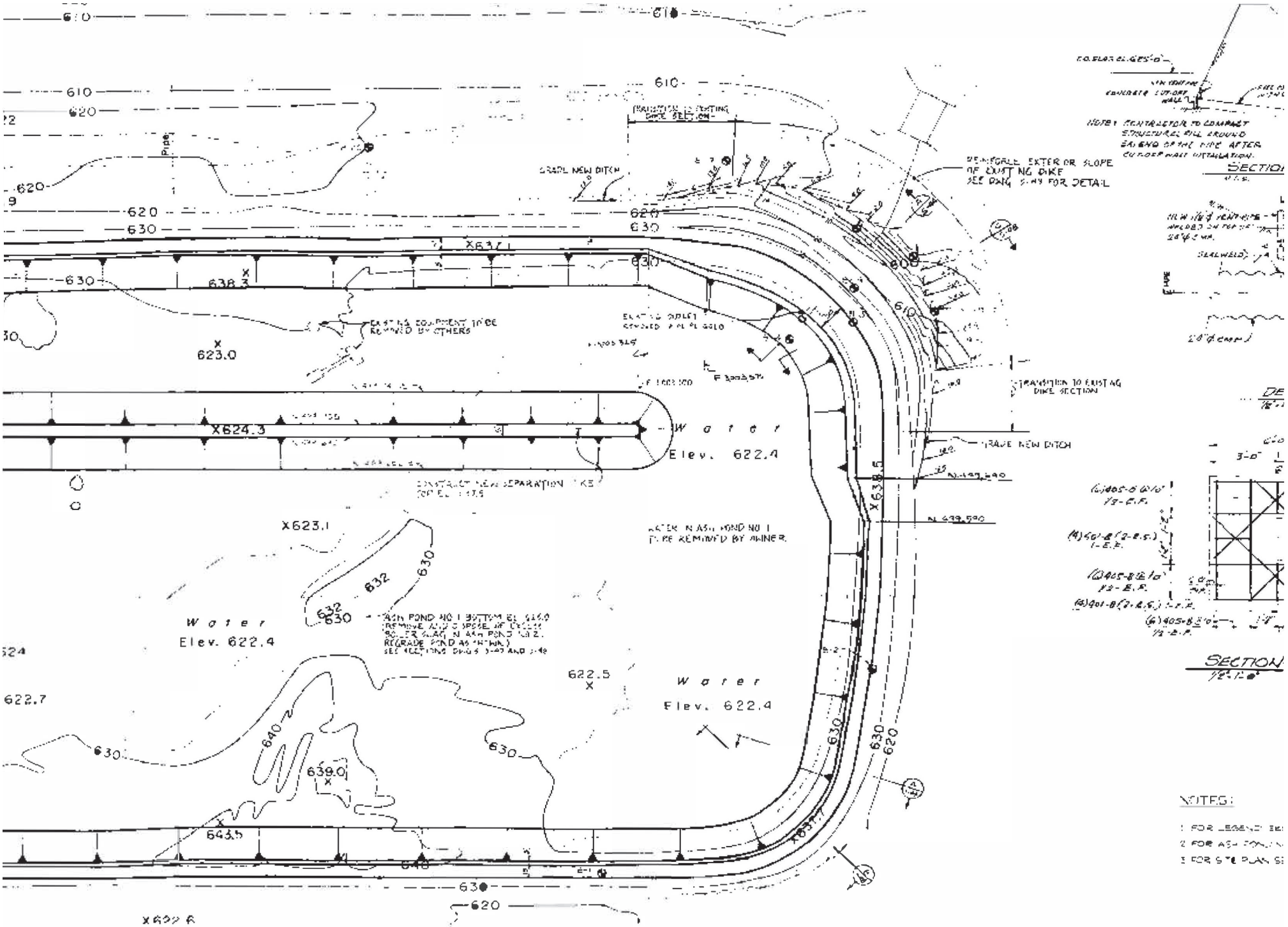
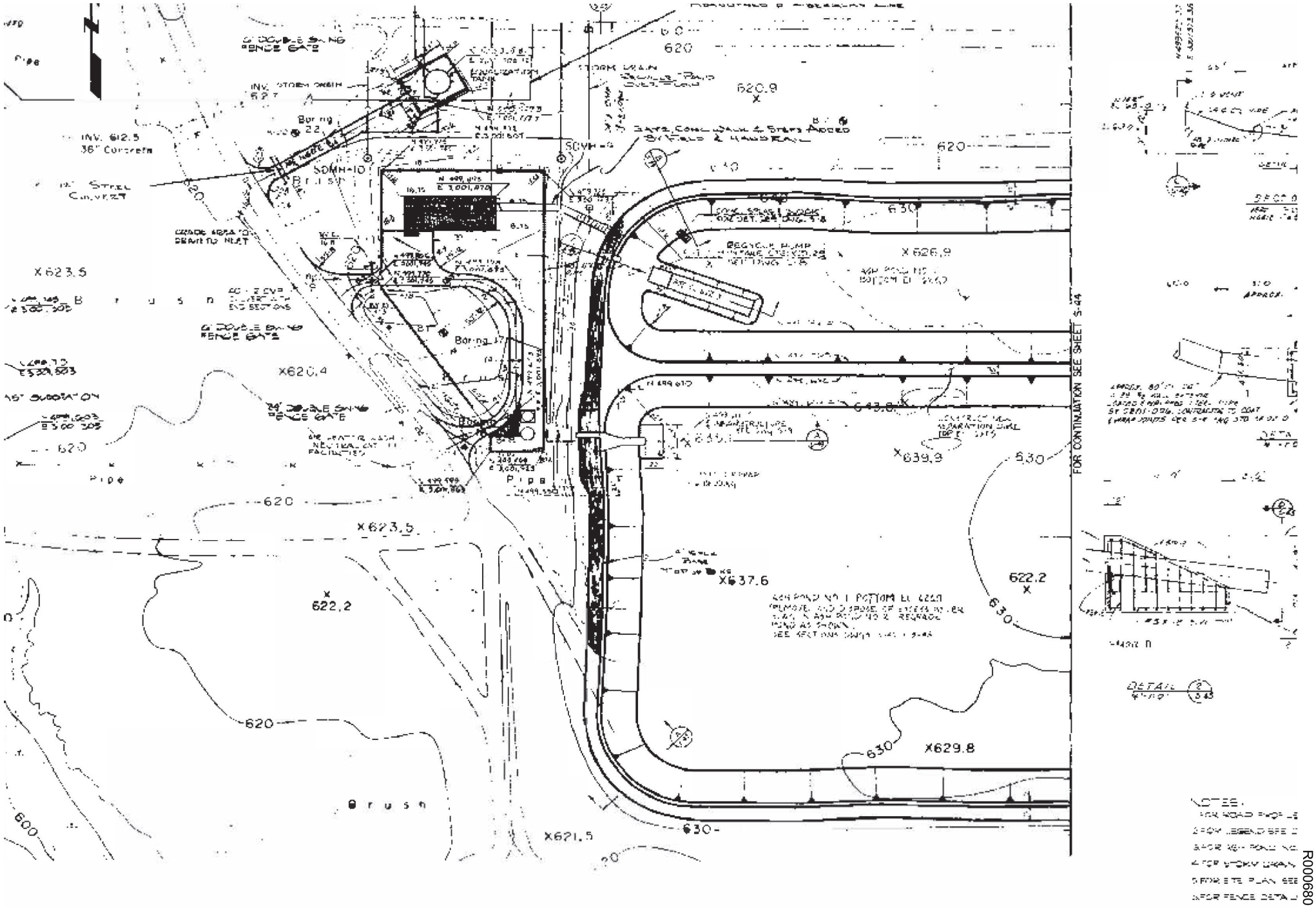


610
620
630
X637.1
638.3
623.0
X624.3
Water
Elev. 622.4
X623.1
632
Water
Elev. 622.4
622.5
Water
Elev. 622.4
622.7
640
639.0
643.5
X638.5
X637.7
X622.6
GRADE NEW DITCH
REINFORCE EXTERIOR SLOPE OF EXISTING DIKE SEE DWG S-49 FOR DETAIL
TRANSITION TO EXISTING DIKE SECTION
GRADE NEW DITCH
EXISTING EQUIPMENT TO BE REMOVED BY OTHERS
CONSTRUCT NEW SEPARATION DIKE
WATER IN ASH POND NO 1 TO BE REMOVED BY OWNER
ASH POND NO 1 BOTTOM EL 616.0
REGRADE POND AS SHOWN
SECTION
NOTES:

R000679



INV. 612.5
36" Concrete
Boring 22
SDMH-10
SDMH-9
Boring 17
X623.5
X620.4
X623.5
X622.2
X621.5
X626.9
X639.9
X637.6
X629.8
622.2
620.9
620
630
600
FOR CONTINUATION SEE SHEET S-44
DETAIL
NOTES:

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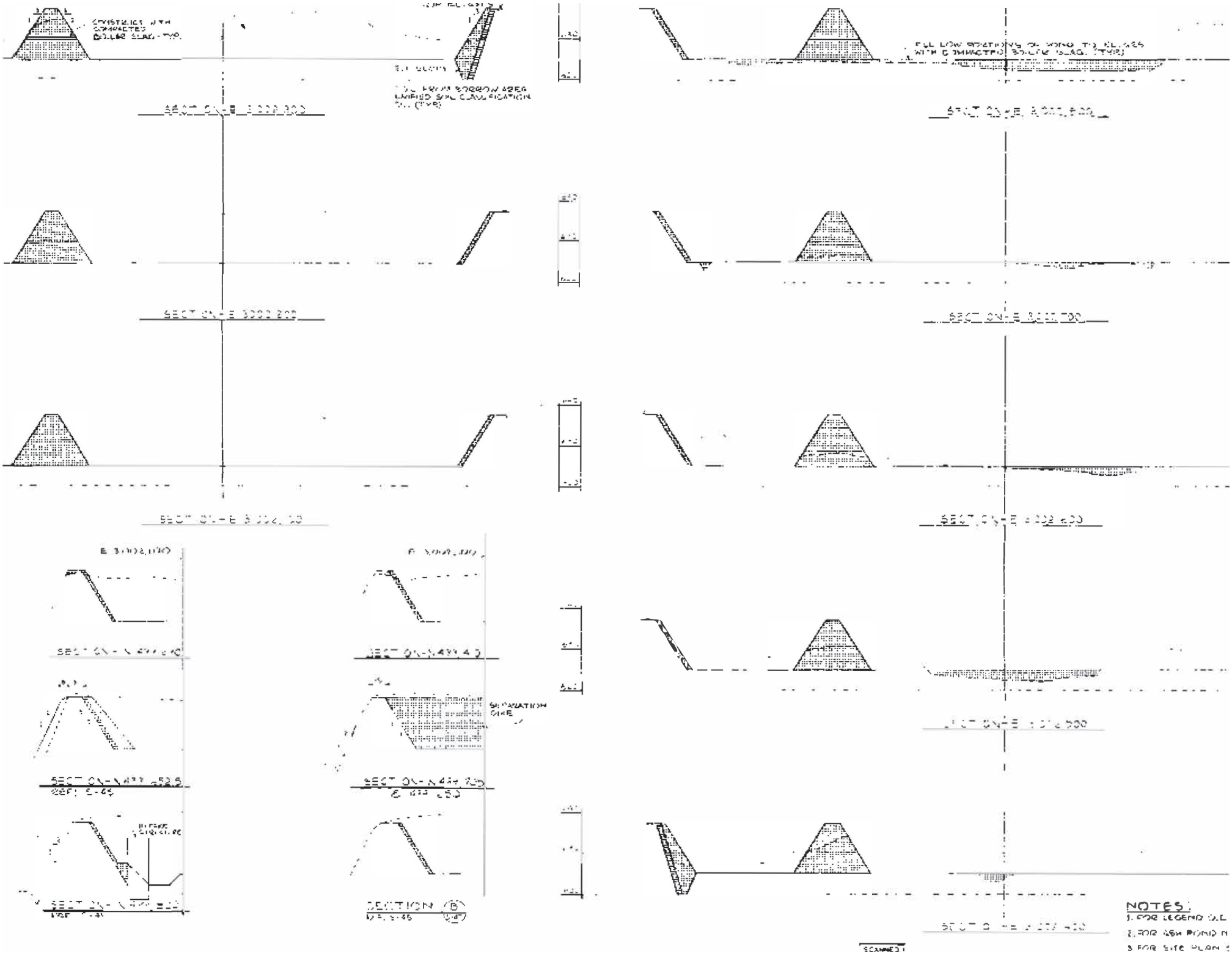

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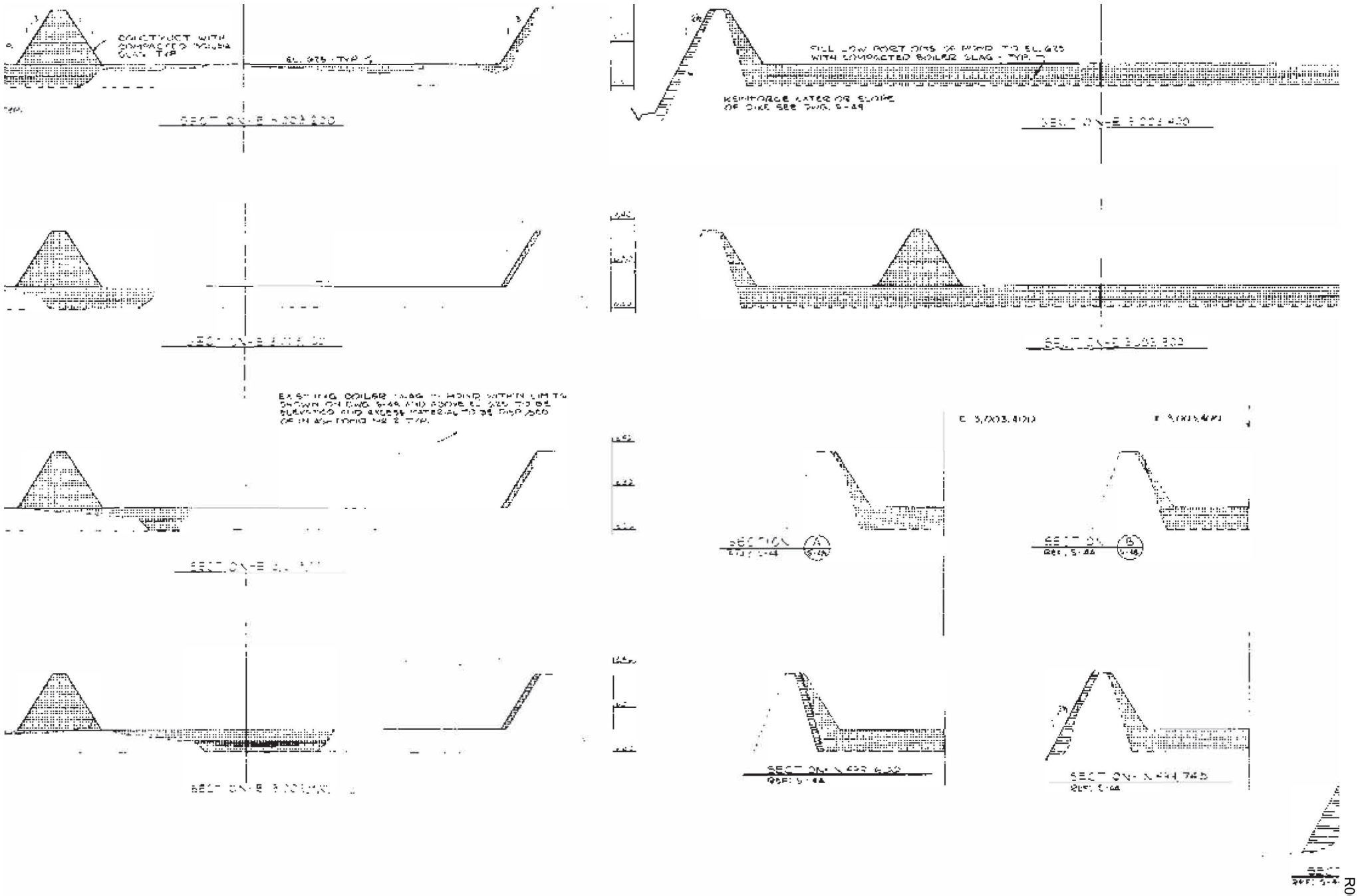


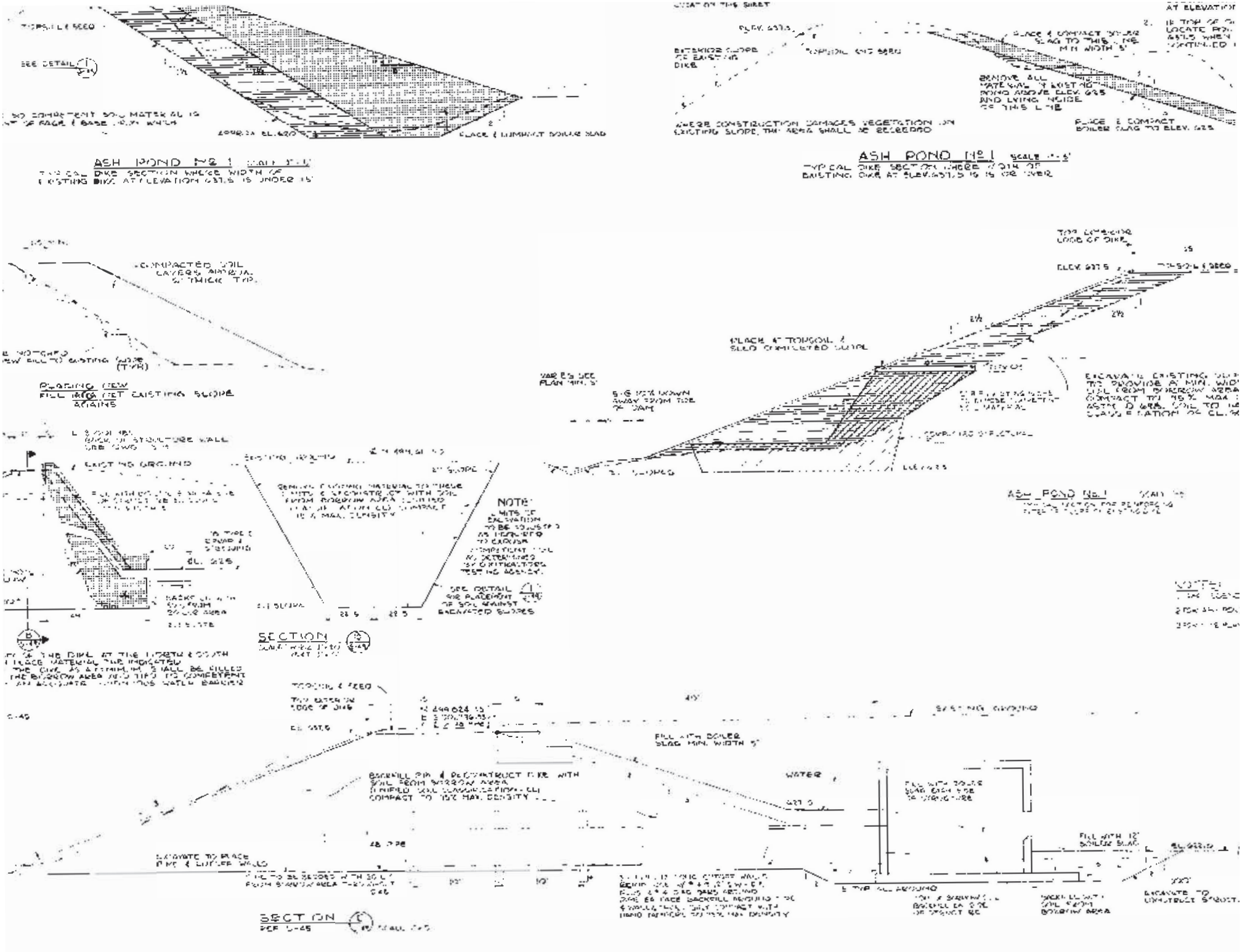
NOTES.

1. FOR LEGEND SE

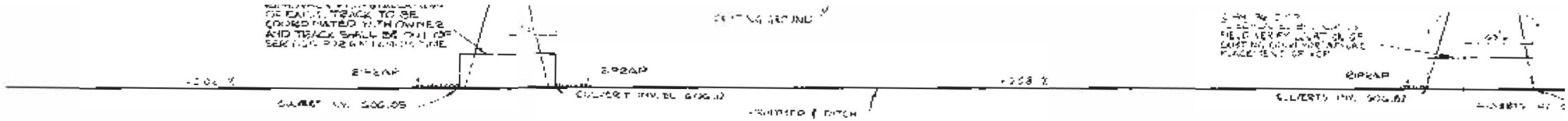
2. FOR ASH POND

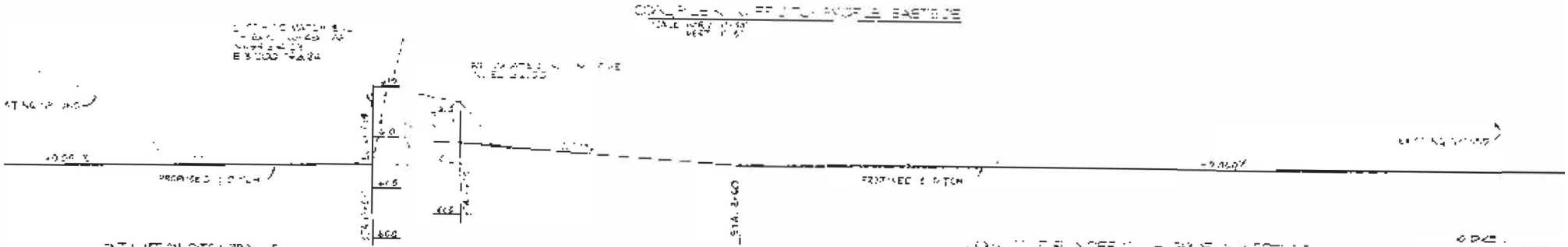
3. FOR SITE PLAN

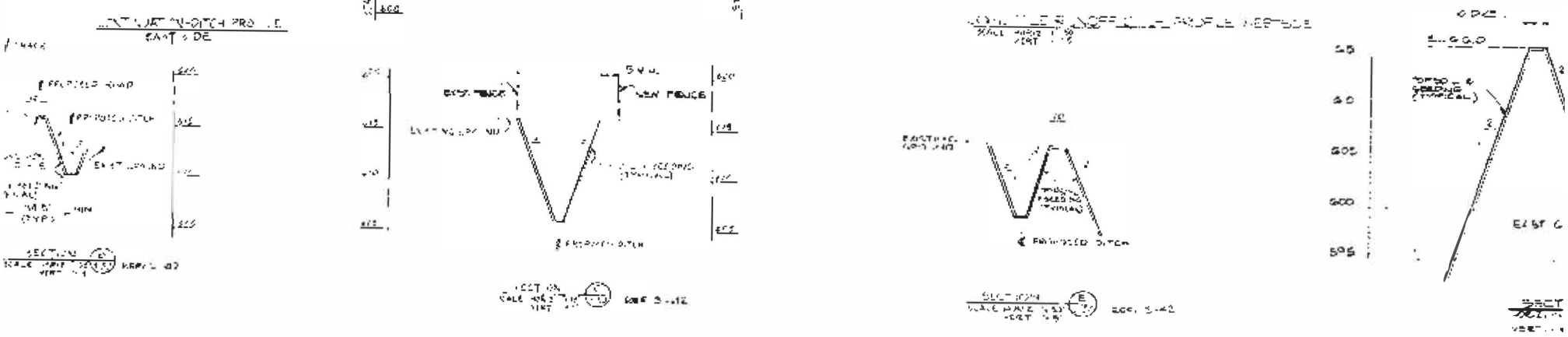
R000682

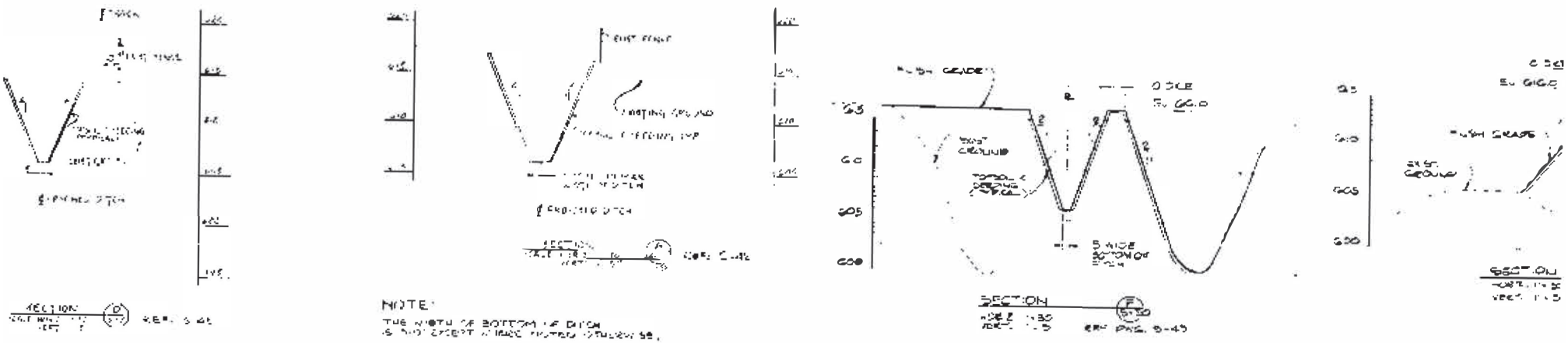

ASH POND No 1
ASH POND No 1
ASH POND No 1
SECTION
SECTION
NOTE
PLACE & COMPACT BOILER SLAG
PLACE & COMPACT BOILER SLAG TO ELEV. 625
PLACE & COMPACT BOILER SLAG TO THIS LINE MIN WIDTH 5'
WHERE CONSTRUCTION DAMAGES VEGETATION ON EXISTING SLOPE, THE AREA SHALL BE RESEEDED
COMPACTED SOIL LAYERS APPROX. 6" THICK TYP.
PLACING NEW FILL AREA NET EXISTING SLOPE AGAINS
EXISTING GROUND
PLACE AT TOPSOIL & SEED COMPLETED SLOPE
TOP EXTERIOR EDGE OF DIKE
ELEV. 627.5
EXCAVATE EXISTING SLOPE TO PROVIDE A MIN. WIDTH SOIL FROM BORROW AREA COMPACT TO 95% MAX. ASTM D 698, SOIL TO BE CLASSIFICATION OF CL.
COMPACTED STRUCTURAL
SEE DETAIL
SEE DETAIL
TOPSOIL & SEED
FILL WITH BOILER SLAG MIN. WIDTH 5'
WATER
EXISTING GROUND
BACKFILL PIPE & RECONSTRUCT DIKE WITH SOIL FROM BORROW AREA
EXCAVATE TO PLACE PIPE & CUTOFF WALLS
FILL WITH 12" BOILER SLAG
EXCAVATE TO CONSTRUCT STRUCT.
BACKFILL WITH SOIL FROM BORROW AREA

R000683









NOTE:
THE WIDTH OF BOTTOM OF DITCH

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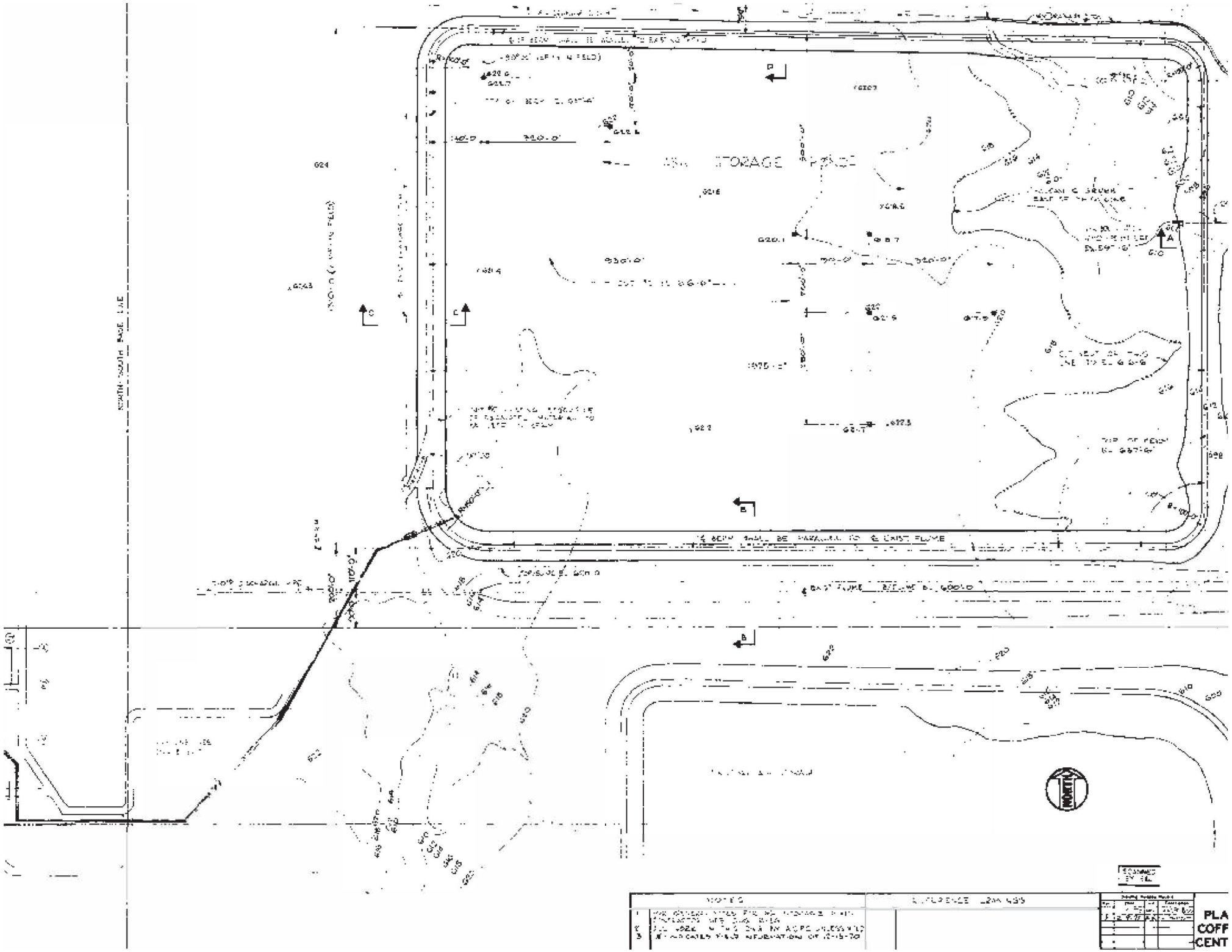

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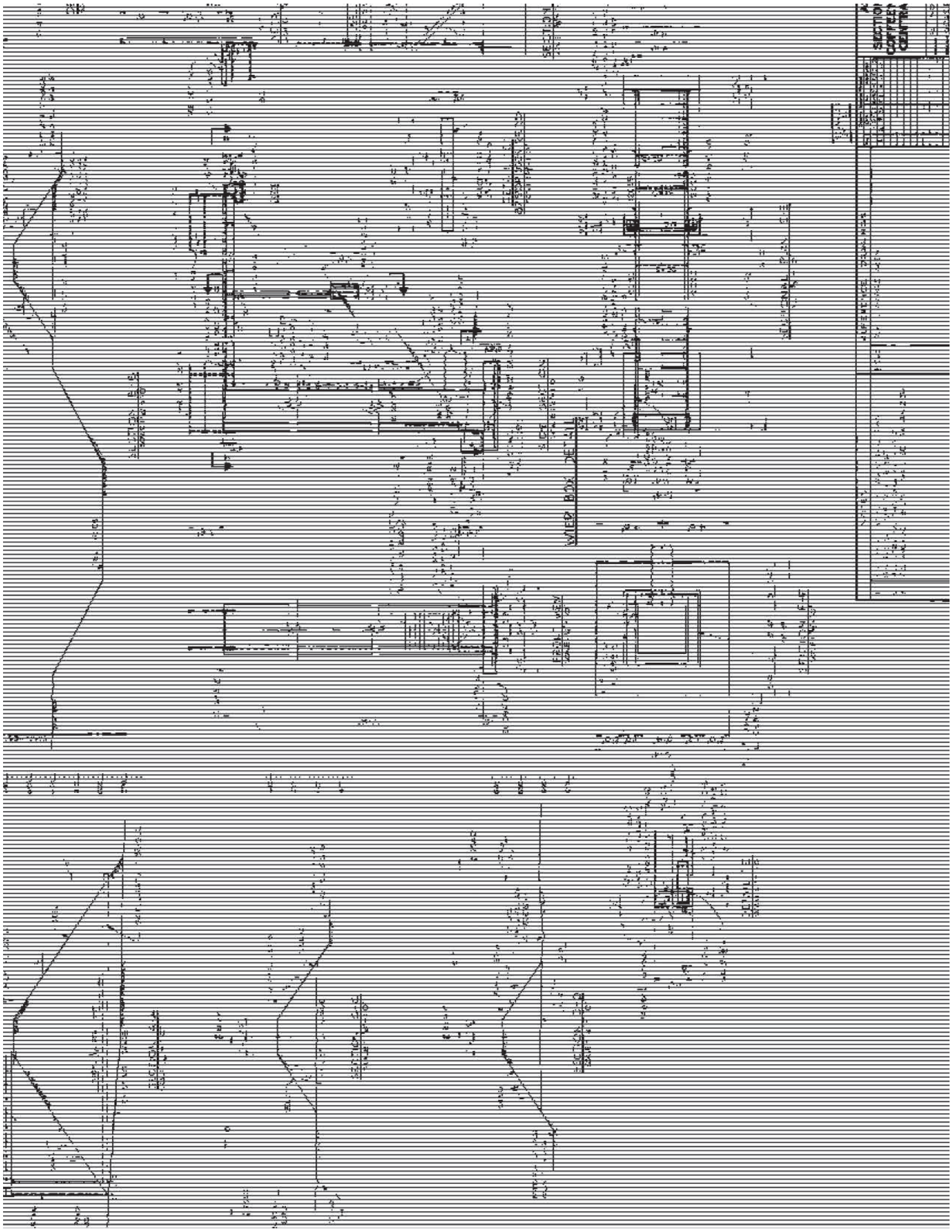

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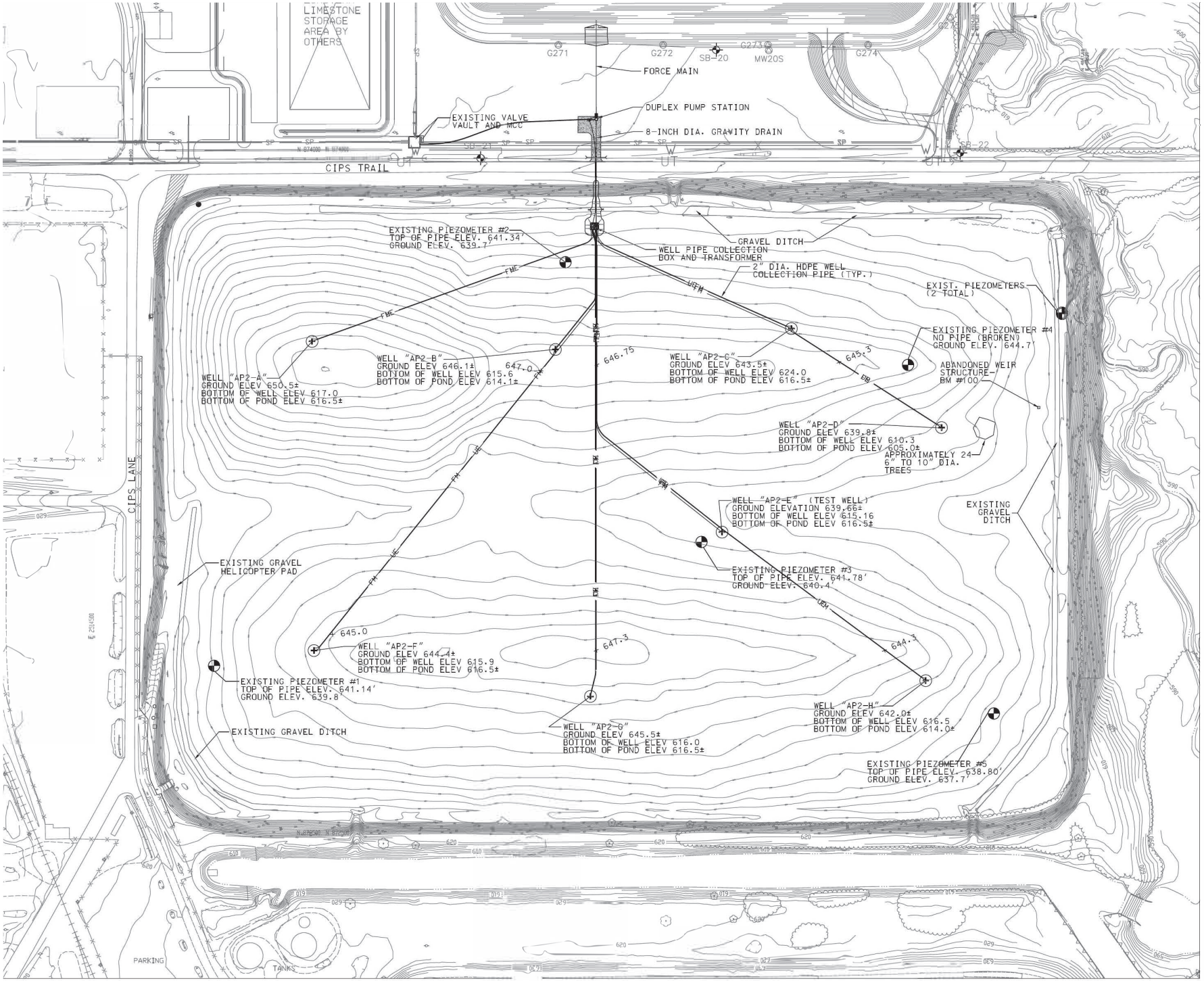


OR COMPLETENESS OF THE IN
GUARANTEE THAT ANY CONDIT
ACTUAL CONDITIONS TO BE E

2. IT SHALL BE THE CONTR
ACTUAL LOCATION OF ALL SU
CONNECTIONS TO UNDERGROUN
CONTRACTOR SHALL NOTIFY A
CONSTRUCTION PLANS AND SH
INFORMATION AND ASSISTANC
UTILITIES AND THE SCHEDUL
OF THE UTILITY. THE CONT
(1-800-892-0123 OR 811) T
RESPONSIBILITY.

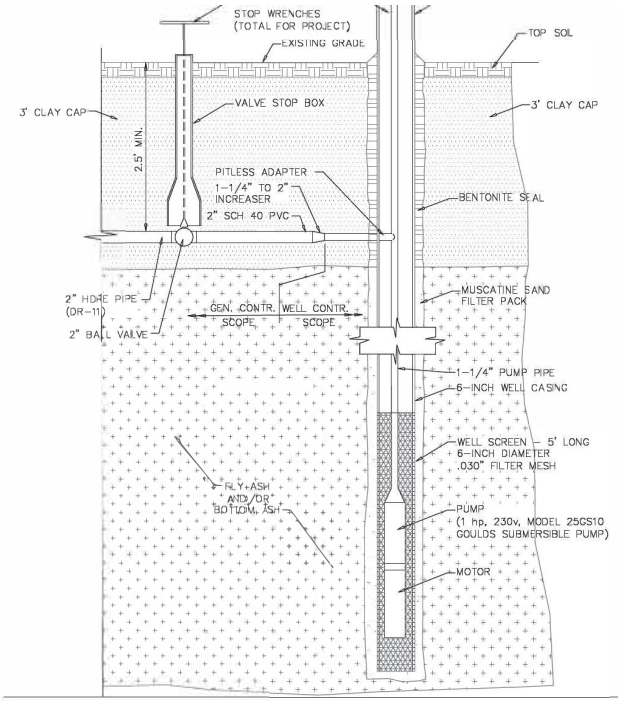
3. THE CONTRACTOR SHALL
OF THE UTILITY OR OWNING-
PROTECTION TO BE INCIDENT
UTILITY LINE OR SERVICE I
CONSTRUCTION. THE CONTRAC
THE UTILITY COMPANY OR AG
DISTURBED BY THE CONTRACT
SERVICE AT ONCE.

COORDINATE TABLE

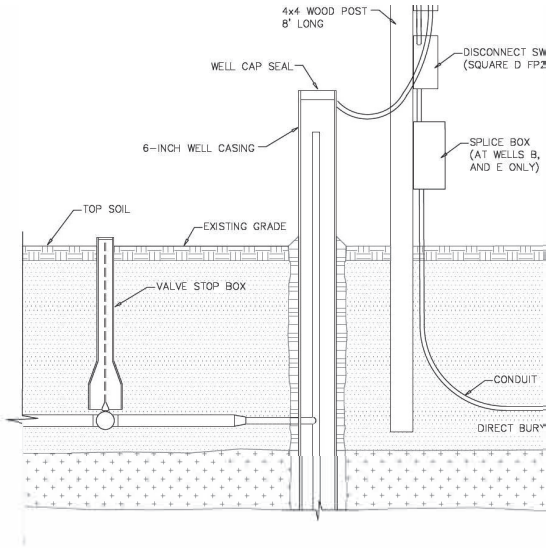
	ELEV.	DESCRIPTION	PLANT COORDINATES NORTH	EAST	ELEV.
2	636.78'	BENCHMK: CHISELED "□" IN N.E. COR. OF WEIR BOX	3610.958	1357.406	616.31'
010	615.74'	CONTROL PT #1 BRASS MONUMENT NEAR N.W. ENTRANCE	3610.440	2430.490	623.44'
[illegible]	[illegible]	CONTROL PT #2 BRASS MONUMENT NEAR EAST BKG AREA	[illegible]	[illegible]	N/A

FM
SS
UE

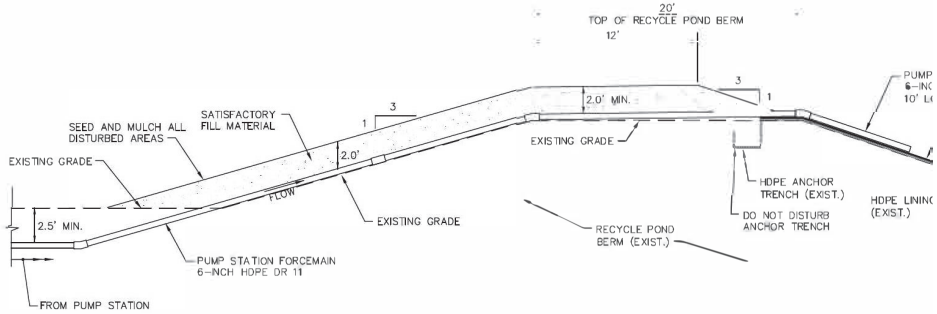
R000688



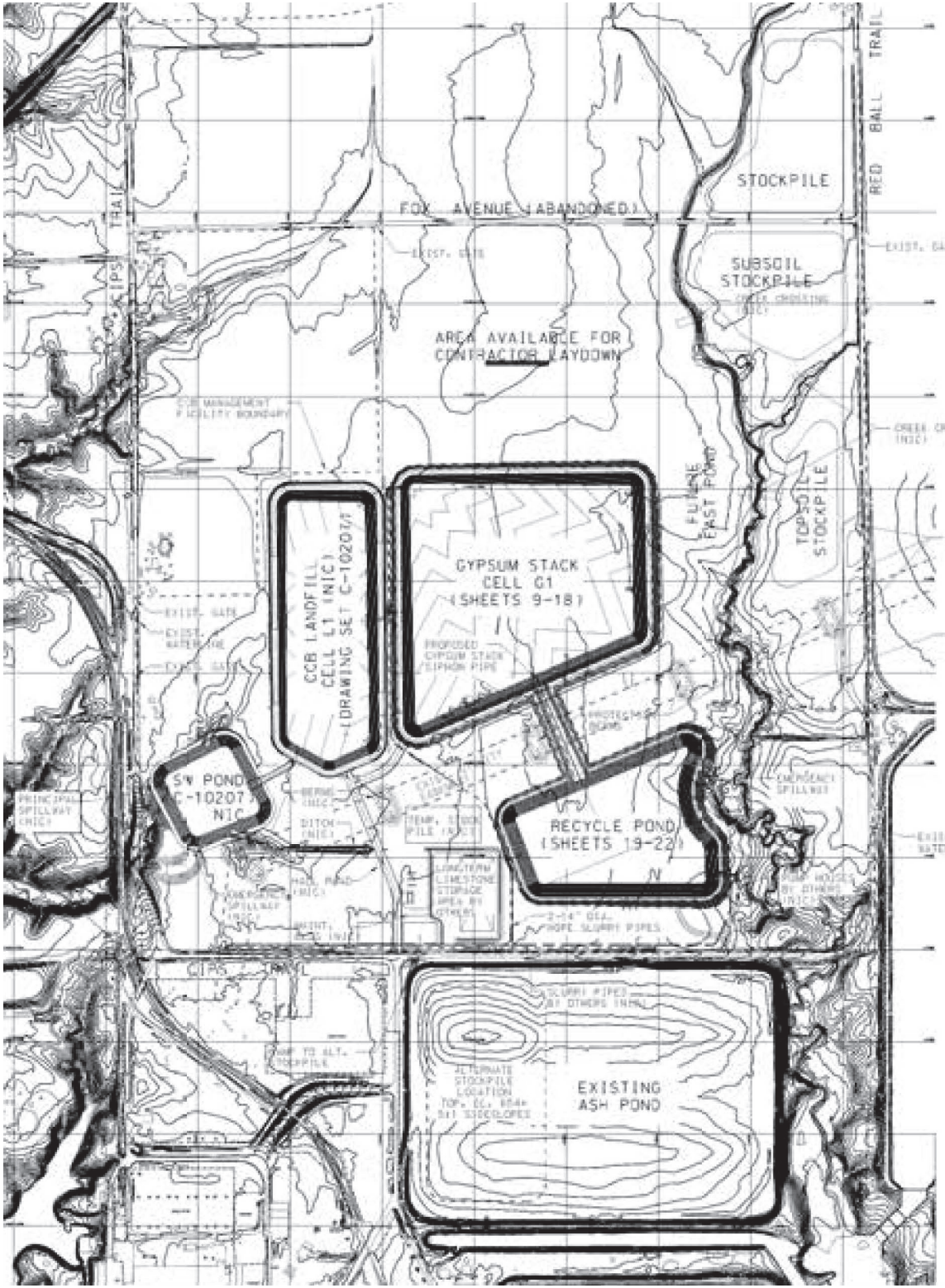
1 WELL PUMP PIPING DETAIL
NOT TO SCALE



2 WELL PUMP CONTROLLER/DISCONNEC
NOT TO SCALE



3 FORCE MAIN OUTLET DETAIL
NOT TO SCALE



OVERHEAD ELECTRIC

WATER MAIN

TELEPHONE LINE

LIMITS OF VEGETATION

GRAVEL ROAD

RAILROAD

CP-1000 — CONTROL POINT - HORIZ. & VERT.

A ——— A' — GEOLOGICAL CROSS SECTION LINE

850 — LANDFILL CONTOURS

SB-55 — BORING

GWXX — PREVIOUSLY INSTALLED GROUNDWATER MONITORING WELL

GWXX — GROUNDWATER MONITORING WELL

MW1.35 — WELLS - NOT PART OF MONITORING PLAN

NOTES:

1. SEE NOTES ON SHEET 2 REGARDING THE RESPONSIBILITY FOR EXISTING UTILITIES.

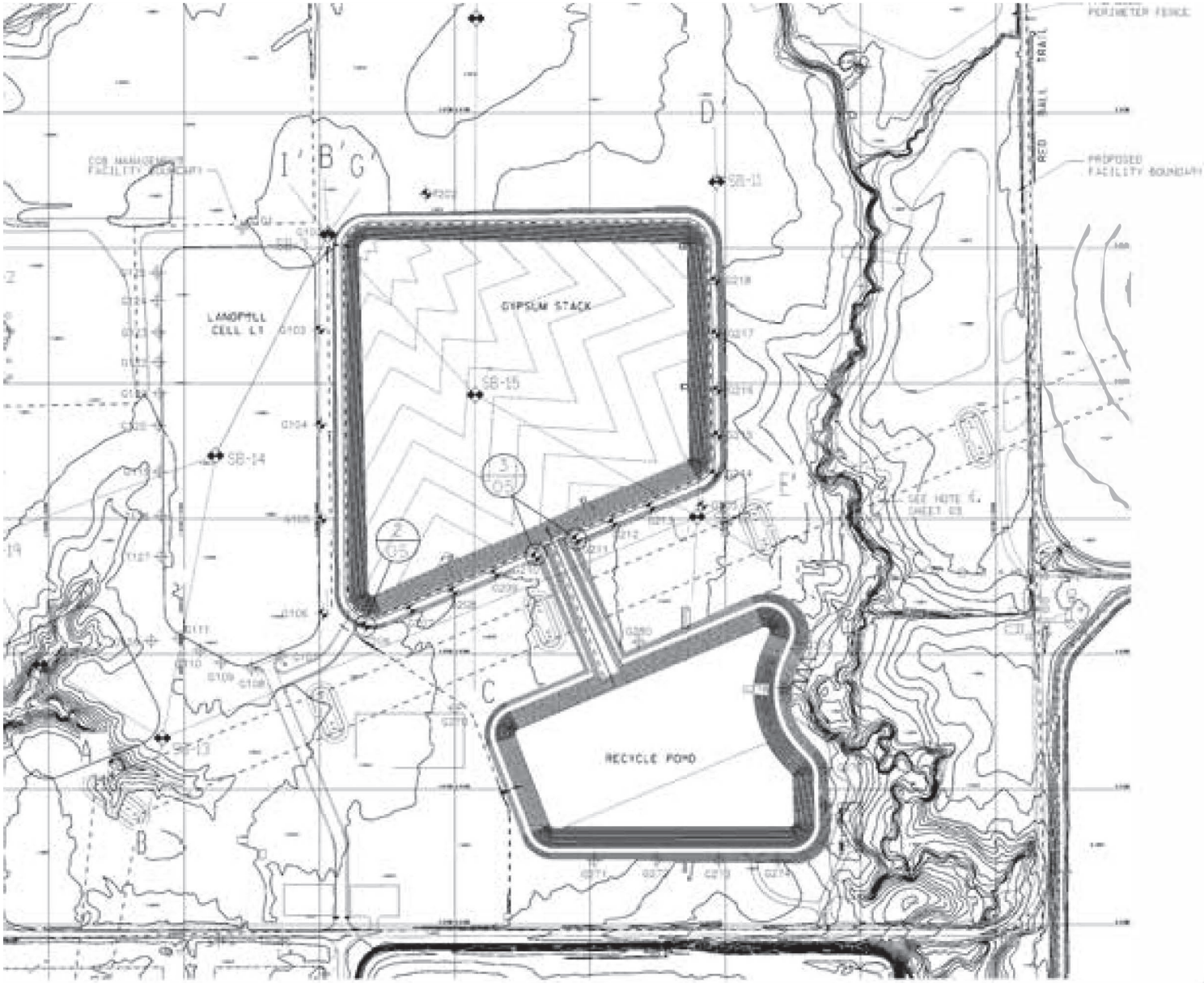
2. (NIC) INDICATES SITE FEATURES WHICH ARE NOT PART OF THIS CONTRACT. THEY ARE SHOWN FOR INFORMATIONAL PURPOSES ONLY.

3. HORIZONTAL AND VERTICAL CONTROL ARE BASED ON NAD 83, ILLINOIS STATE PLANE COORDINATE SYSTEM WEST ZONE, NAVD 88, US SURVEY FT AND THE FOLLOWING PROJECT CONTROL POINTS WERE ESTABLISHED BY HANSON PROFESSIONAL SERVICES:

HORIZONTAL CONTROL

POINT	NORTHING	EASTING	ELEV.	DESCRIPTION
CP-1000	873398.37	2515334.17	620.81	#8 REBAR IN 6" DIA. CONCRETE MON
CP-1001	873965.17	2513180.44	621.96	#8 REBAR IN 6" DIA. CONCRETE MON
CP-1002	877937.14	2514535.34	629.15	#8 REBAR IN 6" DIA. CONCRETE MON
CP-1003	877949.42	2516985.49	622.10	#8 REBAR IN 6" DIA. CONCRETE MON

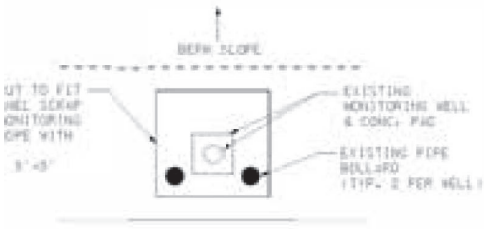
R000689

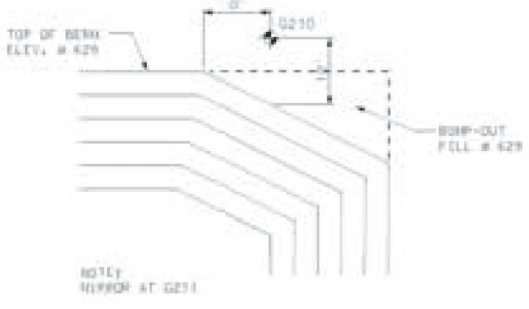


TRANSMISSION TOWERS
OVERHEAD ELECTRIC
WATER MAIN
TELEPHONE LINE
LIMITS OF VEGETATION
GRAVEL ROAD
RAILROAD
CONTROL POINT - HORIZ. & VE
GEOLOGICAL CROSS SECTION LO
LANDFILL CONTOURS
BORING
GYPSUM STACK GROUNDWATER MONITORING WELL
OTHER MONITORING WELL

NOTES:

1. CONTOURS SHOWN IN GYPSUM STACK ARE TOP OF CLA... UPPER PORTION OF THE PROCESS WATER RECOVERY ... ELIMINATED AS PART OF THE CLEAN CLOSURE PROJ...
2. THE PROPERTY IS LOCATED IN SECTIONS 10 & 11, ... RANGE 3 WEST, 3RD P.M., MONTGOMERY COUNTY, I...
3. THE DESIGN ELEMENTS INCLUDED IN THESE DRAWIN... UPON EXISTING AERIAL MAPPING AS OBTAINED FR...
4. ALL DISTURBED AREAS, INCLUDING THE CREST AND ... OF BOTH DAMS WILL BE SEEDED AND MULCHED WITH ... SEED MIXTURE.
5. FILL MATERIAL FOR DAM EMBANKMENT WILL BE PLA... UNCOMPACTED LIFTS OF 9-INCHES AND COMPACTED ... STANDARD PROCTOR DENSITY.
6. SUPERFICIAL CONTOURS WERE DEVELOPED USING AERI... METHODS WITH PHOTOGRAPHS TAKEN BY SURDEX.
7. CURRENT SURFACE TOPOGRAPHY MAY DIFFER FROM TH... ON GOING OPERATIONS AT THE SITE.
8. FOR CLARITY, NOT ALL EXISTING SITE FEATURES ...

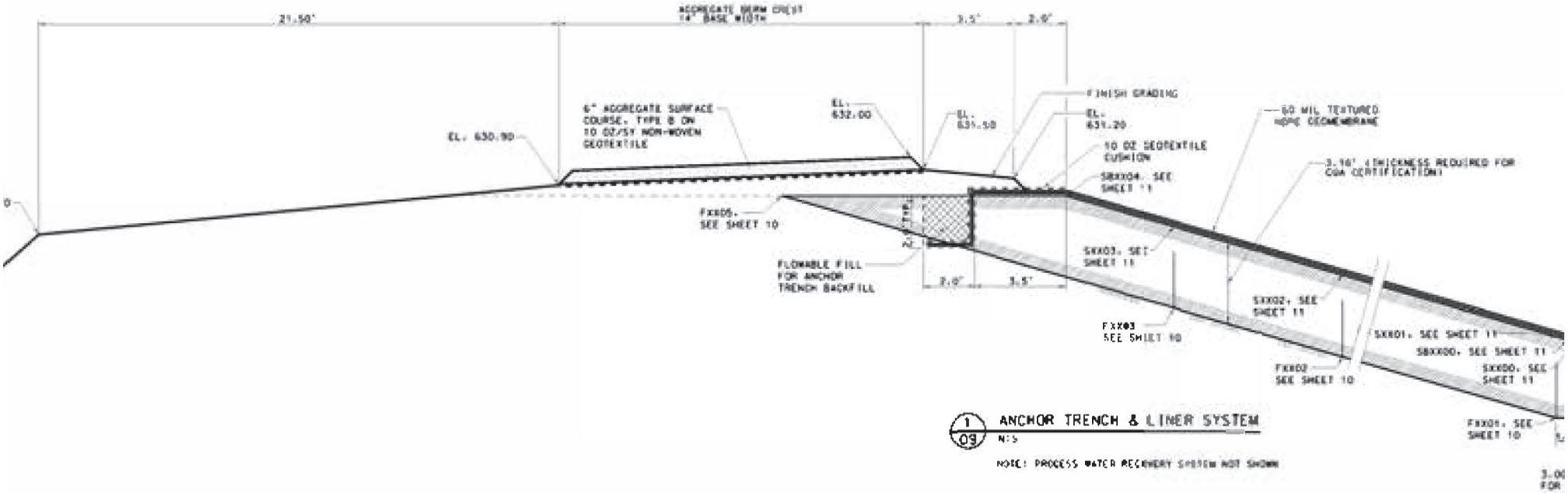






MONITORING WELL BUMP-
AT HAUL ROAD

R000690

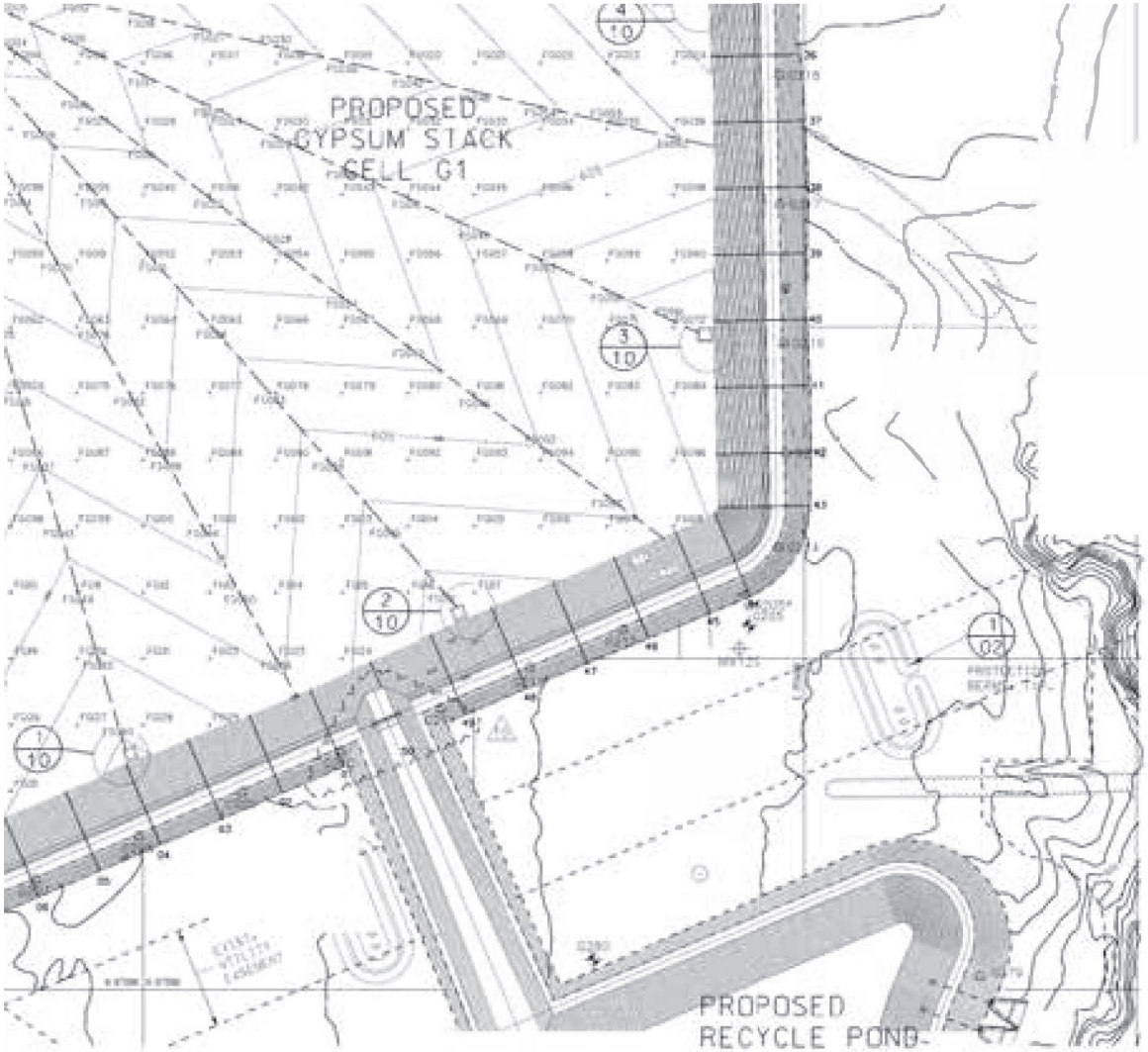


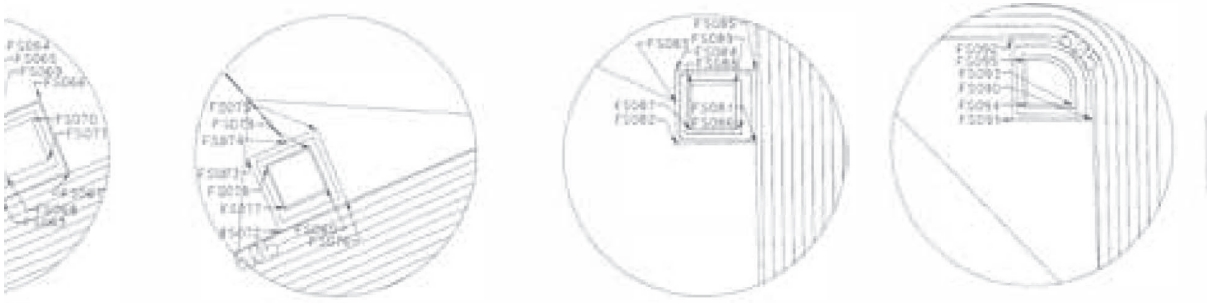
1/09 ANCHOR TRENCH & LINER SYSTEM

N.T.S.

NOTE: PROCESS WATER RECOVERY SYSTEM NOT SHOWN

R000691





DETAIL

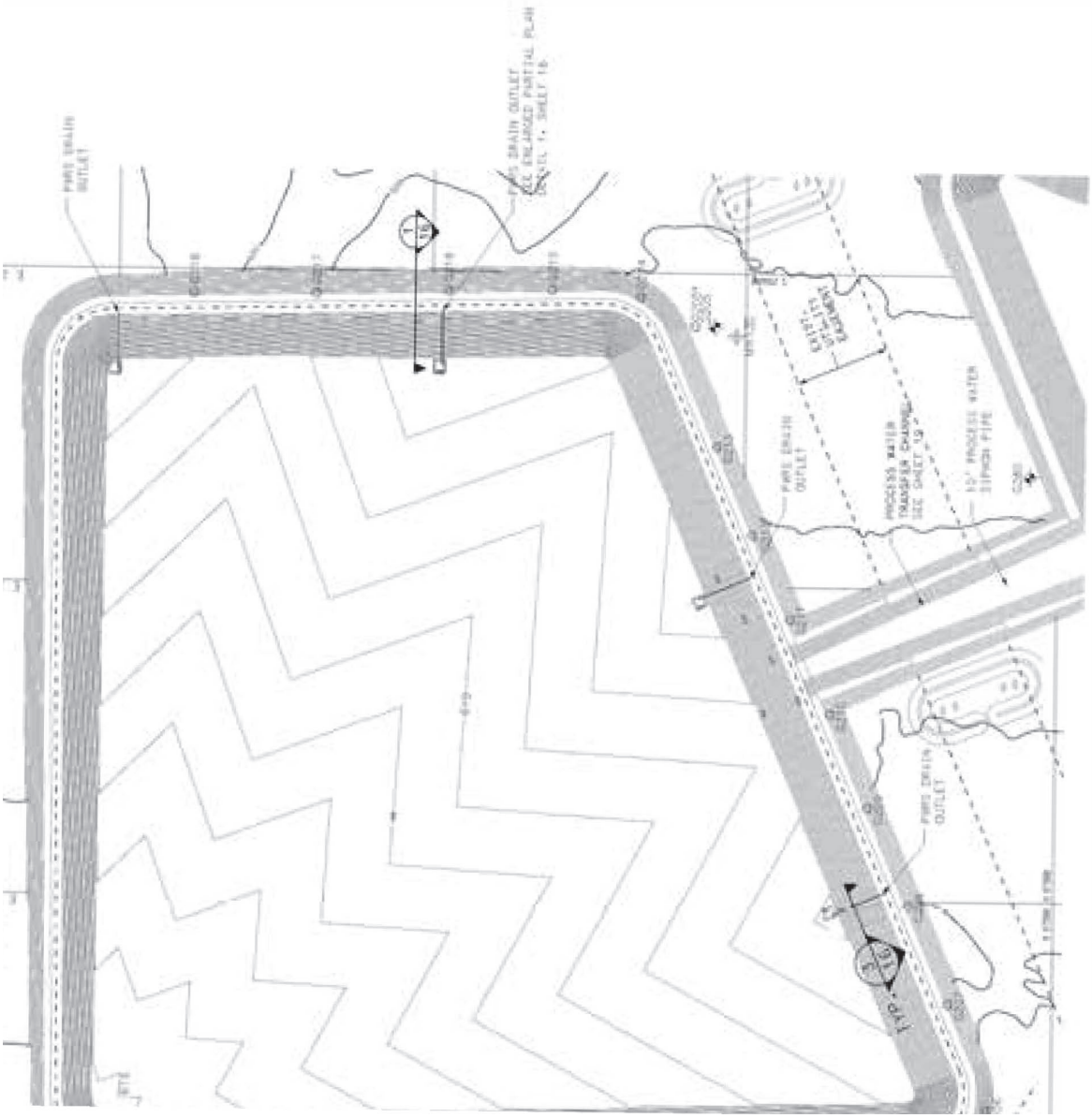
2/10 SUMP DETAIL

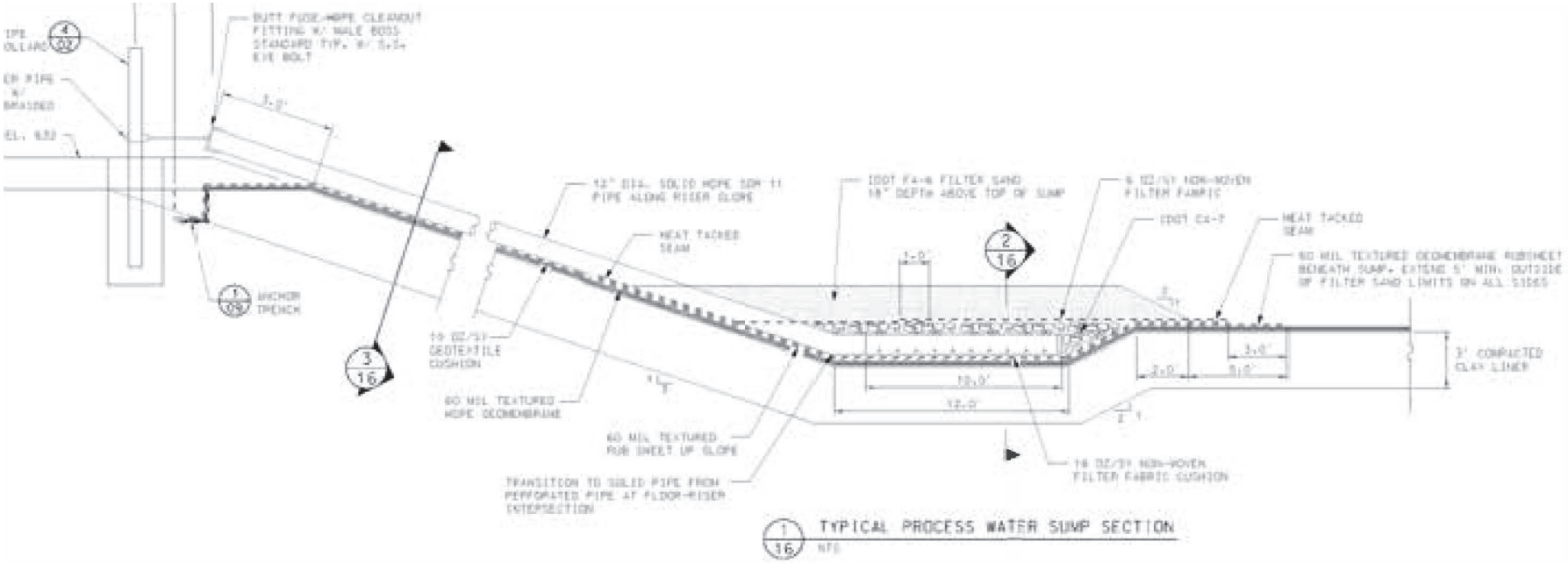
3/10 SUMP DETAIL

4/10 SUMP DETAIL

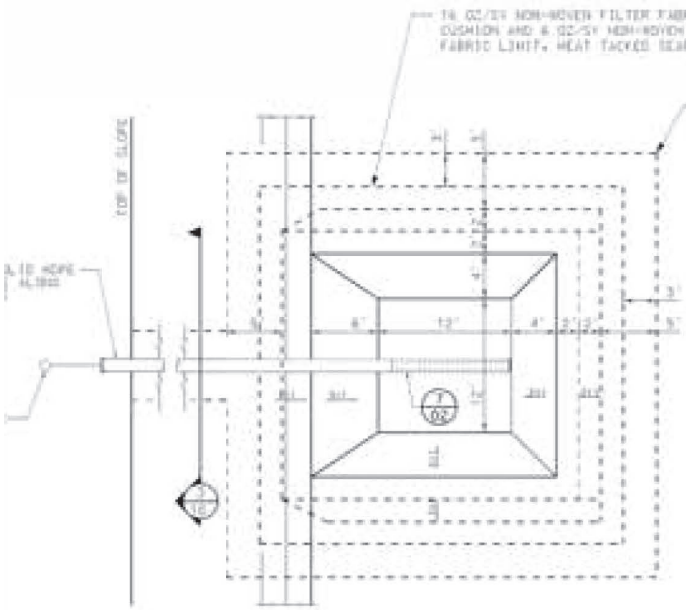
NOTE: SEE OTHER PLAN SHEETS FO

R000692

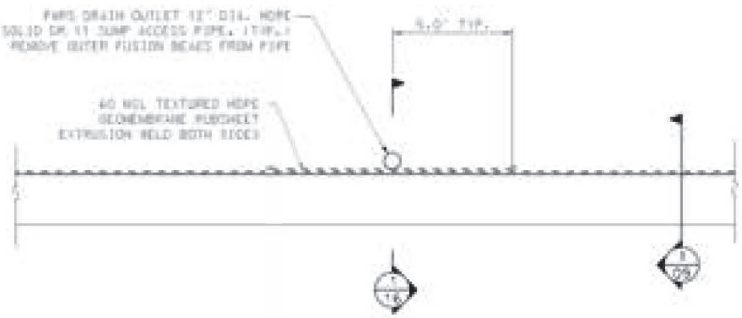

PIPE DRAIN OUTLET
PIPE DRAIN OUTLET
PROCESS WATER TRANSFER CHANNEL
PIPE DRAIN OUTLET
PIPE DRAIN OUTLET



1/16 TYPICAL PROCESS WATER SUMP SECTION
NTS



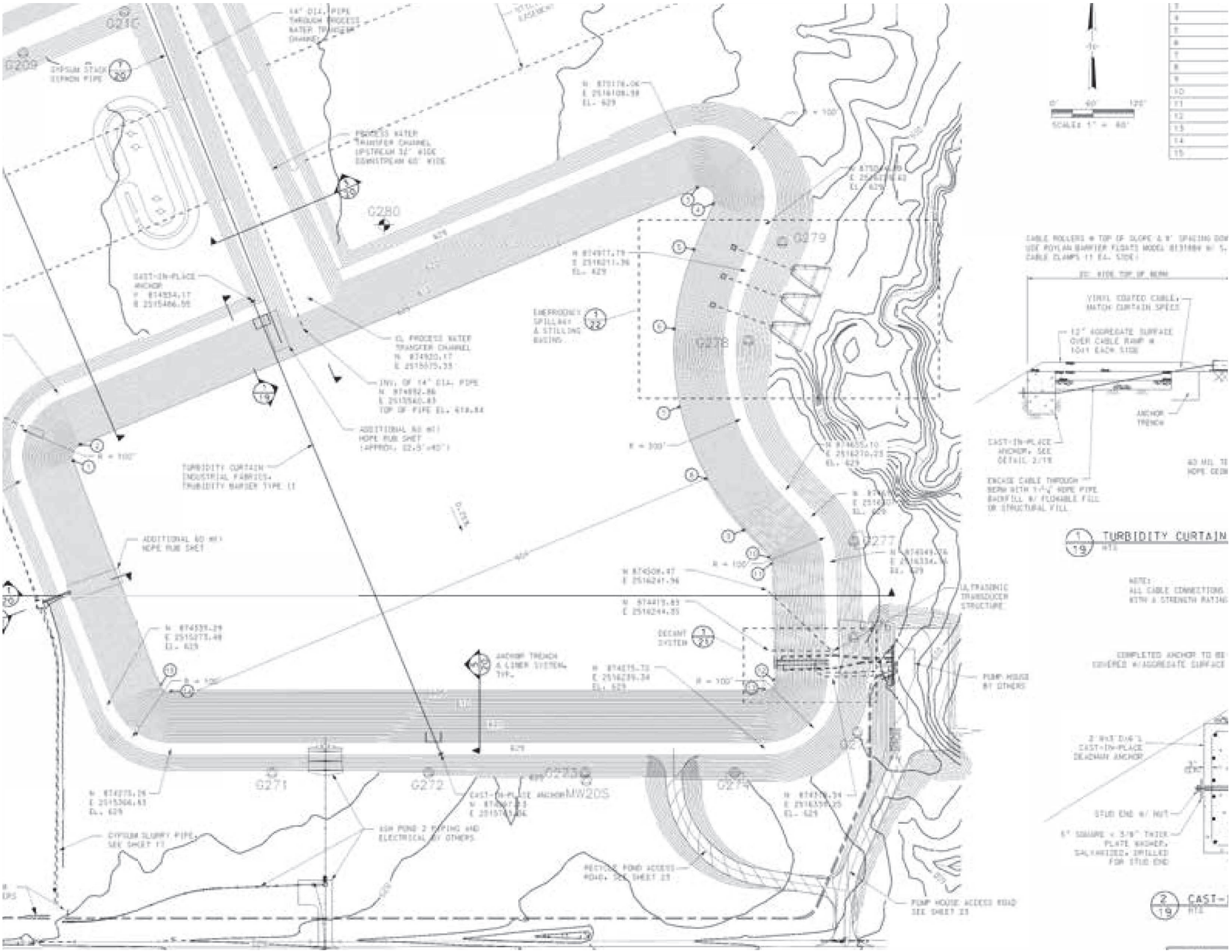
2/16 PWRS SUMP PLAN
NTS



3/16 PROCESS WATER RECOVERY PIPE UP SIDESLOPE
NTS

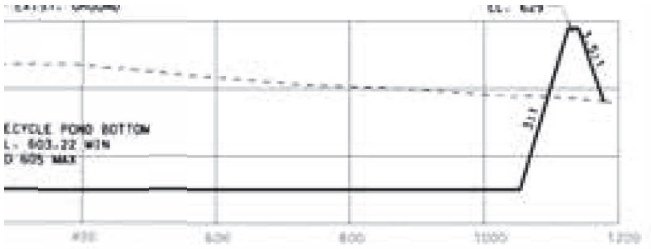
NOTE:
ALL SIDE SLOPE PIPES TO BE SOLID WALL

R000694

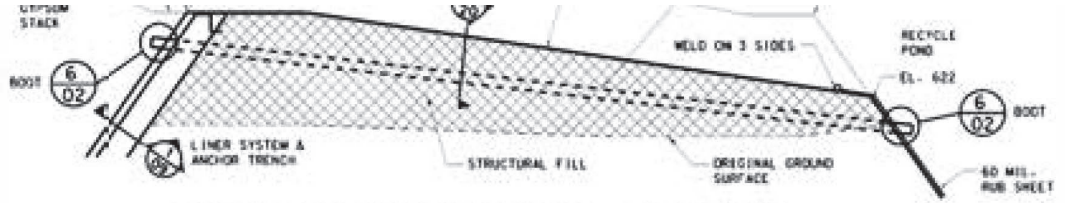


G216
G209
G280
G279
G278
G277
G271
G272
G273
G274
MW20S
14" DIA. PIPE THROUGH PROCESS WATER TRANSFER CHANNEL
GYPSUM STACK SIPHON PIPE
PROCESS WATER TRANSFER CHANNEL UPSTREAM 32' WIDE DOWNSTREAM 60' WIDE
CAST-IN-PLACE ANCHOR
CL PROCESS WATER TRANSFER CHANNEL
INV. OF 14" DIA. PIPE
ADDITIONAL 60 MIL HDPE RUB SHET
TURBIDITY CURTAIN INDUSTRIAL FABRICS, TURBIDITY BARRIER TYPE II
EMERGENCY SPILLWAY & STILLING BASINS
ANCHOR TRENCH & LINER SYSTEM, TYP.
DECANT SYSTEM
ULTRASONIC TRANSDUCER STRUCTURE
PUMP HOUSE BY OTHERS
GYPSUM SLURRY PIPE, SEE SHEET 17
ASH POND 2 PIPING AND ELECTRICAL BY OTHERS
RECYCLE POND ACCESS ROAD, SEE SHEET 23
PUMP HOUSE ACCESS ROAD SEE SHEET 23
SCALE: 1" = 60'
VINYL COATED CABLE, MATCH CURTAIN SPECS
12" AGGREGATE SURFACE OVER CABLE RAMP @ 10:1 EACH SIDE
ANCHOR TRENCH
CAST-IN-PLACE ANCHOR, SEE DETAIL 2/19
ENCASE CABLE THROUGH BERM WITH 1-1/4" HDPE PIPE BACKFILL W/ FLOWABLE FILL OR STRUCTURAL FILL
TURBIDITY CURTAIN
NOTE: ALL CABLE CONNECTIONS WITH A STRENGTH RATING
COMPLETED ANCHOR TO BE COVERED W/AGGREGATE SURFACE
CAST-IN-PLACE DEADMAN ANCHOR
STUD END W/ NUT
5" SQUARE x 3/8" THICK PLATE WASHER, SALVANIZED, DRILLED FOR STUD END

R000695



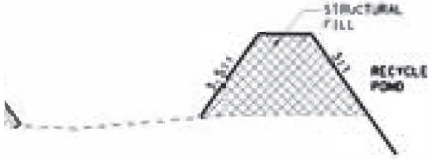
PICAL SECTION THROUGH RECYCLE POND



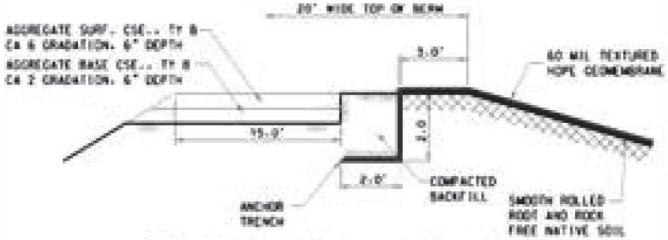
2/20 SECTION THROUGH PROCESS WATER TRANSFER CHANNEL
NTS



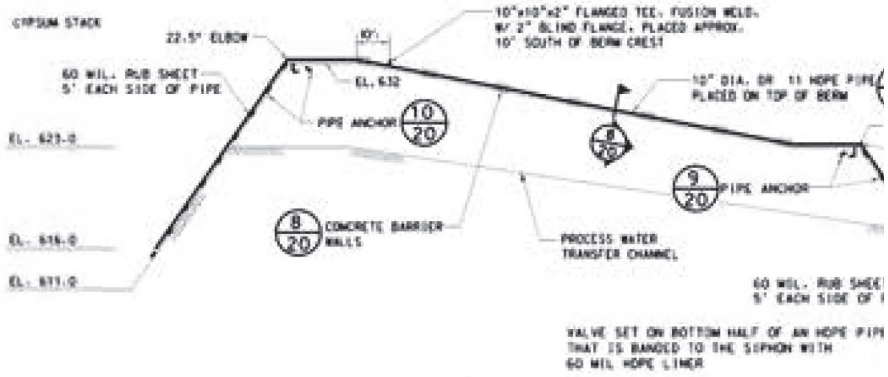
3/20 SECTIO WATER
NTS



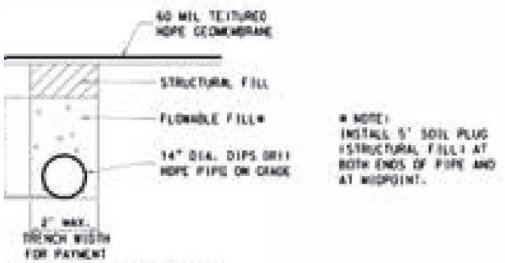
SECTION THROUGH BERMS
NTS



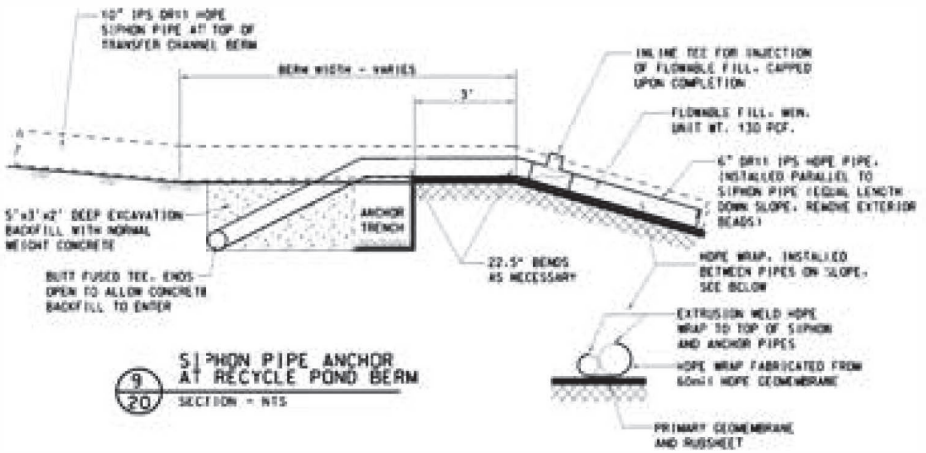
5/20 RECYCLE POND - LINER SYSTEM
NTS



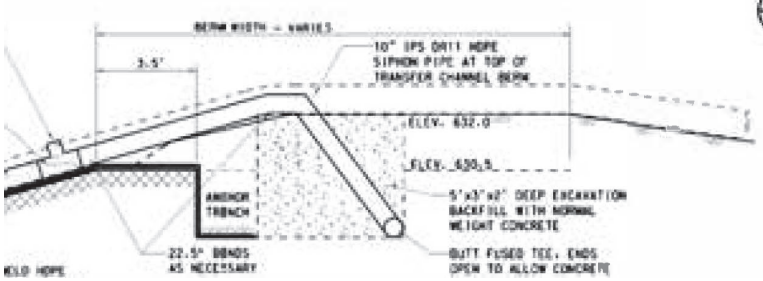
7/20 GYPSUM STACK SIPHON SYSTEM SECTION THROUGH PROCESS WATER TRANSFER CHANNEL
NTS

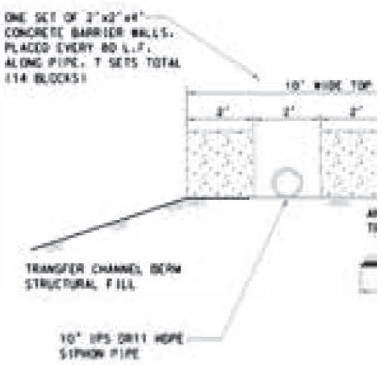


CAL TRENCH SECTION



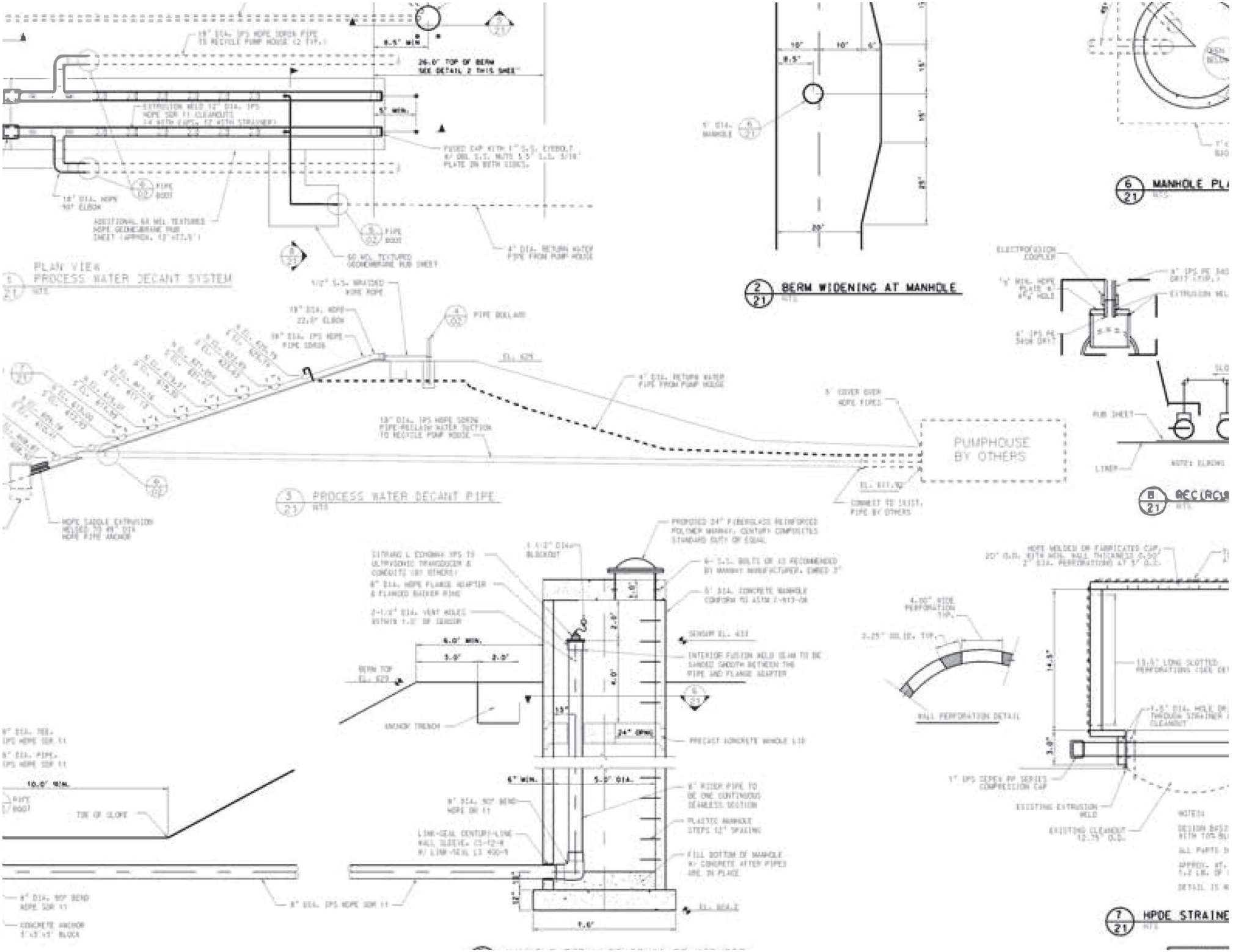
9/20 SIPHON PIPE ANCHOR AT RECYCLE POND BERM
SECTION - NTS



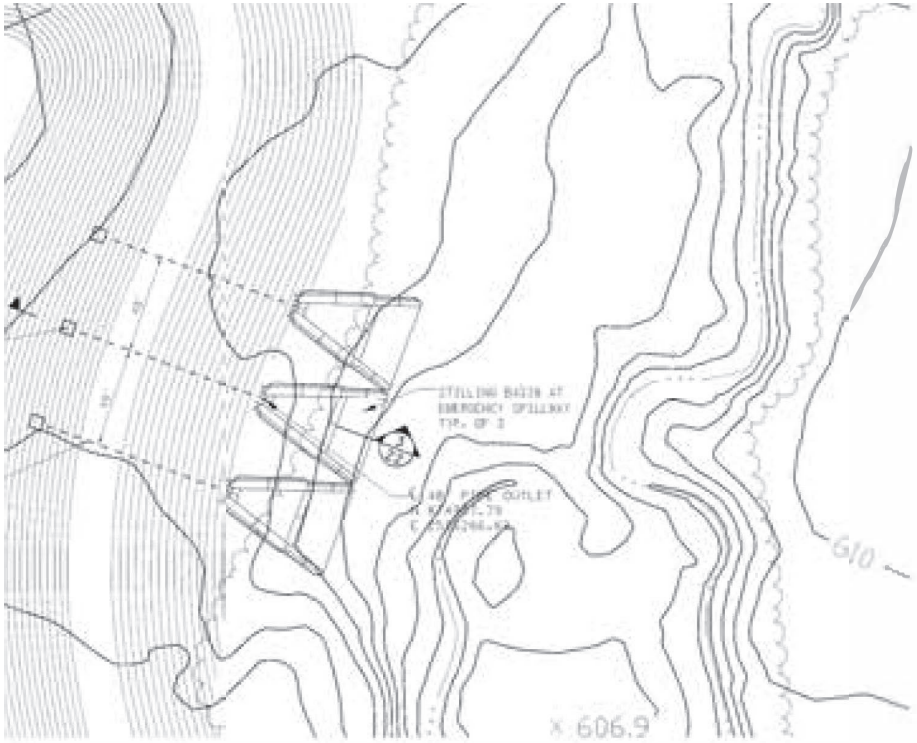


8/20 SIPHON PIPE
SECTION - NTS

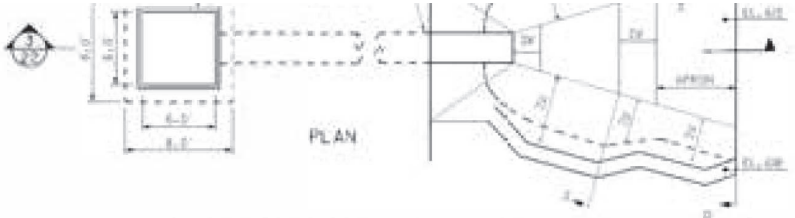
R000696


PLAN VIEW
PROCESS WATER DECANT SYSTEM
BERM WIDENING AT MANHOLE
PROCESS WATER DECANT PIPE
PUMPHOUSE
BY OTHERS
MANHOLE PL
HPDE STRAINE
WALL PERFORATION DETAIL
ANCHOR TRENCH
TOE OF SLOPE
PRECAST CONCRETE MANHOLE LID
FILL BOTTOM OF MANHOLE W/ CONCRETE AFTER PIPES ARE IN PLACE
PLASTIC MANHOLE STEPS 12" SPACING
EXISTING EXTRUSION WELD
EXISTING CLEANOUT 12.75" O.D.
ELECTROFUSION COUPLER
RUB SHEET
LINER
26.0' TOP OF BERM
SEE DETAIL 2 THIS SHEET
PIPE BOLLARD
PIPE BOOT
4" DIA. RETURN WATER PIPE FROM PUMP HOUSE
5' COVER OVER HDPE PIPES
CONNECT TO EXIST. PIPE BY OTHERS
HDPE SADDLE EXTRUSION WELDED TO 49" DIA HDPE PIPE ANCHOR
6.0' MIN.
5.0' DIA.
24" OPNG
10.0' MIN.
8" DIA. IPS HDPE SDR 11
CONCRETE ANCHOR

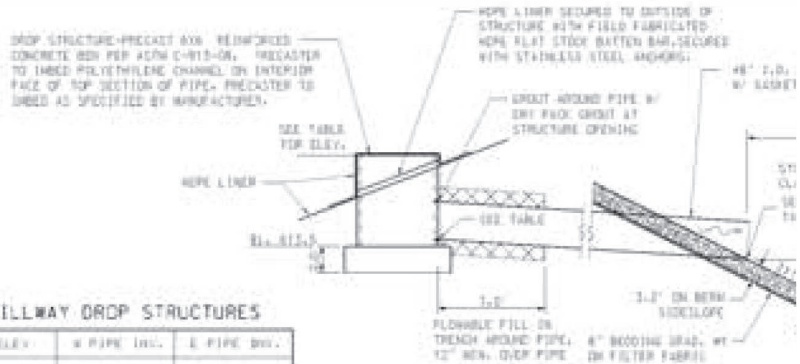
R000697



1/22 STILLING BASIN PLAN AT EMERGENCY SPILLWAY
NTS



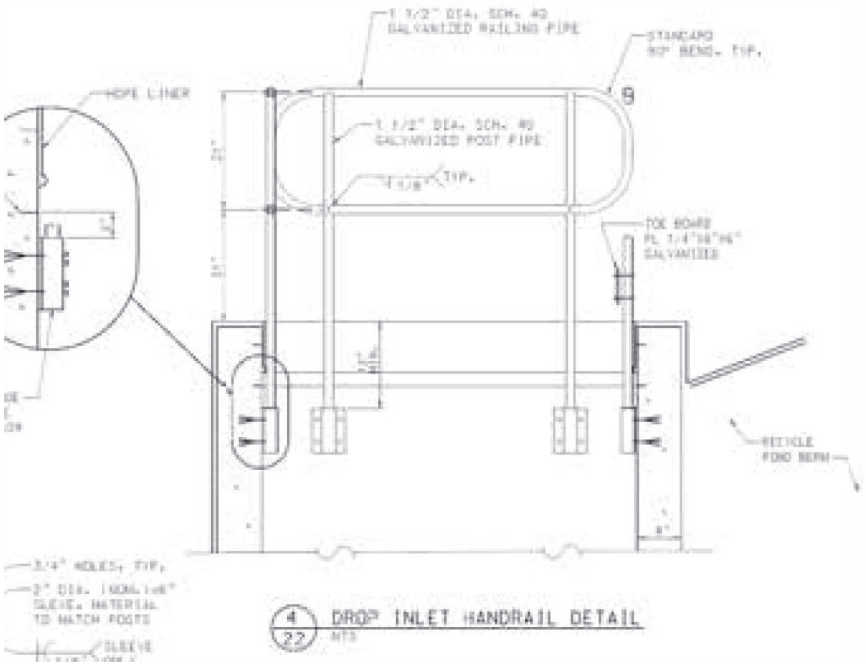
2/22 RIPRAP STILLING BASIN PLAN
NTS



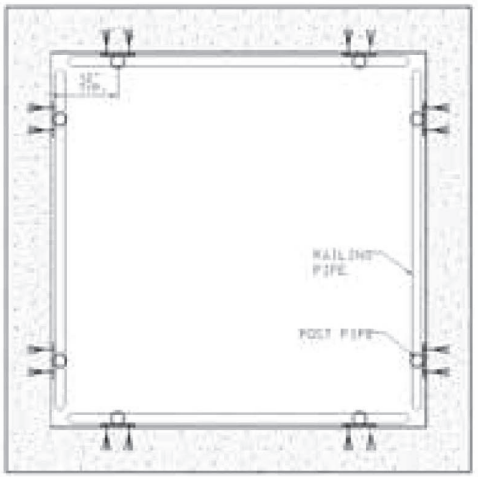
EMERGENCY SPILLWAY DROP STRUCTURES

STRUCTURE	TOP ELEV.	W PIPE INV.	E PIPE INV.
NORTH	624.13	614.93	612.94
MIDDLE	624.15	614.95	613.00
SOUTH	624.11	614.03	613.06

3/22 RIPRAP STILLING BASI
NTS



4/22 DROP INLET HANDRAIL DETAIL
NTS



5/22 DROP INLET HANDRAIL PLAN
NTS

HANDRAIL NOTES

GT-1 CORE ALL INTERSECTIONS OF RAILS AND POSTS, PLEASING APPEARANCE, TAKING CARE TO NOT RE MATERIALS.

GT-2 BUTT WELD END-TO-END JOINTS, OR USE WELDIN

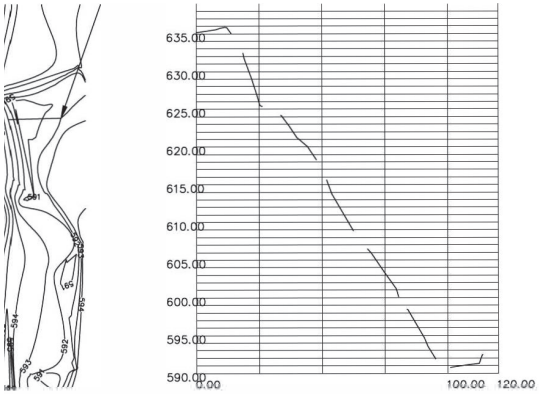
GT-3 CLEAN WELDED AREAS USING A WIRE BRUSH TO R WIPE AWAY DUST WITH A CLEAN DRY RAG AND CL WITH SSPC-SP 1.

GT-4 TREAT ALL WELD ZONES WITH TWO COATS OF COL

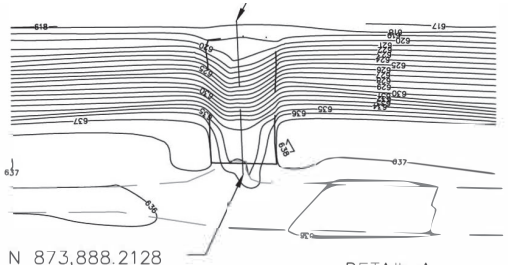
GT-5 COAT THE WELDED HANDRAIL ASSEMBLY PER THE 1 - 4 MIL COAT OF KRYLON INDUSTRIAL 2 - 3 MIL COATS OF KRYLON INDUSTRIAL COLOR: OSHA SAFETY YELLOW

R000698

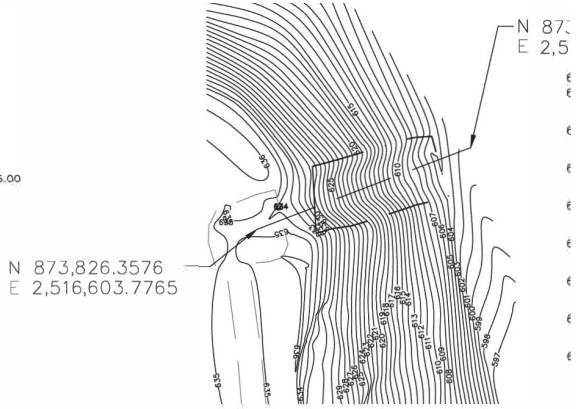
R000699



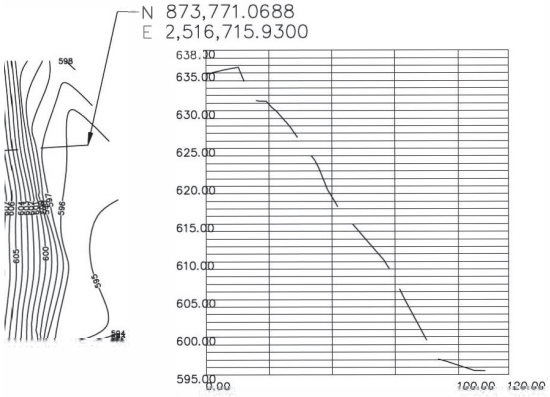
DETAIL G
EAST ERODED SLIDE AREA



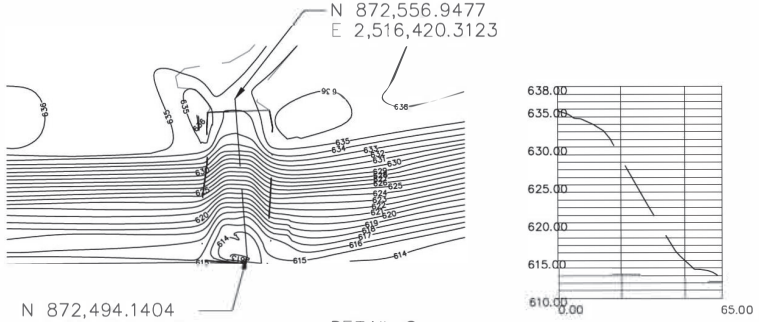
DETAIL A
NORTH PAVED OUTLET



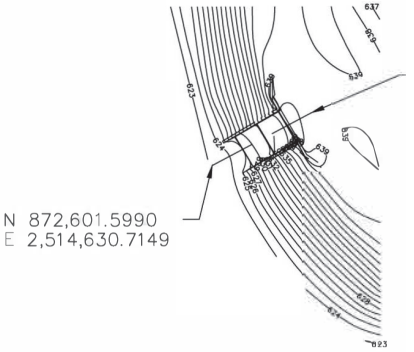
DETAIL B
NORTHEAST PAVED



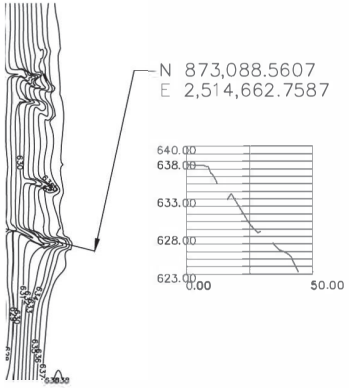
DETAIL H
NEW ERODED SLIDE AREA



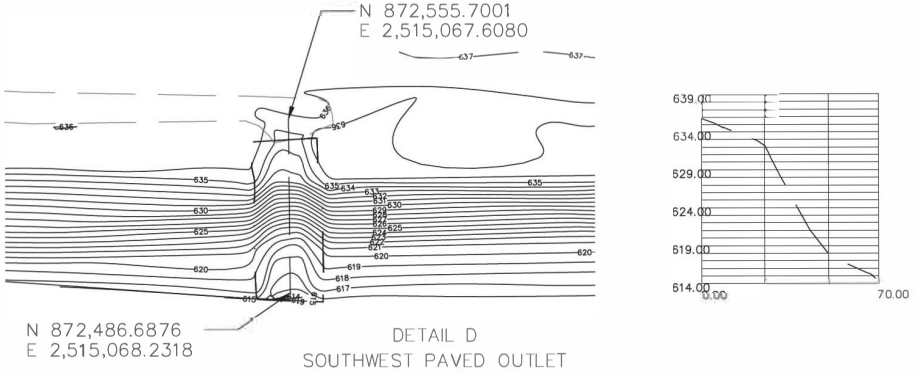
DETAIL C
SOUTHEAST PAVED OUTLET



DETAIL
CONCRETE



DETAIL F
WEST ERODED SLIDE AREA



DETAIL D
SOUTHWEST PAVED OUTLET

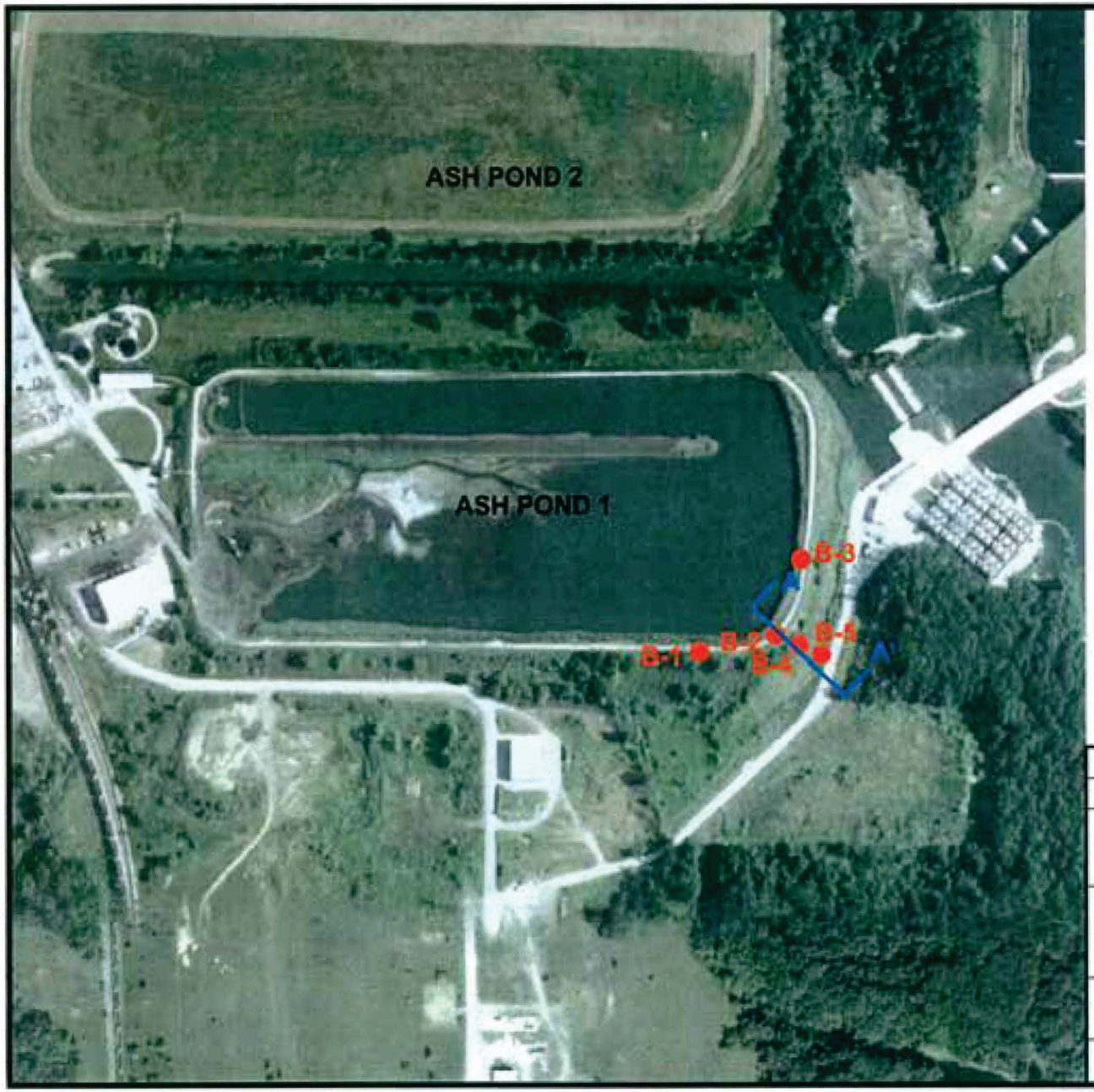




AECOM

Appendix C: Coffeen Power Station Boring and Piezometer Locations

R000701



NOTES

1. Plan adapted from an aerial photograph courtesy of Google Earth.

LEGEND

- Boring Location
- Slope Stability Cross Section

N

0 200 400 800

SCALE IN FEET

Drawn By: SLC	Ck'd By:	App'vd By:
Date: 11-04-10	Date:	Date: 11/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Coffeen Power Station
Coffeen, Illinois

AERIAL PHOTOGRAPH OF SITE AND BORING LOCATIONS

Project Number J017150.01

PLATE 2

R000702



LEGEND

PIEZOMETER LOCATION

Illinois Power Generating Compa

R000703



LEGEND

AECOM PIEZOMETER LOCATION

Illinois Power Generating Compa

AECOM

Appendix D: Project Specifications, Gypsum Stack and Recycle Pond Construction (Hanson 2008)

PROJECT SPECIFICATIONS
GYPSUM STACK AND RECYCLE POND CONSTRUCTION
GYPSUM MANAGEMENT FACILITY
COFFEEN POWER STATION
MONTGOMERY COUNTY, ILLINOIS

Prepared For:

AMEREN ENERGY GENERATING COMPANY

Prepared By:

HANSON PROFESSIONAL SERVICES INC.
1525 South Sixth Street
Springfield, Illinois 62703

January 2008

GYPSUM STACK AND RECYCLE POND CONSTRUCTION
GYPSUM MANAGEMENT FACILITY
COFFEEN POWER STATION
MONTGOMERY COUNTY, ILLINOIS

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02315 - Granular Drainage Materials	02315-1 to 02315-8
02373 - Geotextiles	02373-1 to 02373-8
02376 - Geosynthetic Clay Liner	02376-1 to 02376-9
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DIVISION1–GENERAL REQUIREMENTS
Section 01356 – Storm Water Pollution Prevention Measures

PART 1. GENERAL

1.01 DESCRIPTION

A. This section pertains to the construction and maintenance of temporary erosion control systems to control erosion and sediment damage to adjacent properties and water resources, and the removal of erosion control devices when they are no longer required.

1.02 RELATED SECTIONS

The following sections contain items which are related to the work in this section:

02936 - Topsoil, Seeding, and Mulching.

1.03 REFERENCES

The following reference, or cited portions thereof, governs the work:

Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007.

1.04 SUBMITTALS

A. Submittals shall follow the provisions of Section 01010.

B. Preconstruction Submittals: A storm water best management practices (BMP) plan shall be submitted that includes the following items:

1. Site drawing showing anticipated locations of structural erosion controls, areas of disturbed soils, and drainage patterns;
2. Inspection and record-keeping procedures; and
3. Maintenance procedures for erosion controls.

PART 2. PRODUCTS

2.01 EROSION CONTROL SYSTEMS

Materials for erosion control systems shall be in accordance with Article 280.02 of the IDOT Standard Specifications.

PART 3. EXECUTION

3.01 EXAMINATION

The site shall be examined to determine the extent of work required.

3.02 PRECONSTRUCTION JOBSITE INSPECTION

A. The person who shall be at the jobsite during construction and who shall be responsible for insuring that erosion control work is completed in a timely manner shall be identified at the preconstruction meeting.

B. A jobsite inspection shall be conducted with the Owner's Representative to review and designate the locations and types of erosion protection to be placed. The inspection shall be scheduled at the preconstruction conference and carried out on the job site before beginning any work that will disturb existing drainage or potentially create erodible conditions.

3.03 CONSTRUCTION

A. Temporary erosion control systems shall be constructed in accordance with IDOT Standard 280001 and Article 280.04 of the Standard Specifications and as directed by the Owner's Representative. Erosion control devices shall be in place and approved by the Owner's Representative prior to beginning other work.

B. Incorporate permanent erosion control features into the project at the earliest practicable time to minimize the need for temporary erosion controls.

3.04 MAINTENANCE

A. Temporary erosion control systems shall be maintained in accordance with Article 280.05 of the Standard Specifications, except that measurement and payment provisions shall not apply.

B. Temporary erosion control systems for unprotected disturbed areas shall be cleaned of trapped sediment and repaired immediately prior to project close out.

C. Temporary seeding shall be applied to all disturbed areas except the gypsum stack excavation and the future fill and topsoil stockpiles.

3.05 REMOVAL AND DISPOSAL

When the Owner's Representative deems that temporary erosion control systems are no longer needed, they shall be removed and properly disposed, and silt deposits shall be removed or regarded as directed by the Owner's Representative, and the area seeded. Non-biodegradable temporary erosion control materials shall be disposed of off site. Biodegradable erosion control devices may be disposed of in spoil areas designated by the Owner's Representative. All laws and regulations in disposing of the materials shall be obeyed.

END OF SECTION 01356

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PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to stripping of topsoil and vegetation from areas of the site that are to be excavated.

1.02 RELATED SECTIONS

No related sections.

PART 2. PRODUCTS

No products used.

PART 3. EXECUTION

3.01 EXAMINATION

The Contractor shall examine the site to determine the extent of work required.

3.02 SITE PREPARATION - STRIPPING

A. All vegetation and topsoil encountered within the Gypsum Stack grading limits shall be stripped. Topsoil shall be kept clean and free of all foreign material, and stored in separate stockpiles from vegetation and common excavations. Stockpiles shall be located as indicated on the drawings or as directed by the Owner's Representative.

B. Payment for stripping shall be based upon removal of 24 inches of topsoil in areas that require stripping.

3.03 DISPOSAL

All materials resulting from site preparation operations shall be stockpiled in the designated spoil area. Contractor shall obey all laws and regulations when disposing of the materials.

END OF SECTION 02100

DIVISION 2 – SITEWORK
Section 02200 – Earthwork

PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to excavation, fill, and backfill required for foundation preparation, construction of low-permeability soil layer, anchor trench construction, miscellaneous site grading and berm construction.

1.02 RELATED SECTIONS

A. The following sections contain items which are related to the work in this section:

1. 01356 – Storm Water Pollution Prevention Measures
2. 02100 - Site Preparation
3. 02373 – Geotextiles
4. 02936 - Topsoil, Seeding, and Mulching

1.03 REFERENCES

The following references, or cited portions thereof, govern the work:

1. Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007
2. Department of Sustainable Natural Resources, Soil Survey Standard Test Method, Unified Soil Classification System: Field Method (USCS).

1.04 MEASUREMENT AND PAYMENT

A. The Contractor shall be responsible for estimating the extent of excavation and fill required to complete the work, including, but not limited to, excavation to required elevations; loading, transporting, placing, and compacting low permeability soil; excavation and backfill of anchor trench; and miscellaneous site grading and berm construction. The Contractor shall include the dollar amount associated with all earthwork in his Lump Sum Bid amount.

B. Removal and replacement of unsuitable foundation material and subgrade stabilization measures directed by the Owner's Representative will be paid for on a time and material basis.

1.06 COORDINATION

Existing utilities or other plant facilities shall not be interrupted, except when permitted in writing by the Owner's Representative and then only after acceptable

temporary services have been provided. A minimum 48-hour notice shall be provided prior to proceeding with an approved temporary interruption.

1.08 SUBMITTALS

A. Materials Handling Plan.

A materials handling plan shall be submitted for construction and protection of the low permeability soil liner. The plan shall describe the following:

1. Processing and placement of the low permeability soil type, model number, weight, and critical dimensions of equipment to be used for soil processing, compaction, scarification, and smooth rolling;
2. Method of protecting low permeability soil from changes in moisture content and freezing after placement.

B. Construction Access Ramp Layout.

Layout drawings shall be submitted showing alignment, profile, and typical section of the construction access ramps from the haul road into the bottom of the Gypsum Management Facility excavation. The minimum width of the ramp shall be 50 ft., and the longitudinal grade shall not exceed 8 percent.

PART 2. PRODUCTS

2.01 MATERIALS

A. Earth Fill Material

Earth Fill Material shall consist of a mixture of clay, silt, sand, and gravel-sized particles obtained from previously constructed subsoil stockpiles. These materials can be used separately or mixed as required for best results. When placed, Embankment Material shall have a USCS classification of SM, ML, or CL and shall be uniform. This material shall be free of ice, snow, organic matter, rubbish, and debris. Coarse-grained particles shall be well dispersed to prevent the development of segregated pockets or zones with insufficient fine material to fill the interstices.

B. Soil Liners

The Soil Liner for the Gypsum Management Facility is considered a Clay Liner, and shall be soil classification CL, CL-ML, or CH. The material shall be free of roots, debris, organic or frozen material, and shall have a maximum clod size no greater than the length of the compactor foot for the compaction equipment proposed by the Contractor. When compacted, the material shall have a hydraulic conductivity of less than 1×10^{-4} cm/sec.

C. Soil Stabilizers and Moisture Conditioning Agents

Additives to accelerate drying or to improve stability and workability of soil shall not be permitted unless approved in writing by the Owner's Representative.

2.02 EQUIPMENT

A. Compaction Equipment

1. Tamping foot rollers

Compaction equipment shall consist of tamping foot rollers which have a minimum weight of 40,000 pounds. At least one tamping foot shall be provided for each 110 square in. of drum surface. The length of each tamping foot, measured from the outside surface of the drum, shall be at least 1 in. longer than the loose lift thickness.

2. Steel-Wheeled Rollers

Equipment used to produce a smooth compacted surface shall be a smooth, non-vibratory steel wheeled roller weighing not less than 1,000 lb. per lineal ft.

B. Scarification Equipment

Discs, rotor tillers, or other equipment used to scarify the surface shall be capable of uniformly disturbing the upper 6 in. of surface to provide good bonding between lifts.

C. Mixing and Spreading Equipment

Discs, harrows, and motor graders or other similar equipment shall be available at the site for use in spreading, mixing, and drying Compacted Subsoil Stockpile Material.

PART 3. EXECUTION

3.01 PREPARATION

A. Control of Work

Benchmarks, monuments, and other reference points shall be maintained throughout the work area.

B. Utility Location

Before starting excavation, the location and extent of underground utilities in the work area shall be established.

3.02 EXCAVATION

A. General

Excavation consists of removal and redistribution of material encountered when establishing required grade and subgrade elevations. The Contractor shall be responsible for dewatering, protection, shoring, and disposal of excavated materials as necessary to complete the excavation.

B. Procedures

Excavation may be accomplished by any method and by use of any equipment that is suitable to the work, except that blasting will not be permitted. Based on previous construction experience at the site, it is recommended that excavation to the foundation grade be completed as far in advance of low permeability soil placement as possible to allow the foundation surface to dry and form a "crust" capable of sustaining compactive effort.

C. Overexcavation

All excavation shall be performed to the lines and grades indicated on the plans. Any overexcavation or excess excavation not requested by the Owner's Representative shall be at the expense of the Contractor.

D. Disposal of Excavated Materials

Contractor shall utilize excavated material as stockpile materials for future use as specified in paragraph E.

E. Stockpile Requirements

1. Excavated clay and silty clay materials are to be stockpiled in the short-term subsoil stockpile area.
2. Excess excavated materials are to be stockpile in the areas designated on the drawings.
3. Materials not suitable for use as fill or backfill shall be disposed of onsite in the locations specified by the Owner's Representative.
4. Spread fill material for use by others, topsoil, and low permeability soil are to be stockpiled in layers not to exceed 1 ft loose thickness.
5. Tops of stockpiles are to be graded to ensure positive drainage. Side slopes for stockpiles shall be no steeper than 3H:1V.
6. Perimeter ditches are to be excavated to intercept runoff flowing toward stockpile areas and to route it to outlet locations approved by the Owner's Representative.

3.03 SUBGRADE PREPARATION

A. Areas to receive fill shall be proof rolled under the observation of the Owner's Representative. Soft, loose, weak, or wet materials shall be removed and replaced with compacted fill or stabilized with geotechnical fabric or geogrid as directed by the Owner's Representative. Joints, fractures, and moisture seeps shall be repaired, and local sand deposits, if present at foundation grade, shall be removed and backfilled with compacted fill material as directed by the Owner's Representative.

B. The Owner's Representative may recommend additional drying time for soft, wet subgrade that has not been exposed long enough to permit "crust" formation. If approved by the Owner's Representative, the Contractor may install, at his own expense, geotechnical fabric or geogrid to stabilize the wet subgrade and expedite construction.

C. No fill shall be placed until the subgrade has been examined and approved.

3.04 GENERAL FILL

A. Placement

1. Unless otherwise indicated on the plans, all fill shall be composed of Earth Fill Material.
2. Fill materials used in embankment construction shall normally be placed in lanes parallel to the embankment axis and shall be placed in conformance with the lines, grades, and slopes as indicated on the plans. Placement of fill materials in lanes which are not parallel to the embankment will be allowed only where working room is too restricted for normal placement as determined by the Owner's Representative.
3. Fill shall be spread in approximately flat layers in such a manner as to obtain lifts of relatively uniform thickness without spaces between successively deposited loads. Segregation shall be prevented during placing and spreading. Hauling equipment shall be routed across the fill in such a way as to promote uniform compaction and to prevent the formation of ruts.
4. The maximum compacted thickness of each lift shall not exceed 8 in. where heavy compaction equipment will be used. The maximum compacted thickness shall not exceed 3 in. where power tampers or similar smaller equipment will be used. It may be necessary to reduce the thickness of lifts in order to obtain the required minimum density.
5. Where compacted earth fill is to be placed against existing slopes, each lift shall be keyed into existing slope by removing existing slope material in steps as each new lift is placed.
6. The surface of the fill shall be kept reasonably smooth. The fill surface shall be sloped transverse to the axis of the embankments to allow drainage. If the compacted surface is, in the opinion of the Owner's Representative, too smooth or too dry to bond properly with the

succeeding lift, it shall be roughened by scarifying, light discing, or other acceptable means, and it shall be sprinkled before the succeeding lift is placed thereon. If the surface becomes rutted or uneven subsequent to compaction, it shall be flattened and leveled before placing the next lift. This extra work shall be at the Contractor's expense.

7. Fill operations shall be suspended during periods of extended wet weather. Upon resuming operations, all fill materials that are excessively wet or soft shall be reprocessed in place or removed and stockpiled for reprocessing. The removal of soft material shall be carried to such depth as is necessary to expose firm materials. Fill shall not be placed on frozen surfaces.
8. When filling operations at any section will be suspended for any period in excess of 12 hours or in wet weather, the surface of the fill shall be rolled smooth to seal it against excessive absorption of moisture and to facilitate runoff. Prior to resuming fill placement and compaction, the fill surface shall be scarified and/or disced and moisture conditioned as required.
9. The Contractor will receive no additional compensation for any removal, reprocessing, stockpiling, recompaction, wasting, or similar operation related to suspensions or conditions due to weather or other causes unless caused by the Owner.
10. Earth fill access ramps shall not be constructed within the limits of the compacted embankments without prior approval. When such ramps are approved, they shall be constructed of low permeability soil (in-board of the perimeter berm) or compacted fill (out-board of the perimeter berm).

B. Compaction -

1. Fill materials shall be compacted to a dry density equal to or greater than the following:

   a. The Gypsum Management Facility: 95 percent of the maximum dry density obtained from the Standard Proctor Test, ASTM D698.

   In order to insure uniform coverage and to facilitate construction inspection and control, the compaction of each layer shall proceed in a systematic, orderly, and continuous manner. Rolling shall be parallel to the embankment axis, except where there is insufficient working room for such operations.

2. The moisture content of all earth fill materials shall be as uniform as practicable throughout each lift. Fill shall be compacted at a moisture content that is no more than 2 percent below and no more than 2 percent above optimum moisture content.
3. Moisture conditioning of fill materials shall be performed by discing, harrowing, plowing, blading, or other suitable means prior to excavation. Moisture conditioning where the fill is placed shall be limited to minor adjustments prior to compaction. Addition of moisture shall be by using a

pressure spray bar mounted in front of or to one side of a water tanker so that water will not collect in the tracks of the truck.

4. Compaction of fill materials shall not commence if the moisture content is not within the specified limits. Any materials that are placed but not compacted prior to drying out or becoming too wet shall be removed and replaced or reprocessed at the Contractor's expense.
5. No admixtures as drying agents or to improve the workability of the soil will be allowed.

3.05 SOIL LINERS

A. Sources

The Soil Liners for the Gypsum Management Facility shall be constructed from Soil Liner Material as described in paragraph 2.01(B) above.

B. Test Liner

A compacted low permeability soil test liner of the actual full scale liner shall be constructed in accordance with the following requirements:

1. Test liner will be constructed from the same soil material sources, to the same design specifications, and with similar equipment and procedures as are proposed for the full scale liner.
2. Test liner will be at least four times the width of the widest piece of equipment to be used.
3. Test liner will be no less than 100 ft long to allow equipment to reach normal operating speed before reaching a central 40-ft test area.
4. Test liner will be constructed with maximum 8-in. compacted lifts for a total liner thickness of 3 ft.
5. Test liner will be tested by the Owner's Testing Consultant as described below for each of the following physical properties:

    a. Multiple two-stage Boutwell permeameter tests will be used on the test liner to determine the hydraulic conductivity. The two-stage field hydraulic conductivity test is a falling head infiltration test conducted in a cased borehole, typically 4 in. in diameter. The test is cited in the U.S. EPA Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities, September 1993 (EPA/600/R-93/182).
    b. Undisturbed samples (Shelby tubes) will be tested in the laboratory for hydraulic conductivity to determine if there is a statistical correlation to the field testing results.
    c. Other engineering parameters including, but not limited to, particle size analysis, liquid limits, plasticity, water content, and in-place density that are needed to evaluate the full scale liner will be determined.

6. Additional test fills will be constructed for each new soil type or for each change in equipment or procedures.

C. Full Scale Liner Construction:

1. Full scale liner construction shall not be commenced until the results of the in-place compaction testing and Boutwell permeameter tests on the test liner confirm that the construction procedures and specified compaction requirements produce a in-situ hydraulic conductivities as specified in Section 2.01(B) above.
2. The liner shall be constructed according to the placement and compaction requirements for general fill, except the material shall be compacted to a density of no less than 95 percent of maximum dry density at a moisture content between 100 percent and 105 percent of optimum. The same compaction procedures, such as number of passes, speed, and compaction equipment used on construction of the test liner shall be used. Grade stakes shall not be driven into the clay liner.
3. The completed liner shall be smooth rolled to limit moisture loss and promote run-off of surface water. Moisture content shall be maintained within the specified range and erosion or other damage that occurs in the soil liner shall be repaired as directed by the Owner's Representative until the geosynthetic liner is placed.
4. Repair of any rutting or other damage caused by the installation of the geosynthetic liner will be paid for on a time and material basis.
5. Voids created in the clay barrier layer during construction (including, but not limited to, penetrations for test samples, and other penetrations necessary for construction) shall be repaired by removing material that does not meet the requirements for low permeability soil, placing low permeability soil backfill, granular or pelletized bentonite, or a mixture of bentonite and low permeability soil in lifts no thicker than 2 in. and tamping each lift with a steel rod. Each lift shall be tamped a minimum of 25 times altering the location of the rod within the void for each blow. Other ruts and depressions in the surface of the lifts shall be scarified, filled, and then compacted to grade.

3.06 CUSHION DIRT

Cushion Dirt to be placed beneath the upper High Density Polyethylene (HDPE) Geomembrane is to be placed to the specifications for General Fill in Section 3.04 above, except fill materials for Cushion Dirt shall be compacted to a dry density equal to or greater than 90 percent of the maximum dry density obtained from the Standard Proctor Test, ASTM D698.

3.07 ANCHOR TRENCH CONSTRUCTION

A. Gypsum Management Facility

1. A ledge at the bottom of the anchor trench elevation shall be excavated. Low permeability soil shall be placed and compacted on the ledge as shown on the anchor trench details in the plans.

2. The anchor trench shall be excavated to the depth and width shown on the anchor trench details. The front edge of the trench shall be rounded to eliminate any sharp corners that could cause excessive stress to the geosynthetic liners. Loose soil shall be removed or compacted into the floor of the trench.

3. Subsequent to Geosynthetic Clay Liner (GCL), Bottom HDPE Geomembrane and Geotextile Cushion installation, it shall be verified that the liners cover the entire trench floor, but do not extend up the back of the trench wall. After the liner installation in the trench has been inspected and approved by the Owner's Representative, the trench shall be backfilled with 1 ft. of low permeability soil. The backfill shall be deposited and compacted according to the requirements for general fill in such a manner as to prevent damage to the GCL and liner materials.

4. Subsequent to installation of separation geotextile on top of drainage layer, it shall be verified that the fabric extends across the top of the initial 1 ft layer of trench backfill, but does not extend up the back of the trench wall. After the fabric installation in the trench has been inspected and approved by the Owner's Representative, the trench shall be backfilled with 1 ft of low permeability soil. The backfill shall be deposited and compacted according to the requirements for general fill in such a manner as to prevent damage to the geotextile fabric.

5. Subsequent to installation of the upper HDPE Geomembrane, verify that the liner extends across the top of the initial 1 ft layer of trench backfill, but does not extend up the back of the trench wall. After the liner installation in the trench has been inspected and approved by the Owner's Representative, backfill the remainder of the trench to the top of the low permeability soil layer. Deposit and compact the backfill according to the requirements for general fill in such a manner as to prevent damage to the HDPE Geomembrane.

3.08 TESTING

A. Construction Quality Assurance (CQA) compaction and permeability tests will be made by the Owner's Testing Consultant during the progress of the work as indicated in Appendix 2. The Contractor shall cooperate with the Testing Consultant and allow such tests to be performed.

B. If tests indicate that an area of fill or low permeability soil liner does not meet the specified requirements, additional tests shall be performed to determine the extent of non-compliance. The Contractor shall moisture condition and recompact that area until a passing test result is obtained.

3.08 FINISH GRADING

All excavated and filled areas shall be fine graded and leveled to provide a smooth finish free of debris, foreign matter, objectionable stones, clods, lumps, pockets, or high spots, properly drained and true to indicated elevations. Finish grading shall be only near completion of work or when requested. Any portions of the berm damaged by construction shall be restored. The berm ditch shall be finished to design grade, and the ditch side slopes shaped and trimmed to provide a uniform ditch cross section.

3.09 CONSTRUCTION TOLERANCES

A. The foundation grade and finished earthwork grades shall be no more than 0.4 ft below and not above plan grade.

B. The minimum thickness of low permeability soil layer shall be 3 ft.

END OF SECTION ●2200

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DIVISION 2 - SITE WORK
Section 02275 - Riprap

PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to the placement of riprap for erosion control.

1.02 RELATED SECTIONS

The following section contains items which are related to the work in this section:

02200 - Earthwork

1.03 REFERENCES

Specified references or cited portions thereof, current at date of bidding documents unless otherwise specified, govern the work.

A. Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007.

1.04 SUBMITTALS

Product Data: Provide quarry name and material type prior to delivery.

PART 2. PRODUCTS

2.01 MATERIALS

A. Stone Riprap and Bedding materials according to Article 1005.01 of the Illinois Standard Specifications for Road and Bridge Construction.

B. Filter Fabric material for Stone Riprap according to Article 1080.03, with an AOS (Apparent Opening Size) as indicated on the plans.

C. Supplier shall be listed on the current IDOT Approved Aggregate Source List.

D. Gradation as indicated in the drawings. Quality shall be Class A.

PART 3. EXECUTION

3.01 CONSTRUCTION REQUIREMENTS

A. Stone Riprap and Bedding shall be installed in accordance with Section 281 of the Illinois Standard Specifications for Road and Bridge Construction for the placement of Stone Riprap. Measurement and payment provisions of Section 281 shall not apply.

B. Filter Fabric for Stone Riprap shall be installed in accordance with Section 282 of the Illinois Standard Specifications for Road and Bridge Construction.

C. The Owner's Representative shall be allowed to visually inspect Riprap for compliance with specifications prior to placement.

END OF SECTION 02275

DIVISION 2 – SITEWORK
Section 02315 – Granular Materials

PART 1. GENERAL

1.01 DESCRIPTION

A. Gypsum Management Facility

This section pertains to the following:

1. Furnishing and placing granular drainage materials for the drainage layer and leachate collection system.
2. Furnishing and placing coarse aggregate for encasement of the ring drain collection piping.
3. Furnishing and installing materials for roadbed construction related to the Gypsum Management Facility access roads and the McKinley Road relocation.
4. Recycle Pond Drain.

1.02 RELATED SECTIONS

The following sections contain items which are related to the work in this section:

1. 02300 - Earthwork
2. 02373 – Geotextiles
3. 02640 - HDPE Piping

1.03 REFERENCES

The following references, or cited portions thereof, govern the work:

1. Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007.
2. American Society for Testing and Materials (ASTM):
   a. ASTM D 75 (2003) Practice for Sampling Aggregates.
   b. ASTM D 422 (1963; R 2002) Test Method for Particle-Size Analysis of Soils.
   c. ASTM D 2434 (1968, R 2000) Test Method for Permeability of Granular Soils (Constant Head).
   d. ASTM D 3042 (2003) Test Method for Insoluble Residue in Carbonate Aggregates.
   e. ASTM C 1260 (2005) Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).

3. American Geological Institute (AGI). Geoscience Handbook AGI Data Sheets, 4th Edition.

1.04 MEASUREMENT AND PAYMENT

The Contractor shall be responsible for estimating the extent of granular materials required to complete the work including, but not limited to, construction of drainage layer, encasement of leachate collection piping, and road-bed construction. The Contractor shall include the dollar amount associated with furnishing and placing all granular materials in his Lump Sum Bid amount.

1.05 COORDINATION

A. The geosynthetic liner shall be covered with granular materials as soon as practicable after a section of liner has been approved by the Owner's Representative.

1.06 SUBMITTALS

A. Product Data:

1. Aggregate source list: Submit a list of proposed aggregate sources.

2. Shipping Tickets: Submit shipping tickets for the granular materials delivered to the site. Shipping tickets shall be according to paragraph 1004.01f of the IDOT Standard Specifications.

B. Test Reports.

1. Submit results of grain size analysis (ASTM D422) and hydraulic conductivity testing (ASTM D2434) for gradations established by the Contractor that provide the specified hydraulic conductivity. Test results are required for each proposed source and gradation. Submit test results for each source demonstrating compliance with reactivity, soundness, and abrasion requirements specified herein.

C. Samples:

1. Submit one sample per source for each gradation proposed for use on the project. Samples shall be at least one pound and shall be obtained and shipped according to ASTM D75. Submit samples at least 15 days prior to starting construction of the drainage layer and coarse aggregate encasement for leachate piping.

1.07 STORAGE AND HANDLING

A. Storage and handling of granular materials shall be according to paragraph 1004.01e of the IDOT Standard Specifications.

1.01

PART 2. PRODUCTS

2.01 MATERIALS

A. General

1. Unless otherwise approved by the Owner's Representative, granular materials shall be obtained from sources listed on the current IDOT Approved Aggregate Source List (www.dot.il.gov\materials\approvedaggregatesources.pdf).
2. Coarse Granular materials shall be meet the Description of Gravel, as described in Section 1004.01(a)(1) of the IDOT Standard Specifications, and shwll be spherical to sub-discoidal, sub-rounded to well rounded particles as defined by AGI Data Sheet, 4th Edition, Sheet 8.4 – Comparison Charts for Estimating Roundness and Sphericity.
3. Granular materials shall experience no more than 15 percent carbonate loss per ASTM D3042.
4. Granular materials shall be free of deleterious material, and shall meet the Na_2SO_4 soundness and Los Angeles Abrasion Specifications for Class B quality aggregate per paragraph 1004.01 of the IDOT Standard Specifications.
5. All material shall pass the 2 in. sieve, and no greater than 5 percent shall be retained on the No. 200 sieve.
6. Granular materials shall be innocuous to alkali-silica reactivity, and shall exhibit internal expansions of less than 0.10 percent at 16 days after casting as determined by ASTM C 1260.

B. Gypsum Management Facility Granular Materials

1. Granular Materials for Drainage Layer

Gradation for granular material for drainage layer shall be as required to provide a minimum hydraulic conductivity (ASTM D2434) of 1×10^{-3} cm/sec.

2. Coarse Aggregate around Ring Drain Collection Piping

Coarse Aggregate used to encase the ring drain collection piping shall be IDOT Gradation CA 7 material as outlined in Article 1004.01 of the IDOT Standard Specifications for Road and Bridge Construction.

3. Filter Sand

Filter Sand used for protective cover over the ring drain collection system shall be IDOT Gradation FA 1, Class B or better according to Article 1003 of the IDOT Standard Specifications for Road and Bridge Construction.

4. Aggregate Base Course, Type B

Aggregate Base Course, Type B used for base material for all new access roads and shall be IDOT Gradation CA 2, in accordance with Section 1004.04 of the IDOT Standard Specifications for Road and Bridge Construction. The material shall originate from an IDOT approved source. The Na_2SO_4 soundness and Los Angeles Abrasion Specifications for Class B quality aggregate per paragraph 1004.01 of the IDOT Standard Specifications shall not apply.

5. Aggregate Surface Course, Type B

Aggregate Surface Course, Type B used for surface material for all new access roads and the McKinley Road relocation shall be IDOT Gradation CA 6, in accordance with Section 1004.04 of the IDOT Standard Specifications for Road and Bridge Construction. The material shall originate from an IDOT approved source. The Na_2SO_4 soundness and Los Angeles Abrasion Specifications for Class B quality aggregate per paragraph 1004.01 of the IDOT Standard Specifications shall not apply.

2.02 EQUIPMENT

Equipment for spreading and compacting granular materials shall be low ground pressure equipment to prevent damage to the underlying geosynthetic liners.

PART 3. EXECUTION

3.01 PROTECTION OF GEOSYNTHETICS

A. Protection of the geosynthetic liners is critically important. Approved geosynthetic liner shall be covered by granular material as soon as practicable. Granular material shall be placed to a minimum thickness of 1 ft before any heavy equipment or loaded trucks are allowed on the lined area.

B. No equipment will be permitted directly on the geosynthetic liner.

C. Any damage to the geosynthetic liner system shall be repaired, as directed by the Owner's Representative, at the expense of the Contractor.

3.02 GRANULAR DRAINAGE LAYER (GYPSUM MANAGEMENT FACILITY)

A. Placement on Cell Floor

1. The granular material shall be back-dumped on the geotextile cushion fabric in a sequence of operations beginning at the perimeter of the liner on the cell floor.
2. Placement of material on the fabric shall be accomplished by spreading dumped material off of previously placed material with a bulldozer blade or endloader, in such a manner as to prevent tearing or shoving of the cloth. Dumping of material directly on the fabric will only be permitted to establish an initial working platform. No vehicles or construction equipment shall be allowed on the fabric prior to placement of the granular blanket to a minimum thickness of 1 ft.

B. Placement on Cell Side Slopes

1. Placement of granular material on cell side slopes shall be accomplished using methods and equipment similar to that specified for placement of material on cell floor.
2. The Contractor may place gypsum underlain with separation geotextile fabric to buttress the granular material on the slope:

    a. The Construction Quality Assurance (CQA) survey to certify thickness of drainage material shall be completed within the footprint of the gypsum stack before gypsum placement.

b. Separation geotextile fabric shall extend beyond the toe of gypsum buttress a sufficient distance to prevent contamination of the granular drainage layer. See Sections 02373 and 02320 for construction of separation geotextile fabric and gypsum, respectively.

3.04 COARSE AGGREGATE FOR ENCASEMENT OF RING DRAIN COLLECTION PIPING (GYPSUM MANAGEMENT FACILITY)

A. The geotextile filter fabric for encasement of leachate collection piping shall be placed on the approved cushion geotextile fabric according to Section 02373 – Geotextiles.

B. The coarse aggregate shall be placed on the encasement fabric to the width shown on the plans to the level of the bottom of the ring drain collection piping.

C. Course aggregate shall be placed and tamped along the pipe during pipe installation. The coarse aggregate shall be placed longitudinally along the pipe in lifts not to exceed 8 in. thick to a height of at least the center of the pipe. The aggregate shall be maintained at equal elevation on each side of the pipe, and the first lift of material shall be mechanically tamped to ensure that the space under the pipe is completely filled. The top of pipe shall not be covered until the CQA survey certifies leachate piping grade has been completed.

C. After the CQA survey has been completed, coarse aggregate material shall continue to be placed in lifts not to exceed 8 in. thick, as specified in the previous paragraph until the minimum cover height shown in the plans is attained.

D. The running of trucks or heavy equipment over leachate piping shall be avoided until there is at least a 12 in. cover of Filter Sand over the completed geotextile envelop. Temporary ramps no steeper than 10H:1V transverse to the piping shall be provided for temporary equipment crossings until the first lift of gypsum is placed.

3.03 ROADWAY CONSTRUCTION

A. Prepare the roadway subgrade as shown on the plans, in accordance with Section 02200 – Earthwork.

B. Furnish Geotechnical Fabric for Ground Stabilization in accordance with Section 02373 – Geotextiles.

C. Furnish Aggregate Base Course, Type B in accordance with Article 351 of the IDOT Standard Specifications for Road and Bridge Construction.

D. Furnish Aggregate Surface Course, Type B in accordance with Article 402 of the IDOT Standard Specifications for Road and Bridge Construction.

3.04 TESTING

A. CQA gradation and permeability tests will be made by the Owner's Testing Consultant during the progress of the work as indicated in Appendix 2. The Contractor shall cooperate with the Testing Consultant and allow such tests to be performed.

B. If tests indicate that an area of granular material or coarse aggregate does not meet the specified requirements, then the Contractor shall remove the material and replace it with suitable material.

3.05 FINISH GRADING

The granular drainage layer shall be fine graded to provide a smooth finish before a CQA survey of the completed portion of the drainage layer is requested. Ruts or erosion damage shall be repaired before placement of the separation geotextile fabric.

3.06 CONSTRUCTION TOLERANCES

The minimum thickness of drainage layer shall be 1 ft.

END OF SECTION 02315

PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to furnishing and installing geotextile fabrics on prepared surfaces.

1.02 RELATED SECTIONS

The following sections contain items which are related to the work in this section:

1. 02300 - Earthwork
2. 02315 - Granular Materials
3. 02800 – HDPE Geomembrane

1.03 REFERENCES

The following references, or cited portions thereof, govern the work:

1. Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007.
2. American Society for Testing and Materials (ASTM):
    a. ASTM 3776 (1996; R 2002) Standard Test Method for Mass per Unit Area (Weight) of Fabric;
    b. ASTM D 3786 (2001) Test Method for Hydraulic Bursting Strength of Textile Fabrics – Diaphragm Bursting Strength Tester Method;
    c. ASTM D 4533 (2004) Test Method for Trapezoid Tearing Strength of Geotextiles;
    d. ASTM D 4632 (1991; R 2003) Test Method for Grab Breaking Load and Elongation of Geotextiles;
    e. ASTM D 4751 (2004) Test Method for Determining Apparent Opening Size of Geotextile;
    f. ASTM D 4833 (2000) Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products;
    g. ASTM D 4873 (2002) Guide for Identification, Storage, and Handling of Geosynthetic Rolls;
    h. ASTM D 4884 (1996; R 2003) Test Method for Strength of Sewn or Thermally Bonded Seams of Geotextiles;
    i. ASTM D5261-92(2003) Standard Test Method for Measuring Mass per Unit Area of Geotextiles

j. ASTM D6241-04 Standard Test Method for the Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe

1.04 MEASUREMENT AND PAYMENT

A. The Contractor shall be responsible for estimating the extent of geotextile fabric required to complete the work including fabric for laps, anchorage, repairs, and samples for Construction Quality Assurance (CQA) testing. The Contractor shall include the dollar amount associated with all geotextile construction in his Lump Sum Bid amount, except as specified in paragraph B.

B. Geotextile fabric for ground stabilization, when directed by the Owner's Representative, will be paid for on a time and materials basis.

C. No additional payment will be made for geotextile fabric for ground stabilization installed at the Contractor's discretion.

1.05 SUBMITTALS

A. Product Data

1. The manufacturer's list of guaranteed properties for each geotextile fabric or geogrid proposed for use on the project shall be submitted.
2. The manufacturer's installation guidelines shall be submitted.

B. Samples

Samples of geotextile fabrics shall be submitted for CQA prequalification testing. Sample size and sampling frequency are specified in Appendix 2.

C. Inventory

A copy of the roll inventory that identifies, as a minimum, manufacturer or supplier, product or style number, roll number, width, and length of roll as identified on the roll label shall be submitted.

1.06 STORAGE AND HANDLING

Geotextiles shall be stored and handled according to ASTM D4873.

PART 2. PRODUCTS

2.01 MATERIALS

A. Geotextile Fabric for Liner System

Geotextile fabrics for use in the cell liner system shall consist of non-woven filaments of polypropylene, polyester, or polyethylene. Stabilizers and/or inhibitors shall be added to the base polymer if necessary to make the filaments resistant to deterioration caused by ultraviolet light and heat exposure. Reclaimed or recycled fibers or polymer shall not be added to the formulation. Non-woven fabric may be needle-punched, heat-bonded, or a combination thereof. The filaments shall be dimensionally stable (i.e., filaments shall maintain their relative position with respect to each other) and resistant to delamination. The edges of the geotextile shall be finished to prevent the outer fiber from pulling away from the geotextile. The filaments shall be free from any chemical treatment or coating that might significantly reduce porosity and permeability.

Fabric shall have the following physical properties:

Physical Properties[1]	4 oz. (Separation)	6 oz. (PWRS)	16 oz. (CA Envelope)
Mass/Unit Area ($oz./yd^2$) ASTM D5261	4.0	6.0	16.0
Grab Tensile Strength (lb.) ASTM D4632	115	160	380
Grab Elongation (%) ASTM D4632	50	50	50
Puncture Strength (lb.) ASTM D4833	65	85	240
Puncture (CBR) Strength (lb.) ASTM D6241	310	410	1025
Mullen Burst Strength (psi) ASTM D3786	210	280	750
Trapezoidal Tear Strength (lb.) ASTM D4533	50	60	150
Width (ft.)	15	15	15
Apparent Opening Size (AOS) Max. US Std. Sieve No. ASTM D4751	70	70	100
UV Resistance[2] (%) ASTM D4355	70	70	70
Roll Width (ft.)	15	15	15

Notes:

(1) All Values listed are Minimum Average Roll Values (MARV) unless otherwise noted, calculated as the typical minus two standard deviations.

(2) UV Resistance is a minimum value and not a MARV. Evaluation to be on 2.0 inch strip tensile specimens after 500 hours exposure.

A. Cushion Geotextile Fabric.

Cushion geotextile fabric shall consist of non-woven filaments of polypropylene, polyester, or polyethylene. Stabilizers and/or inhibitors shall be added to the base polymer if necessary to make the filaments resistant to deterioration caused by ultraviolet light and heat exposure. Reclaimed or recycled fibers or polymer shall not be added to the formulation. Non-woven fabric may be needle-punched, heat-bonded, or a combination thereof. The filaments shall be dimensionally stable (i.e., filaments shall maintain their relative position with respect to each other) and resistant to delamination. The edges of the geotextile shall be finished to prevent the outer fiber from pulling away from the geotextile. The filaments shall be free from any chemical treatment or coating that might significantly reduce porosity and permeability.

Fabric shall have the following physical properties:

Physical Properties[1]	**10 oz. (Cushion)**
Mass per unit area (oz/yd^2) ASTM D5261	10
Grab Tensile Strength (lb.) ASTM D4632	230
Grab Tensile Elongation (%) ASTM D4632	50
Trapezoidal Tear Strength (lb.) ASTM D4533	95
Puncture (CBR) Strength (lb.) ASTM D6241	700
Puncture (CBR) Elongation (in.) ASTM D6241	1.5
UV Resistance[2] (%) ASTM D4355	70
Apparent Opening Size (Max.) (AOS) Sieve No. - ASTM D4751	---
Roll Width (ft.)	15

Notes:
(1) All Values listed are Minimum Average Roll Values (MARV) unless otherwise noted, calculated as the typical minus two standard deviations..
(2) UV Resistance is a minimum value and not a MARV. Evaluation to be on 2.0 inch strip tensile specimens after 500 hours exposure.

B. Geotechnical Fabric for Ground Stabilization

Geotechnical fabric for ground stabilization shall conform to Article 1080.02 of the IDOT Standard Specifications for Road and Bridge Construction.

C. Thread for Seams

High strength thread should be used such that seam test should conform to ASTM D4884. The thread shall meet the chemical, ultraviolet, and physical requirements of the geotextile, and the color shall be different from that of the geotextile.

D. Securing Devices

Pins, staples, and other devices that project through the geotextile fabric are not permitted for fabrics installed above the geomembrane. Sandbags, stone, or other appropriate means approved by the Owner's Representative shall be used to prevent movement of the geotextile.

2.02 EQUIPMENT

A. Equipment for spreading and compacting granular materials shall be low ground pressure equipment to prevent damage to the underlying geosynthetic liners.

PART 3. EXECUTION

3.01 SAMPLES FOR CQA TESTING

A. Geotextile fabric samples shall be obtained, identified and packaged from rolls designated by the Owner's Representative according to ASTM D4873.

B. Samples shall be 3 ft. wide by the full roll width.

3.02 BASE PREPARATION

A. Surface on which the geotextile will be placed shall be prepared to a relatively smooth surface condition, and shall be free from obstruction, debris, depressions, erosion features, or any irregularities that would prevent continuous, intimate contact of the geotextile with the entire surface. Rills, gullies, and ruts must be graded out of the surface before geotextile placement. Areas on which geotextile are to be placed shall be graded and/or dressed in accordance with Section 02200 – Earthwork and Section 02315 – Granular Drainage Materials. Immediately prior to placing the geotextile, the prepared base will be inspected by the Owner's Representative, and no material shall be placed thereon until that area has been approved.

B. Geotextile cushion fabric will be installed directly on the geosynthetic liner. Jointly inspect the liner with the Owner's Representative before commencing fabric installation each day. Notify the Owner's Representative promptly of any damage or defects observed in the liner as fabric installation progresses. Do not place fabric in the damaged or defective area until the liner has been repaired and

approved by the Owner's Representative. Submit a daily inspection report identifying the area of fabric placement and certifying that there were no visible defects in the area of fabric placement.

C. Do not run heavy vehicle traffic directly on the geosynthetic liner or cushion geotextile. Use vehicles and equipment as specified in paragraph 2.02 to transport and deploy fabric on the liner. Operate the equipment with care, and place protective cover over the geomembrane, if necessary, to avoid damaging the liner. Route traffic and personnel over installed cushion fabric and use the installed fabric as a working platform to the greatest extent possible.

3.03 INSTALLATION

A. General Requirements:

1. Geotextile fabric shall be unrolled and laid out following these requirements to the greatest extent practical:

   a. Orient panels with the longest dimension parallel to the slope.
   b. Minimize the number of seams in corners and odd-shaped areas.
   c. Extend panels on slopes a minimum of 5 ft onto a horizontal surface.

   Geotextile panels shall be unrolled using methods that will not damage the fabric and will protect underlying surface from damage. While unrolling, the geotextile fabric shall be visually inspected for imperfections and faulty or suspect areas marked. Ballast shall be placed on fabric to prevent wind uplift. Expansion and contraction should be allowed for by leaving slack.

   Heavy vehicle traffic shall not be run directly on geotextile fabric. Fabric in areas of heavy traffic shall be protected with protective cover over the fabric.

2. Laps

   Individual panels of geotextile fabric shall be lapped according to manufacturer's instructions and as specified herein. Provide a minimum overlap of 3 in. unless otherwise specified herein or in the plans. Shingle overlaps so that water or other material cannot run down the slope between the two layers of fabric.

3. Field Seams

Continuously sew all laps on slopes steeper than 10H:1V. This requirement does not apply to the heavy geotextile fabric for envelopment of coarse aggregate around leachate piping.

4. Defects and Repairs

Examine the installed geotextile fabric for defects, holes discontinuous seams, puckered or separated laps, etc. Repair defective laps and seams. Patch holes and defects according to manufacturer's recommendations and as directed by the Owner's Representative. Do not cover suspect or patched areas until they have been inspected and approved by the Owner's Representative.

B. Geotextile Fabric for Separation

1. Use low ground pressure equipment to avoid rutting the granular material.
2. Horizontal seams (parallel to top of slope) will be permitted on cell side slopes to facilitate staged construction of the drainage layer on the side slope.
3. Extend separation geotextile fabric into and across the bottom of the anchor trench and complete backfill of the trench according to Section 02200.

C. Geotextile Fabric for Coarse Aggregate Envelope

1. Geotextile for coarse aggregate envelope will be installed directly on the cushion fabric. Remove any foreign materials from the cushion fabric within the footprint of the coarse aggregate leachate piping encasement before installing the geotextile envelope. Place sufficient width to completely envelop the coarse aggregate and provide a longitudinal lap of at least 6 in.
2. After the coarse aggregate encasement has been completed, according to Section 02315, wrap the geotextile around the mounded aggregate, and cover the lap with at least 6 in. of material before permitting vehicle or equipment on the fabric.
3. Any ballast material other than coarse aggregate, according to Section 02315, that is placed within the envelope will require removal during coarse aggregate construction.

D. Geotechnical Fabric for Ground Stabilization

1. Install Geotechnical Fabric for Ground Stabilization in accordance with Section 210 of the IDOT Standard Specifications for Road and Bridge Construction.

2. If approved by the Owner's Representative, the Contractor may, at his own expense, install geotextile or geogrid for ground stabilization outside the limits designated by the Owner's Representative.
3. Submit as-built drawings that clearly delineate limits and type of ground stabilization.

3.04 PROTECTION

A. Protect installed fabric until it is covered by at least 1 ft. of overlying material.

B. Any damage to the geotextile during its installation or during placement of overlying materials shall be replaced by the Contractor at no cost to the Owner. Unless otherwise noted, the work shall be scheduled so that the covering of the geotextile with a layer of the specified material is accomplished within 14 calendar days after placement of the geotextile. Failure to comply shall require replacement of geotextile. The geotextile shall be protected from damage prior to and during the placement of overlying materials. Before placement of overlying materials, the Contractor shall demonstrate that the placement technique will not cause damage to the geotextile.

3.05 TESTING AND INSPECTION

A. Prequalification Testing

Geotextiles are subject to CQA testing by the Owner's Testing Consultant to verify conformance with the manufacturer's list of guaranteed properties according to Appendix 2. The Contractor shall provide samples as specified herein. If tests indicate nonconformance to the list of guaranteed properties, provide additional samples as directed by the Owner's Representative to determine the extent of the non-conformance. Any fabric that does not conform to the list of guaranteed properties shall be removed from the site.

B. Installed fabric shall be inspected by the Owner's Representative. No material shall be placed on the fabric, other than ballast, until the installation has been approved by the Owner's Representative. Ballast shall not obscure seams or significant length of unseamed laps. The Owner's Representative may require removal of ballast to inspect suspect areas.

C. If the Owner's Representative suspects that completed work has been damaged by construction methods that do not conform to the specifications, he may require removal of completed work to verify the integrity of the underlying materials. The Contractor shall bear the cost of removal and subsequent repair as directed by the Owner's Representative.

END OF SECTION 02373

DIVISION 2 - SITEWORK
Section 02376 – Geosynthetic Clay Liner

PART 1. GENERAL

1.01 DESCRIPTION

A. This section covers furnishing and installation of a reinforced needlepunched Geosynthetic Clay Liner (GCL) at the Gypsum Management Facility and the CCB Management Facility.

B. The work includes furnishing all equipment and materials, providing all labor, supervision, administration and management necessary to perform the work as specified herein and as shown on the plans.

1.02 RELATED SECTIONS

None.

1.03 REFERENCES

The following references, or cited portions thereof, govern the work

1. American Society for Testing and Materials (ASTM):

   a. ASTM D 4632 (1991; R 2003), Standard Test Method for Grab Breaking Load and Elongation of Geotextiles;
   b. ASTM D 4643 (2000), Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method;
   c. ASTM D 5084 (2003), Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter;
   d. ASTM D 5261 (1992; R 2003), Test Method for Measuring Mass Per Unit Area of Geotextiles;
   e. ASTM D 5321 (2002), Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method;
   f. ASTM D 5887 (2004), Test Method for Measurement of Index Flux Through Saturated Geosynthetic Clay Liner Specimens Using a Flexible Wall Permeameter;
   g. ASTM D 5888 (1995; R 2002), Practice for Storage and Handling of Geosynthetic Clay Liners;
   h. ASTM D 5889 (1997; R 2003), Practice for Quality Control of Geosynthetic Clay Liners;

i. ASTM D 5890 (2002), Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners;
j. ASTM D 5891 (2002), Test Method for Fluid Loss of Clay Component of Geosynthetic Clay Liners.

1.04 SUBMITTALS

A. With the bid, the Contractor shall furnish the following information:

1. Conceptual description of the proposed plan for placement of the GCL panels over the areas of installation.
2. GCL Manufacturer's Quality Control (MQC) Plan for documenting compliance with Sections 2.01 and 2.02 of these specifications.
3. GCL manufacturer's historical data for reinforced GCL of a) 10,000-hour creep shear testing per Section 2.01 D, and b) seam flow data at 2 psi confining pressure per Section 2.01 E.
4. A copy of GCL manufacturer's International Standards Organization (ISO) Quality Certificate of Registration.
5. Statement of experience from the proposed GCL supplier.
6. Statement of experience from the proposed GCL installer.

B. At the Owner Representative's or Owner's request, the Contractor shall furnish:

1. A representative sample of the GCLs.
2. A project reference list for the GCL(s) consisting of the principal details of at least ten projects totaling at least 10 million sq. ft (100,000 sq. meters) in size.

C. Upon shipment, the Contractor shall furnish:

1. The GCL manufacturer's Quality Assurance/Quality Control (QA/QC) certifications to verify that the materials supplied for the project are in accordance with the requirements of this specification.
2. Inventory of materials received.

D. As installation proceeds, the Contractor shall submit certificates of subgrade acceptance, signed by the Contractor and Construction Quality Assurance (CQA) Inspector (see Sections 1.06 and 3.03) for each area that is covered by the GCL.

E. Warranty

After construction, the contractor shall submit material and installation warranty certificates.

1.05 QUALIFICATIONS

A. GCL Manufacturer must have produced at least 10 million sq. ft. (1 million sq. meters) of GCL, with at least 8 million sq. ft. (800,000 sq. meters) installed.

B. The GCL Installer must either have installed at least 1 million sq. ft. (100,000 sq. meters) of GCL, or must provide to the Engineer satisfactory evidence, through similar experience in the installation of other types of geosynthetics, that the GCL will be installed in a competent, professional manner.

1.06 CONSTRUCTION QUALITY ASSURANCE (CQA)

A. The Owner shall provide a third-party inspector for CQA of the GCL installation. The inspector shall be an individual or company who is independent from the manufacturer and installer and who shall be responsible for monitoring and documenting activities, related to the CQA of the GCL throughout installation.

B. Testing of the GCL as necessary to support the CQA effort shall be performed by a third party laboratory retained by the Owner and independent from the GCL manufacturer and installer.

WARRANTY

The geomembrane material shall be warranted, on a pro-rata basis against manufacturer's defects for a period of five (5) years from the date of liner installation. The installation shall be warranted against defects in workmanship for a period of (1) year from the date of liner completion.

PART 2. PRODUCTS

2.01 MATERIALS

A. Acceptable products for the GCL are GCL Bentomat® SDN, as manufactured by CETCO, 1350 West Shure Drive, Arlington Heights, Illinois 60004 USA (847-392-5800), or an engineer-approved reinforced needlepunched GCL material equal to Bentomat SDN.

B. The delineation of areas to receive GCL shall be agreed by the Installer and the Engineer prior to installation.

C. The GCL and its components shall have the properties shown in the GCL Certified Properties table at the end of this section.

D. The reinforced GCL shall have 10,000 hour test data for large-scale constant-load (creep) shear testing for related products under hydrated conditions. The

displacement shall be 0.13 in. (3.3 mm) or less at a constant shear load of 250 psf (12 kPa) and a normal load of 500 psf (24 kPa).

E. The reinforced GCL shall have seam test data from an independent laboratory showing that the seam flow with a grooved cut in one of the nonwoven geotextiles is less than 1×10^{-8} $m^3/m^2/s$ at 2 psi hydraulic pressure.

F. The minimum acceptable dimensions of full-size GCL panels shall be 150 ft. (45.7 m) in length. Short rolls [(those manufactured to a length greater than 70 ft. (21 meters) but less than a full-length roll)] may be supplied at a rate no greater than three (3) per truckload or three (3) rolls every 36,000 sq. ft. (3,500 sq. meters) of GCL, whichever is less.

G. A 6-inch (150 mm) overlap guideline shall be imprinted on both edges of the upper geotextile component of the GCL as a means for providing quality assurance of the overlap dimension. Lines shall be printed in easily visible, non-toxic ink.

2.02 PRODUCT QUALITY DOCUMENTATION

The GCL manufacturer shall provide the Contractor or other designated party with manufacturing QA/QC certifications for each shipment of GCL. The certifications shall be signed by a responsible party employed by the GCL manufacturer and shall include:

A. Certificates of analysis for the bentonite clay used in GCL production demonstrating compliance with the swell index and fluid loss parameters shown in the GCL Certified Properties tables.

B. Manufacturer's test data for finished GCL product(s) of bentonite mass/area, GCL tensile strength and GCL peel strength (reinforced only) demonstrating compliance with the index parameters shown in the GCL Certified Properties tables.

C. GCL lot and roll numbers supplied for the project (with corresponding shipping information).

2.03 PRODUCT LABELING

A. Prior to shipment, the GCL manufacturer shall label each roll, identifying:

1. Product identification information (Manufacturer's name and address, brand product code).
2. Lot number and roll number.
3. Roll length, width and weight.

2.04 PACKAGING

A. The GCL shall be wound around a rigid core whose diameter is sufficient to facilitate handling. The core is not necessarily intended to support the roll for lifting but should be sufficiently strong to prevent collapse during transit.

B. All rolls shall be labeled and bagged in packaging that is resistant to photodegradation by ultraviolet (UV) light.

2.05 ACCESSORY BENTONITE

A. The granular bentonite sealing clay used for overlap seaming, penetration sealing and repairs shall be made from the same natural sodium bentonite as used in the GCL and shall be as recommended by the GCL manufacturer. Seaming of GCLs shall be conducted in accordance with the manufacturer's guidelines for each particular GCL. Please refer to the installation guidelines for Bentomat /Claymax GCLs.

PART 3. EXECUTION

3.01 SHIPPING AND HANDLING

A. The rolls of GCL shall be packaged and shipped by appropriate means to prevent damage to the material and to facilitate off-loading.

B. The Installation Supervisor shall be present during delivery and unloading of the GCL. A visual inspection of each roll should be made during unloading to identify if any packaging has been damaged. Rolls with damaged packaging should be marked and set aside for further inspection. The packaging should be repaired prior to being placed in storage. The Installation Supervisor shall prepare and submit an inventory that includes lot and roll number for materials received.

C. The Installer is responsible for unloading the GCL. The Owner will make available equipment and operators employed at the site to assist with unloading. The Installer shall coordinate with the Owner to determine equipment availability and should contact the Manufacturer prior to shipment to ascertain the appropriateness of the proposed unloading methods and equipment.

3.02 STORAGE

A. Storage of the GCL rolls shall be the responsibility of the Installer. A dedicated storage area shall be provided by the Owner at the job site. Submit storage area requirements (size and preferred location) with bid documents.

B. Rolls should be stored in a manner that prevents sliding or rolling from the stacks and may be accomplished by the use of chock blocks. Rolls should be stacked at a height no higher than that at which the lifting apparatus can be safely handled (typically no higher than four).

C. All stored GCL materials and the accessory bentonite must be covered with a plastic sheet or tarpaulin until their installation.

D. The integrity and legibility of the labels shall be preserved during storage.

3.03 EARTHWORK

A. The low permeability soil layer upon which the GCL is installed shall be prepared and compacted prior to installation. The surface shall be smooth, firm, and unyielding, and free of:

1. Vegetation.
2. Construction debris.
3. Sticks.
4. Sharp rocks.
5. Void spaces.
6. Ice.
7. Abrupt elevation changes.
8. Standing water.
9. Cracks larger than 0.25 in. (6 mm) in width.
10. Any other foreign matter that could contact the GCL.

B. Immediately prior to GCL deployment, the low permeability soil layer shall be final-graded by the contractor to fill in all voids or cracks and then smooth-rolled to provide the best practicable surface for the GCL. At completion of this activity, no wheel ruts, footprints or other irregularities shall exist in the subgrade. Furthermore, all protrusions extending more than 0.5 in. (12 mm) from the surface shall either be removed, crushed or pushed into the surface with a smooth-drum compactor.

C. On a continuing basis, the project CQA inspector shall certify acceptance of the subgrade before GCL placement.

D. It shall be the Installer's responsibility thereafter to indicate to the Owner's Representative any change in the condition of the low permeability soil layer that could cause the subgrade to be out of compliance with any of the requirements listed in this Section. The Installation Supervisor shall certify in the daily report that no GCL was placed over visibly defective low permeability soil surface.

E. At the top of sloped areas of the job site, an anchor trench for the GCL shall be excavated by the contractor in accordance with the project plans. The trench shall

be excavated and approved by the CQA Inspector prior to GCL placement. No loose soil shall be allowed at the bottom of the trench and no sharp corners or protrusions shall exist anywhere within the trench.

3.04 GCL PLACEMENT

A. GCL rolls shall be delivered to the working area of the site in their original packaging. Immediately prior to deployment, the packaging shall be carefully removed without damaging the GCL. The orientation of the GCL (i.e., which side faces up) shall be in accordance with the Owner Representative's recommendations.

B. Equipment which could damage the GCL, shall not be allowed to travel directly on it. If the installation equipment causes rutting of the subgrade, the subgrade must be restored to its originally accepted condition before placement continues.

C. Care must be taken to minimize the extent to which the GCL is dragged across the subgrade in order to avoid damage to the bottom surface of the GCL. A temporary geosynthetic subgrade covering commonly known as a slip sheet or rub sheet may be used to reduce friction damage during placement.

D. The GCL panels shall be placed parallel to the direction of the slope.

E. All GCL panels shall lie flat on the underlying surface, with no wrinkles or folds, especially at the exposed edges of the panels.

F. Only as much GCL shall be deployed as can be covered at the end of the working day with soil, a geomembrane, or a temporary waterproof tarpaulin. The GCL shall not be left uncovered overnight. If the GCL is hydrated when no confining stress is present, the Installer shall remove and replace the hydrated material as directed by the Owner Representative.

3.05 ANCHORAGE

A. As directed by the project drawings and specifications, the end of the GCL roll shall be placed in an anchor trench at the top of the slope. The front edge of the trench shall be rounded so as to eliminate any sharp corners. Loose soil shall be removed from the floor of the trench. The GCL shall cover the entire trench floor, but shall not extend up the rear trench wall.

3.06 SEAMING

A. The GCL seams shall be constructed by overlapping their adjacent edges according to the manufacturer's recommendations. Care should be taken to ensure that the overlap zone is not contaminated with loose soil or other debris.

B. The minimum dimension of the longitudinal overlap should be 6 in. (150 mm) for Bentomat SDN. If the GCL is manufactured with a grooved cut in the nonwoven geotextile that allows bentonite to freely extrude into the longitudinal overlap then no bentonite-enhanced seam is required for this overlap. If the GCL does not have a grooved cut in one of the nonwoven geotextiles in the longitudinal overlap, then bentonite-enhanced seams are required as described below.

C. End-of-roll overlapped seams shall be constructed with a minimum overlap of 24 in. (600 mm) for Bentomat SDN. Seams at the ends of the panels should be constructed such that they are shingled in the direction of the grade to prevent the potential for runoff flow to enter the overlap zone. End-of-roll overlapped seams for all reinforced GCL seams require bentonite-enhanced seams as described below.

D. Bentonite-enhanced seams shall be constructed between the overlapping adjacent panels as follows. The underlying edge of the longitudinal overlap is exposed and then a continuous bead of granular sodium bentonite is applied along a zone defined by the edge of the underlying panel and the 6-inch (150 mm) line. The granular bentonite shall be applied at a minimum application rate of one quarter pound per lineal ft. (0.4 kg/m). A similar bead of granular sodium bentonite is applied at the end-of-roll overlap.

3.07 DETAIL WORK

A. There shall be no penetrations through the GCL.

B. Cutting the GCL should be performed using a sharp utility knife. Frequent blade changes are recommended to avoid damage to the geotextile components of the GCL during the cutting process.

3.08 DAMAGE REPAIR

A. If the GCL is damaged (torn, punctured, perforated, etc.) during installation, it may be possible, if approved by the Owner's Representative, to repair it by cutting a patch to fit over the damaged area. The patch shall be obtained from a new GCL roll and shall be cut to size such that a minimum overlap of 12 in. (300 mm) is achieved around all of the damaged area. Granular bentonite or bentonite mastic shall be applied around the damaged area prior to placement of the patch. It may be desirable to use an adhesive to affix the patch in place so that it is not displaced during cover placement. Patching shall be observed and approved by the Owner's Representative.

GCL CERTIFIED PROPERTIES

MATERIAL PROPERTY	TEST METHOD	TEST FREQUENCY $ft^2(m^2)$	REQUIRED VALUES
Bentonite Swell Index[1]	ASTM D 5890	1 per 50 tonnes	24 mL/2g min.
Bentonite Fluid Loss[1]	ASTM D 5891	1 per 50 tonnes	18 mL max.
Bentonite Mass/Area[2]	ASTM D 5993	40,000 ft^2 (4,000 m^2)	0.75 lb/ft^2 (3.6 kg/m^2) min
GCL Grab Strength[3]	ASTM D 6768	200,000 ft^2 (20,000 m^2)	30 lbs/in (53 N/cm) MARV
GCL Peel Strength[3]	ASTM D 6496	40,000 ft^2 (4,000 m^2)	2.5 lbs/in (4.4 N/cm) min
GCL Index Flux[4]	ASTM D 5887	Weekly	1×10^{-8} $m^3/m^2/sec$ max
GCL Hydraulic Conductivity[4]	ASTM D 5887	Weekly	5×10^{-9} cm/sec max
GCL Hydrated Internal Shear Strength[5]	ASTM D 5321 ASTM D 6243	Periodic	500 psf (24 kPa) typ @ 200 psf

Notes

[1] Bentonite property tests performed at a bentonite processing facility before shipment the manufacturer's production facilities.

[2] Bentonite mass/area reported at 0 percent moisture content.

[3] All tensile strength testing is performed in the machine direction using ASTM D 6768. All peel strength testing is performed using ASTM D 6496. Upon request, tensile and peel results can be reported per modified ASTM D 4632 using 4 inch grips.

[4] Index flux and permeability testing with deaired distilled/deionized water at 80 psi (551kPa) cell pressure, 77 psi (531 kPa) headwater pressure and 75 psi (517 kPa) tailwater pressure. Reported value is equivalent to 925 gal/acre/day. This flux value is equivalent to a permeability of $5x10^{-9}$ cm/sec for typical GCL thickness. Actual flux values vary with field condition pressures. The last 20 weekly values prior the end of the production date of the supplied GCL may be provided.

[5] Peak values measured at 200 psf (10 kPa) normal stress for a specimen hydrated for 48 hours. Site-specific materials, GCL products, and test conditions must be used to verify internal and interface strength of the proposed design.

END OF SECTION 02376

DIVISION 2 - SITE WORK
Section 02640 – HDPE Piping

PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to construction of the HDPE (High Density Polyethylene) Piping at the Gypsum Management Facility and the CCB Management Facility.

1.02 RELATED SECTIONS

None.

1.03 REFERENCES

The following references, or cited portions thereof, govern the work

A. American Society of Testing and Materials:

1. ASTM D 2683 (2004); Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing.
2. ASTM D 3261 (2003); Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing.
3. ASTM D 3350 (2005); Specification for Polyethylene Plastics Pipe and Fittings Materials.
4. ASTM F 412 (2001a); Terminology Relating to Plastic Piping System.
5. ASTM F 1055 (1998); Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing.
6. ASTM F 1056 (2004); Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings.

1.04 SUBMITTALS

A. Qualifications

Submit qualifications of the Welding Supervisor who will be responsible for construction quality control of the pipe joining process.

B. Material Certifications

Submit manufacturer certifications that the pipe provided complies with the requirements herein.

C. Product Data

1. Submit product data and operating instructions for pipe joining equipment.
2. Submit pipe manufacturer's recommended procedures for storing, handling, and installing pipe and fittings.

1.05 QUALIFICATIONS

A. The Contractor or Subcontractor performing the work under this section shall have in his employ a Welding Supervisor who has completed a minimum of 1,000 ft of pipe joining work using the type of equipment proposed for use in this work. The Welding Supervisor shall be on site at all times during pipe line installation, and shall provide direct supervision over other employees.

1.06 WARRANTY

A. The pipe and fittings shall be warranted, on a pro-rata basis, against manufacturer's defects for a period of five (5) years from the date of pipe installation. The installation shall be warranted against defects in workmanship for a period of one (1) year from the date of completion of the leachate collection piping system.

PART 2. PRODUCTS

2.01 MATERIALS

A. Pipe

1. Pipe material shall be High Density Polyethylene (HDPE) PE 3408, according to ASTM F412, with a cell class designation of 345464C, according to ASTM D3350. Iron pipe size (IPS) and standard dimension ratio (SDR) shall be as indicated in the plans.
2. Size and spacing of holes in perforated pipe shall be as indicated in the plans.

B. Fittings

1. Fittings shall be made of the same material, and shall have a pressure rating no less than 160 psi. Butt fusion, socket, or electrofusion fittings, according to ASTM D3261, ASTM D2683, and ASTM F1055, respectively, are acceptable.

2.02 EQUIPMENT

A. Butt Fusion Machine

The butt fusion machine shall include the following features:

1. Facer with rotating planer block design.
2. Heater faces coated by the manufacturer to prevent molten plastic from adhering to the heater face.
3. Hydraulic-operated jaws suitable for use with the pipe sizes indicated in the plans.

B. Socket Fusion Equipment

Socket fusion heating tools and depth gauges shall be of the same manufacturer, unless they are all marked F1056, indicating compliance with ASTM F1056.

C. All equipment shall conform to any requirements specified in the pipe and socket manufacturer's installation instructions, and shall be approved by the Owner's Representative.

PART 3. EXECUTION

3.01 MATERIAL DELIVERY, STORAGE, AND HANDLING

A. HDPE pipe and fittings shall be packaged and shipped by appropriate means to prevent damage to the material and to facilitate off-loading. The Owner will provide an on-site storage site. Storage site requirements (size and preferred location) shall be submitted with the bid documents.

B. Storage and handling shall be according to manufacturer's recommendations.

3.02 BASE PREPARATION

All HDPE piping shall be installed on a layer of coarse aggregate placed by the Contractor in accordance with the plans. The grade of the coarse aggregate base shall be verified before installing the piping.

3.03 INSTALLATION

All pipe and fittings shall be installed according to the manufacturer's recommendations. Removal of weld beads is not required. Contractor shall place coarse aggregate along the pipe to provide lateral stability. Welds shall not be obscured until they have been approved by the Owner's Representative, the top of pipe shall not be covered until the Construction Quality Assurance (CQA) survey has been completed to verify conformance with specified tolerances.

3.04 INSPECTIONS

A. The Owner's Representative shall shall be visually inspect pipe materials to verify that each pipe material is properly stamped (by the manufacturer) for ASTM acceptance before installation. Defective or damaged materials shall be removed from the site.

B. Each weld and connection shall be visually inspected by the Owner's Representative. Defective welds shall be repaired as directed by the Owner's Representative and according to manufacturer's recommendations. Welds and connections shall not be covered until they have been approved by the Owner's Representative.

3.05 TOLERANCES

A. HDPE piping shall be located within 0.5 ft. of plan location, and elevation shall be within 0.1 ft. of plan elevation with no adverse slopes.

END OF SECTION 02936

DIVISION 2 - SITEWORK
Section 02800 - HDPE
Geomembrane

PART 1. GENERAL

1.01 DESCRIPTION

A. This section includes manufacturing, furnishing, and installing High Density Polyethylene (HDPE) Geomembranes for the Gypsum Management Facility and the Gypsum Management Facility Recycle Pond.

B. The work includes furnishing all equipment and materials and providing all labor, supervision, administration and management necessary to perform the work as shown on the plans.

1.02 RELATED SECTIONS

A. The following sections contain items which are related to the work in this section:

1. 02373 – Geotextiles
2. 02376 – Geosynthetic Clay Liner

1.03 REFERENCES

A. The following references, or cited portions thereof, govern the work:

1. American Society for Testing and Materials (ASTM):

a. D 638, Standard Test Method for Tensile Properties of Plastics.
b. D 751, Standard Test Methods for Coated Fabrics.
c. D 792, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.
d. D 1004, Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.
e. D 1204, Standard Test Method for Linear Dimensional Changes of Non Rigid Thermoplastic Sheeting or Film at Elevated Temperature.
f. D 1238, Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.
g. D 1505, Standard Test Method for Density of Plastics by Density-Gradient Technique.
h. D 1603, Standard Test Method for Carbon Black in Olefin Plastics.
i. D 3895, Test Method for Oxidative Induction Time of Polyolefins by Thermal Analysis.
j. D 4218, Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique.

k. D 4437, Standard Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes.
l. D 4833, Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products.
m. D 5199, Standard Test Method for Measuring Nominal Thickness of Smooth Geomembranes.
n. D 5397, Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefins using Notched Constant Tensile Load Test.
o. D 5596, Standard Practice for Microscopical Examination of Pigment Dispersion in Plastic Compounds.
p. D 5641, Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.
q. D 5721, Practice for Air-Oven Aging of Polyolefin Geomembranes.
r. D 5820, Test Method for Air Testing.
s. D 5885, Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High Pressure Differential Scanning Calorimetry.
t. D 5994, Standard Test Method for Measuring Nominal Thickness of Textured Geomembranes
u. D 6365, Standard Practice for the Nondestructive Testing of Geomembrane Seams using The Spark Test

2. Geosynthetic Research Institute (GRI):

a. GRI GM 6, Pressurized Air Channel Test for Dual Seamed Geomembranes
b. GRI GM 9, Cold Weather Seaming of Geomembranes
c. GRI GM 10, Specification for Stress Crack Resistance of HDPE Geomembrane Sheet
d. GRI GM 13, Test Properties, Testing Frequency and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes
e. GRI GM 14, Test Frequencies for Destructive SeamTesting

1.04 SUBMITTALS

A. Submit the following to the Engineer or Owner, for review and approval, within a reasonable time so as to expedite shipment or installation of the Geomembrane:

1. Documentation of manufacturer's qualifications as specified in subsection 1.05A of this Section.
2. Manufacturer's Quality Control program manual or descriptive documentation.
3. A material properties sheet, including at a minimum all properties specified in GRI GM 13, including test methods used.
4. Sample of the material.

5. Documentation of Installer's qualifications, as specified below and in subsection 1.05B of this Section.
   a. Submit a list of at least ten completed facilities. For each name and type of facility; its location; the date of installation; number of contact at the facility; type and thickness of geomembrane and; surface area of the installed geomembrane.
   b. Submit resumes or qualifications of the Installation Supervisor, Master Seamer and Technicians to be assigned to this project.
   c. Quality Control Program.
6. Example Material Warranty and Liner Installation Warranty complying with subsections 1.07 and 1.08 of this Section.
7. Resin Supplier's name, resin production plant identification, resin brand name and number, production date of the resin, resin Manufacturer's quality control certificates, and certification that the properties of the resin meet the requirements

B. Shop Drawings

1. Submit copies of shop drawings for engineer's approval within a reasonable time so as not to delay the start of geomembrane installation. Shop drawings shall show the proposed panel layout identifying seams and details. Seams should generally follow direction of the slope. Butt seams or roll-end seams should not occur on a slope unless approved by the Owner's Representative. Butt seams on a slope, if allowed, should be staggered.
2. Placement of geomembrane will not be allowed to proceed until Owner's Representative has received and approved the shop drawings.

C. Additional Submittals (In-Progress and at Completion)

1. Manufacturer's warranty (refer to subsection 1.08).
2. Geomembrane installation warranty (refer to subsection 1.09).
3. Daily written acceptance of subgrade surface (refer to subsection 3.01.C).
4. Low-temperature seaming procedures if applicable (refer to subsection 3.03.A)
5. Prequalification test seam samples (refer to subsection 3.05.A.6).
6. Field seam non-destructive test results (refer to subsection 3.05.B.1).
7. Field seam destructive test results (refer to subsection 3.05.C.6).
8. Daily field installation reports (refer to subsection 3.05.G).
9. Installation record drawing, as discussed in subsection 3.05.G).

1.05 QUALITY CONTOL

A. Manufacturer's Qualifications:

The manufacturer of geomembrane of the type specified or similar product shall have at least five years experience in the manufacture of such geomembrane. In addition, the geomembrane manufacturer shall have manufactured at least

10,000,000 sq. ft. of the specified type of geomembrane or similar product during the last five years.

B. Installer's Qualifications:

1 The Geomembrane Installer shall be the Manufacturer, approved Manufacturer's Installer or a contractor approved by the Owner's Representative to install the geomembrane.

2 The Geomembrane Installer shall have at least three years experience in the installation of the specified geomembrane or similar. The Geomembrane Installer shall have installed at least 10 projects involving a total of 5,000,000 sq. ft. of the specified type of geomembrane or similar during the last three years.

3 Installation shall be performed under the direction of a field Installation Supervisor who shall be responsible throughout the geomembrane installation, for geomembrane panel layout, seaming, patching, testing, repairs, and all other activities of the Geomembrane Installer. The Field Installation Supervisor shall have installed or supervised the installation and seaming of a minimum of 10 projects involving a total of 5,000,000 sq. ft. of geomembrane of the type specified or similar product.

4 Seaming shall be performed under the direction of a Master Seamer (who may also be the Field Installation Supervisor or Crew Foreman) who has seamed a minimum of 3,000,000 sq. ft. of geomembrane of the type specified or similar product, using the same type of seaming apparatus to be used in the current project. The Field Installation Supervisor and/or Master Seamer shall be present whenever seaming, patching, other welding operations, and testing is performed.

5 All seaming, patching, other welding operations, and testing shall be performed by qualified technicians employed by the Geomembrane Installer.

1.06 DELIVERY, STORAGE AND HANDLING

A. Each roll of geomembrane delivered to the site shall be labeled by the manufacturer. The label shall be firmly affixed and shall clearly state the manufacturer's name, product identification, material thickness, roll number, roll dimensions and roll weight.

B. Geomembrane shall be protected from mud, dirt, dust, puncture, cutting or any other damaging or deleterious conditions.

C. Rolls shall be stored away from high traffic areas. Continuously and uniformly support rolls on a smooth, level prepared surface.

D. Rolls shall not be stacked more than three high.

1.07 PROJECT CONDITIONS

Geomembrane shall not be installed in the presence of standing water, while precipitation is occurring, during excessive winds, or when material temperatures are outside the limits specified in Section 3.03.

1.08 MATERIAL WARRANTY

As required by specification, or as required in GRI GM 13 (attachment A)

1.09 GEOMEMBRANE INSTALLATION WARRANTY

The Geomembrane Installer shall guarantee the geomembrane installation against defects in the installation and workmanship for 1 year commencing with the date of final acceptance.

1.10 GEOMEMBRANE PRE-CONSTRUCTION MEETING

A. Geomembrane Pre-Construction Meeting shall be held at the site prior to installation of the geomembrane. At a minimum, the meeting shall be attended by the Geomembrane Installer, Owner, Owner's representative (Engineer and/or CQA Firm), and the General Contractor.

B. Topics for this meeting shall include:
   1. Responsibilities of each party.
   2. Lines of authority and communication. Resolution of any project document ambiguity.
   3. Methods for documenting, reporting and distributing documents and reports.
   4. Procedures for packaging and storing archive samples.
   5. Review of time schedule for all installation and testing.
   6. Review of panel layout and numbering systems for panels and seams including details for marking on geomembrane.
   7. Procedures and responsibilities for preparation and submission of as-built panel and seam drawings.
   8. Temperature and weather limitations. Installation procedures for adverse weather conditions. Defining acceptable subgrade, geomembrane, or ambient moisture and temperature conditions for working during liner installation.
   9. Subgrade conditions, dewatering responsibilities and subgrade maintenance plan.
   10. Deployment techniques including allowable subgrade for the geomembrane.
   11. Plan for controlling expansion/contraction and wrinkling of the geomembrane.
   12. Covering of the geomembrane and cover soil placement.
   13. Measurement and payment schedules.
   14. Health and safety.

C. The meeting shall be documented by the Owner's Representative and minutes shall be transmitted to all parties.

PART 2. PRODUCTS

2.01 SOURCE QUALITY CONTROL

Manufacturing Quality Control

A. The test methods and frequencies used by the manufacturer for quality control/quality assurance of the above geomembrane prior to delivery, shall be in accordance with GRI GM 13, or modified as required for project specific conditions.

B. The manufacturer's geomembrane quality control certifications, including results of quality control testing of the products, as specified in subsection 2.01.C of this Section, must be supplied to the Owner's Representative. The certification shall be signed by a responsible party employed by the manufacturer, such as the QA/QC Manager, Production Manager, or Technical Services Manager. Certifications shall include lot and roll numbers and corresponding shipping information.

C. The Manufacturer will provide Certification that the geomembrane and welding rod supplied for the project have the same base resin and material properties.

2.02 GEOMEMBRANE

A. The geomembrane shall consist of new, first quality products designed and manufactured specifically for the purpose of this work which shall have been satisfactorily demonstrated by prior testing to be suitable and durable for such purposes. The geomembrane rolls shall be seamless, high density polyethylene (HDPE- Density >0.94g/cm) containing no plasticizers, fillers or extenders and shall be free of holes, blisters or contaminants, and leak free verified by 100% in line spark or equivalent testing. The geomembrane shall be supplied as a continuous sheet with no factory seams in rolls. The geomembrane will meet the property requirements as shown in Table A. (GRI GM 13)

B. Material shall be reviewed for conformance to the project specifications by the Owner's Representative

C. The geomembrane seams shall meet the property requirements as shown in Table 2, (Attachment B).

PART 3. EXECUTION

3.01 SUBGRADE PREPARATION

A. Geomembrane installed over geosynthetic clay liner (GCL).

The area of GCL to be covered with geomembrane shall be jointly inspected daily with the Owner's Representative before commencing geomembrane installation for the day, and the condition of the GCL shall be continuously observed as geomembrane installation progresses. Rocks, stones, sticks, sharp objects and debris of any kind shall be removed from the surface of the GCL. The Owner's Representative shall be notified of any discontinuities, premature hydration, or

otherwise defective GCL. Geomembrane shall not be placed over suspect areas until they have been repaired to the satisfaction of the Owner's Representative. The Installation Supervisor shall certify daily in writing that the GCL surface was acceptable at the time of geomembrane installation.

B. Geomembrane installed over cushion dirt.

The area of cushion dirt to be covered with geomembrane shall be prepared in accordance with the Section 02200 – Earthwork. The surface shall be smooth and free of ruts and holes, rocks, stones, sticks, sharp objects and debris of any kind.

C. The Geomembrane installer shall provide daily written acceptance for the surface to be covered by the geomembrane in that day's operations. The surface shall be maintained in a manner, during geomembrane installation, to ensure subgrade suitability.

D. All subgrade damaged by construction equipment and deemed unsuitable by the Owner's Representative for geomembrane deployment shall be repaired prior to placement of the geomembrane. All repairs shall be reviewed by the Owner's Representative and approved by the Geomembrane Installer. This damage, repair, and the responsibilities of the contractor and Geomembrane Installer shall be defined in the preconstruction meeting.

3.02 GEOMEMBRANE PLACEMENT

A. No geomembrane shall be deployed until the applicable certifications and quality control certificates listed in subsection 1.04 of this Section are submitted to and approved by the Owner's Representative. Should geomembrane material be deployed prior to approval by the Owner's Representative it will be at the sole risk of the Geomembrane Installer and/or Contractor. If the material does not meet project specifications it shall be removed from the work area at no cost to the owner.

B. The geomembrane shall be installed to the limits shown on the project drawings and essentially as shown on approved panel layout drawings.

C. No geomembrane material shall be unrolled and deployed if the material temperatures are lower than 0 degrees C (32 degrees F). Temperature limitations should be defined in the preconstruction meeting. Typically, only the quantity of geomembrane that will be anchored and seamed together in one day should be deployed.

D. No vehicular traffic shall travel on the geomembrane other than an approved low ground pressure All Terrain Vehicle or equivalent.

E. Sand bags or equivalent ballast shall be used as necessary to temporarily hold the geomembrane material in position under the foreseeable and reasonably - expected wind conditions. Sand bag material shall be sufficiently close- knit to prevent soil fines from working through the bags and discharging on the geomembrane.

F. Geomembrane placement shall not be done if moisture prevents proper subgrade preparation, panel placement, or panel seaming. Moisture limitations

should be defined in the preconstruction meeting.

G. Damaged panels or portions of the damaged panels which have been rejected shall be marked and their removal from the work area recorded.

H. The geomembrane shall not be allowed to "bridge over" voids or low areas in the subgrade. In these areas, the subgrade shall be prepared to allow the geomembrane to rest in intimate contact with the subgrade.

I. Wrinkles caused by panel placement or thermal expansion should be minimized in accordance with section 1.10 B. 11.

J. Considerations on Site Geometry: In general, seams shall be oriented parallel to the line of the maximum slope. In corners and odd shaped geometric locations, the total length of field seams shall be minimized. Seams shall not be located at low points in the subgrade.

K. Overlapping: The panels shall be overlapped prior to seaming to whatever extent is necessary to effect a good weld and allow for proper testing. In no case shall this overlap be less than 75mm (3 in.).

3.03 SEAMING PROCEDURES

A. Cold weather installations should follow guidelines as outlined in GRI GM9.

B. No geomembrane material shall be seamed when liner temperatures are less than 0 degrees C (32 degrees F).

C. No geomembrane material shall be seamed when the sheet temperature is above 75 degrees C (170 degrees F) as measured by an infrared thermometer or surface thermocouple.

D. Seaming shall primarily be performed using automatic fusion welding equipment and techniques. Extrusion welding shall be used where fusion welding is not possible such as at pipe penetrations, patches, repairs and short (less than a roll width) runs of seams.

E. Fishmouths or excessive wrinkles at the seam overlaps, shall be minimized and when necessary cut along the ridge of the wrinkles back into the panel so as to effect a flat overlap. The cut shall be terminated with a keyhole cut (nominal 10 mm (1/2 in) diameter hole) so as to minimize crack/tear propagation. The overlay shall subsequently be seamed. The key hole cut shall be patched with an oval or round patch of the same base geomembrane material extending a minimum of 150 mm (6 in.) beyond the cut in all directions.

3.04 PIPE AND STRUCTURE PENETRATION SEALING SYSTEM

A. Provide penetration sealing system as shown in the Project Drawings.

B. Penetrations shall be constructed from the base geomembrane material, flat stock, prefabricated boots and accessories as shown on the Project Drawings. The pre-fabricated or field fabricated assembly shall be field welded to the geomembrane as shown on the Project Drawings so as to prevent leakage. This assembly shall be tested as outlined in section 3.05.B. Alternatively, where field non destructive testing can not be performed, attachments will be field spark tested by standard holiday leak detectors in accordance with ASTM 6365 Spark testing should be done in areas where both air pressure testing and vacuum testing are not possible.

1. Equipment for Spark testing shall be comprised of but not limited to: A

hand held holiday spark tester and conductive wand that generates a high voltage.

2. The testing activities shall be performed by the Geomembrane Installer by placing an electrically conductive tape or wire beneath the seam prior to welding. A trial seam containing a non welded segment shall be subject to a calibration test to ensure that such a defect (non welded segment) will be identified under the planned machine settings and procedures. Upon completion of the weld, enable the spark tester and hold approximately 25mm (1 in) above the weld moving slowly over the entire length of the weld in accordance with ASTM 6365. If there is no spark the weld is considered to be leak free.
3. A spark indicates a hole in the seam. The faulty area shall be located, repaired and retested by the Geomembrane Installer.
4. Care should be taken if flammable gases are present in the area to be tested.

3.05 FIELD QUALITY CONTROL

The Owner's Representative shall be notified prior to all pre qualification and production welding and testing, or as agreed upon in the pre construction meeting.

A. Prequalification Test Seams

1. Test seams shall be prepared and tested by the Geomembrane Installer to verify that seaming parameters (speed, temperature and pressure of welding equipment) are adequate.
2. Test seams shall be made by each welding technician and tested in accordance with ASTM D 4437 at the beginning of each seaming period. Test seaming shall be performed under the same conditions and with the same equipment and operator combination as production seaming. The test seam shall be approximately 3.3 meters (10 feet) long for fusion welding and 1 meter (3 feet) long for extrusion welding with the seam centered lengthwise. At a minimum, tests seams should be made by each technician 1 time every 4–6 hours; additional tests may be required with changes in environmental conditions.
3. Two 25 mm (1 in) wide specimens shall be die-cut by the Geomembrane Installer from each end of the test seam. These specimens shall be tested by the Geomembrane Installer using a field tensiometer testing both tracks for peel strength and also for shear strength. Each specimen shall fail in the parent material and not in the weld, "Film Tear Bond"(F.T.D. failure). Seam separation equal to or greater than 10% of the track width shall be considered a failing test.
4. The minimum acceptable seam strength values to be obtained for all specimens tested are listed in Subsection 3.05.C.4 of this Section. All four specimens shall pass for the test seam to be a passing seam.
5. If a test seam fails, an additional test seam shall be immediately conducted. If the additional test seam fails, the seaming apparatus shall be rejected and not used for production seaming until the deficiencies are

corrected and a successful test seam can be produced.

6. A sample from each test seam shall be labeled. The label shall indicate the date, geomembrane temperature, number of the seaming unit, technician performing the test seam and pass or fail description. The sample shall then be given to the Owner's Representative for archiving.

B. Field Seam Non-destructive Testing

1. All field seams shall be non-destructively tested by the Geomembrane Installer over the full seam length before the seams are covered. Each seam shall be numbered or otherwise designated. The location, date, test unit, name of tester and outcome of all non-destructive testing shall be recorded and submitted to the Owner's Representative.
2. Testing should be done as the seaming work progresses, not at the completion of all field seaming. All defects found during testing shall be numbered and marked immediately after detection. All defects found should be repaired, retested and remarked to indicate acceptable completion of the repair.
3. Non-destructive testing shall be performed using vacuum box, air pressure or spark testing equipment.
4. Non-destructive tests shall be performed by experienced technicians familiar with the specified test methods. The Geomembrane Installer shall demonstrate to the Owner's Representative all test methods to verify the test procedures are valid.
5. Extrusion seams shall be vacuum box tested by the Geomembrane Installer in accordance with ASTM D 4437 and ASTM D 5641 with the following equipment and procedures:
   a. Equipment for testing extrusion seams shall be comprised of but not limited to: a vacuum box assembly consisting of a rigid housing, a transparent viewing window, a soft rubber gasket attached to the base, port hole or valve assembly and a vacuum gauge; a vacuum pump assembly equipped with a pressure controller and pipe connections; a rubber pressure/vacuum hose with fittings and connections; a plastic bucket; wide paint brush or mop; and a soapy solution.
   b. The vacuum pump shall be charged and the tank pressure adjusted to approximately 35 kPa (5 psig).
   c. The Geomembrane Installer shall create a leak tight seal between the gasket and geomembrane interface by wetting a strip of geomembrane approximately 0.3m (12 in) by 1.2m (48 in) (length and width of box) with a soapy solution, placing the box over the wetted area, and then compressing the box against the geomembrane. The Geomembrane Installer shall then close the bleed valve, open the vacuum valve, maintain initial pressure of approximately 35 kPa (5 psig) for approximately 5 seconds. The geomembrane should be continuously examined through the viewing window for the presence of soap bubbles, indicating a leak. If no bubbles appear after 5 seconds, the area shall be

considered leak free. The box shall be depressurized and moved over the next adjoining area with an appropriate overlap and the process repeated.

d. All areas where soap bubbles appear shall be marked, repaired and then retested.

e. At locations where seams cannot be non destructively tested, such as pipe penetrations, alternate nondestructive spark testing (as outlined in section 3.04.B) or equivalent should be substituted.

f. All seams that are vacuum tested shall be marked with the date tested, the name of the technician performing the test and the results of the test.

6. Double Fusion seams with an enclosed channel shall be air pressure tested by the Geomembrane Installer in accordance with ASTM D 5820 and ASTM D 4437 and the following equipment and procedures:

a. Equipment for testing double fusion seams shall be comprised of but not limited to: an air pump equipped with a pressure gauge capable of generating and sustaining a pressure of 210 kPa (30 psig), mounted on a cushion to protect the geomembrane; and a manometer equipped with a sharp hollow needle or other approved pressure feed device.

b. The Testing activities shall be performed by the Geomembrane Installer. Both ends of the seam to be tested shall be sealed and a needle or other approved pressure feed device inserted into the tunnel created by the double wedge fusion weld. The air pump shall be adjusted to a pressure of 210 kPa (30 psig), and the valve closed,. Allow 2 minutes for the injected air to come to equilibrium in the channel, and sustain pressure for 5 minutes. If pressure loss does not exceed 28 kPa (4 psig) after this five minute period the seam shall be considered leak tight. Release pressure from the opposite end verifying pressure drop on needle to ensure testing of the entire seam. The needle or other approved pressure feed device shall be removed and the feed hole sealed.

c. If loss of pressure exceeds 28 kPa (4 psig) during the testing period or pressure does not stabilize, the faulty area shall be located, repaired and retested by the Geomembrane Installer.

d. Results of the pressure testing shall be recorded on the liner at the seam tested and on a pressure testing record.

C. Destructive Field Seam Testing

1. One destructive test sample per 150 linear m (500 linear ft) seam length or another predetermined length in accordance with GRI GM 14 shall be taken by the Geomembrane Installer from a location specified by the Owner's Representative. The Geomembrane Installer shall not be informed in advance of the sample location. In order to obtain test results prior to completion of geomembrane installation, samples shall be cut by the Geomembrane Installer as directed by the Owner's Representative as seaming progresses.

2. All field samples shall be marked with their sample number and seam number. The sample number, date, time, location, and seam number shall be recorded. The Geomembrane Installer shall repair all holes in the geomembrane resulting from obtaining the seam samples. All patches shall be vacuum box tested or spark tested. If a patch cannot be permanently installed over the test location the same day of sample collection, a temporary patch shall be tack welded or hot air welded over the opening until a permanent patch can be affixed.
3. The destructive sample size shall be 300 mm (12 in) wide by 1 m (36 in) long with the seam centered lengthwise. The sample shall be cut into three equal sections and distributed as follows: one section given to the Owner's Representative as an archive sample; one section given to the Owner's Representative for laboratory testing as specified in paragraph 5 below; and one section retained by the Geomembrane Installer for field testing as specified in paragraph 4 below.
4. For field testing, the Geomembrane Installer shall cut 10 identical 25 mm (1 in) wide replicate specimens from his sample. The Geomembrane Installer shall test five specimens for seam shear strength and five for peel strength. Peel tests will be performed on both inside and outside weld tracks. To be acceptable, 4 of 5 test specimens must pass the stated criteria in section 2.02 with less than 10% separation. If 4 of 5 specimens pass, the sample qualifies for testing by the testing laboratory if required.
5. If independent seam testing is required by the specifications it shall be conducted in accordance with ASTM 5820 or ASTM D4437 or GRI GM 6.
6. Reports of the results of examinations and testing shall be prepared and submitted to the Owner's Representative.
7. For field seams, if a laboratory test fails, that shall be considered as an indicator of the possible inadequacy of the entire seamed length corresponding to the test sample. Additional destructive test portions shall then be taken by the Geomembrane Installer at locations indicated by the Engineer, typically 3 m (10 ft) on either side of the failed sample and laboratory seem tests shall be performed. Passing tests shall be an indicator of adequate seams. Failing tests shall be an indicator of non-adequate seams and all seams represented by the destructive test location shall be repaired with a cap-strip extrusion welded to all sides of the capped area. All cap-strip seams shall be non-destructively vacuum box tested until adequacy of the seams is achieved. Cap strip seams exceeding 50 M in length (150 FT) shall be destructively tested.

D. Identification of Defects

1. Panels and seams shall be inspected by the Installer and Owner's Representative during and after panel deployment to identify all defects, including holes, blisters, undispersed raw materials and signs of contamination by foreign matter.

E. Evaluation of Defects: Each suspect location on the liner (both in geomembrane

seam and non-seam areas) shall be non-destructively tested using one of the methods described in Section 3.05.B. Each location which fails non-destructive testing shall be marked, numbered, measured and posted on the daily "installation" drawings and subsequently repaired.

1. If a destructive sample fails the field or laboratory test, the Geomembrane Installer shall repair the seam between the two nearest passed locations on both sides of the failed destructive sample location.
2. Defective seams, tears or holes shall be repaired by reseaming or applying a extrusion welded cap strip.
3. Reseaming may consist of either:
   a. Removing the defective weld area and rewelding the parent material using the original welding equipment; or
   b. Reseaming by extrusion welding along the overlap at the outside seam edge left by the fusion welding process.
4. Blisters, larger holes, and contamination by foreign matter shall be repaired by patches and/or extrusion weld beads as required. Each patch shall extend a minimum of 150 mm (6 in) beyond all edges of the defects.
5. All repairs shall be measured, located and recorded.

F. Verification of Repairs on Seams: Each repair shall be non-destructively tested using either vacuum box or spark testing methods. Tests which pass the non-destructive test shall be taken as an indication of a successful repair. Failed tests shall be reseamed and retested until a passing test results. The number, date, location, technician and test outcome of each patch shall be recorded.

G. Daily Field Installation Reports: At the beginning of each day's work, the Installer shall provide the Engineer with daily reports for all work accomplished on the previous work day. Reports shall include the following:
1. Total amount and location of geomembrane placed;
2. Total length and location of seams completed, name of technicians doing seaming and welding unit numbers;
3. Drawings of the previous day's installed geomembrane showing panel numbers, seam numbers and locations of non-destructive and destructive testing;
4. Results of pre-qualification test seams;
5. Results of non-destructive testing; and
6. Results of vacuum testing of repairs.

H. Destructive test results shall be reported prior to covering of liner or within 48 hours.

3.06 LINER ACCEPTANCE

A. Geomembrane liner will be accepted by the Owner's Representative when:

1. The entire installation is finished or an agreed upon subsection of the installation is finished;

2. All Installer's QC documentation is completed and submitted to the owner
3. Verification of the adequacy of all field seams and repairs and associated geomembrane testing is complete.

3.07 ANCHOR TRENCH

A. Construct as specified on the project drawings.

3.08 DISPOSAL OF SCRAP MATERIALS

A. On completion of installation, the Geomembrane Installer shall dispose of all trash and scrap material in a location approved by the Owner, remove equipment used in connection with the work herein, and shall leave the premises in a neat acceptable manner. No scrap material shall be allowed to remain on the geomembrane surface.

PART 4. GRI GM13 SPECIFICATIONS

Geosynthetics Research Institute (GRI) Test Method GM13 – "Test Methods, Test Properties and Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes", Revision 8, Dated July 10, 2006.

ATTACHMENT A:

Minimum Average Weld Properties for Smooth and Textured HDPE Geomembranes (English units)								
Property	**Test Method**	**30 mil**	**40 mil**	**50 mil**	**60 mil**	**80 mil**	**100 mil**	**120 mil**
Peel strength (fusion & extrusion) lb/in.	ASTM 4437	39	52	65	78	104	130	156
Shear strength (fusion & extrusion) lb/in.	ASTM 4437	60	80	100	120	160	200	239

END OF SECTION 02800

DIVISION 2 - SITE WORK
Section 02936 - Topsoil, Seeding, and Mulching

PART 1. GENERAL

1.01 DESCRIPTION

This section pertains to seeding and placing mulch or erosion control blanket over seeded areas.

1.02 RELATED SECTIONS

A. Specified elsewhere:

1. 02200 - Earthwork

1.03 REFERENCES

The following reference or cited portions thereof, current at date of bidding documents unless otherwise specified, governs the work.

A. Illinois Department of Transportation (IDOT): Standard Specifications for Road and Bridge Construction, adopted January 1, 2007.

1.04 SPECIFICATIONS

A. Work shall conform to the applicable requirements of Sections 250 and 251 of Standard Specifications for Road and Bridge Construction and to the requirements hereinafter specified.

B. Exceptions: All references in the IDOT specifications to methods of measurement and payment shall not apply.

1.05 WARRANTY

A. Warranty for one (1) year plus one growing season from date of substantial completion shall be provided.

PART 2. PRODUCTS

2.01 MATERIALS

A. Seed: Seed shall conform to Article 1081.04 of the IDOT Standard Specifications. The composition of the Ameren Energy Resources Generating hay seeding mix shall

be as follows:

Seed Type	Pounds/Acre
Vernal Alfalfa	12
Wrangler Alfalfa	8
Medium Red Clover	6
Timothy	4

B. Mulch Material and Erosion Control Blanket: Mulch material shall conform to Article 1081.06 and the excelsior blanket/knitted straw mat shall conform to Article 1081.10 of the IDOT Standard Specifications.

C. Fertilizer and agricultural ground limestone will not be permitted.

PART 3. EXECUTION

3.01 CONSTRUCTION

A. Seed bed preparation and seeding methods shall conform to Section 250 of the IDOT Specifications. Seeding of areas disturbed by construction activities after September 30, 2008 may be deferred until Spring 2009.

B. Seed shall be applied to the perimeter berm ditch, to disturbed portions of the perimeter berm, and to all disturbed earth surfaces outside of the existing perimeter berm. IDOT seeding mixture 7 shall be used on stockpiles. IDOT seeding mixture 1A shall be used on the gypsum stack perimeter earthen berm, the recycle pond dam embankment and on slopes that are 4H:1V or steeper. The Ameren hay seed mix shall be used on slopes flatter that 4H:1V.

C. Application rates for IDOT seed mixtures shall be as specified in Section 250 of the IDOT Specifications. The application rate for the Ameren Energy Resources Generating's seed mix shall be as specified in the Ameren Energy Resources Generating's hay seeding mix.

D. Seeded areas shall be mulched in accordance with Article 251.03. The Contractor may use either Method 2 or Method 3.

3.02 MAINTENANCE OF COMPLETED WORK

A. All areas seeded by the Contractor shall be maintained by the Contractor during the period between completion of such work and final completion and acceptance of the Contractor's work by the Owner. This maintenance shall be such that the completed work, at time of acceptance, complies in all respects with the requirements herein specified.

B. The areas seeded will be required to germinate. If the seed does not germinate, the Contractor will be required to regrade and reseed at no additional cost.

END OF SECTION 02936

DIVISION 3 - CONCRETE
Section 03100 - Concrete Formwork

PART 1. GENERAL

1.01 WORK INCLUDES

A. The complete installation of the formwork for cast-in-place concrete, with shoring, bracing and anchorage, openings for other work, form accessories, form stripping.

1.02 RELATED SECTIONS

A. Section 03200 - Concrete Reinforcement.

B. Section 03300 - Cast-In-Place Concrete.

C. Section 03400 – Concrete Embedment Liner.

1.03 REFERENCES

A. ACI 347 - Recommended Practice For Concrete Formwork.

B. ACI 301 - Specifications For Structural Concrete For Buildings.

1.04 DESIGN REQUIREMENTS

A. Design, engineer and construct formwork, shoring and bracing to conform to design and code requirements; resultant concrete to conform to required shape, line and dimension.

1.05 QUALITY ASSURANCE

A. Perform Work in accordance with ACI 347 and 301.

1.06 REGULATORY REQUIREMENTS

A. Conform to applicable code for design, fabrication, erection and removal of formwork.

1.07 DELIVERY, STORAGE, AND HANDLING

A. Store off ground in ventilated and protected manner to prevent deterioration from moisture.

1.08 COORDINATION

A. Coordinate this Section with other Sections of work which require attachment of components of formwork.

B. If formwork is placed which results in insufficient concrete cover over reinforcement, request instructions from Owner's Representative before proceeding.

PART 2. PRODUCTS

2.01 WOOD FORM MATERIALS

A. Softwood Plywood: 3/4 in. PS 1-83 "B-B" (concrete form) plywood, Class I, exterior grade or better, mill-oiled and edge sealed with each piece bearing legible inspection trademark.

B. Architectural Plywood: 3/4 in. PS 1-83 "B-B" plyform, Class I, with High Density smooth overlay, 1 surface, edge sealed with each piece bearing legible inspection trademark.

2.02 MANUFACTURERS - PREFABRICATED FORMS

A. Weyerhauser Concrete Form.

B. Georgia Pacific, G-P Exterior Soft Wood Plywood Product.

C. Plywood and Door Corporation's Finn-Form.

2.03 PREFABRICATED FORMS

A. Preformed Steel Forms: Minimum 16 gage matched, tight fitting, stiffened to support weight of concrete without deflection detrimental to tolerances and appearance of finished surfaces.

B. Glass Fiber Fabric Reinforced Plastic Forms: Matched, tight fitting, stiffened to support weight of concrete without deflection detrimental to tolerances and appearance of finished concrete surfaces.

2.04 FORMWORK ACCESSORIES

A. Form Ties: Snap-off type, galvanized metal, adjustable length, 1 in. back break dimension, free of defects that could leave holes larger than 1 in. in concrete surface; Dayton-Sure Grip snap-in-form ties, as manufactured by Dayton Superior

Corp., Symons Ties as manufactured by Symons Corporation, Snap-Tys as manufactured by Richmond Corporation. Ties shall be removed after forms are removed, and holes filled with mortar that matches the adjacent surfaces.

B. Form Release Agent: Colorless mineral oil which will not stain concrete, or absorb moisture; by Magic Kote manufactured by Symons Manufacturing Co., Form Coat manufactured by Concrete Services Co., Formeel manufactured by Lambert Corp.

C. Corners: Chamfered, wood strip type; 3/4 x 3/4 in. size on all exterior corners, 3 x 3 in. size where shown on the drawings; maximum possible lengths.

D. Nails, Spikes, Lag Bolts, Through Bolts, Anchorages: Sized as required, of sufficient strength and character to maintain formwork in place while placing concrete.

E. Concrete Embedment Liner, where required, shall be installed in accordance with Section 03400 – Concrete Embedment Liner.

PART 3. EXECUTION

3.01 EXAMINATION

A. Verify lines, levels and centers before proceeding with formwork. Ensure that dimensions agree with drawings.

3.02 EARTH FORMS

A. Earth forms are not permitted, except for footings.

3.03 ERECTION - FORMWORK

A. Erect formwork, shoring and bracing to achieve design requirements, in accordance with requirements of ACI 301. Metal forms shall be installed in strict accordance with manufacturer's directions and specifications.

B. Provide bracing to ensure stability of formwork. Shore or strengthen formwork subject to overstressing by construction loads.

C. Arrange and assemble formwork to permit dismantling and stripping. Do not damage concrete during stripping. Permit removal of remaining principal shores.

D. Align joints and make watertight. Keep form joints to a minimum.

E. Obtain approval before framing openings in structural members which are not indicated on drawings.

3.04 APPLICATION - FORM RELEASE AGENT

A. Apply form release agent on formwork in accordance with manufacturer's recommendations.

B. Apply prior to placement of reinforcing steel, anchoring devices, and embedded items.

C. Do not apply form release agent where concrete surfaces will receive special finishes or applied coverings which are affected by agent.

3.05 INSERTS, EMBEDDED PARTS, AND OPENINGS

A. Provide formed openings where required for items to be embedded in or passing through concrete work.

B. Locate and set in place items which will be cast directly into concrete.

C. Coordinate work of other Sections in forming and placing openings, slots, reglets, recesses, chases, sleeves, bolts, anchors, and other inserts.

D. Install accessories in accordance with manufacturer's instructions, straight, level, and plumb. Ensure items are not disturbed during concrete placement.

E. Provide temporary ports or openings in formwork where required to facilitate cleaning and inspection. Locate openings at bottom of forms to allow flushing water to drain.

F. Close temporary openings with tight fitting panels, flush with inside face of forms, and neatly fitted so joints will not be apparent in exposed concrete surfaces.

3.06 FORM CLEANING

A. Clean and remove foreign matter within forms as erection proceeds.

B. Clean formed cavities of debris prior to placing concrete.

C. Flush with water or use compressed air to remove remaining foreign matter. Ensure that water and debris drain to exterior through clean-out ports.

D. During cold weather, remove ice and snow from within forms. Do not use de-icing salts or water to clean out forms. Use compressed air or other means to remove foreign matter.

3.07 FORMWORK TOLERANCES

A. Construct formwork to maintain tolerances required by ACI 301.

3.08 FIELD QUALITY CONTROL

A. Inspect erected formwork, shoring, and bracing to ensure that work is in accordance with formwork design, and that supports, fastenings, wedges, ties, and items are secure.

B. Do not reuse wood formwork more than three times for concrete surfaces to be exposed to view. Do no patch formwork.

3.09 FORM REMOVAL

A. Do not remove forms or bracing until concrete has gained sufficient strength to carry its own weight and imposed loads.

B. Loosen forms carefully. Do not wedge pry bars, hammers, or tools against finished concrete surfaces scheduled for exposure to view.

C. Store removed forms in manner that surfaces to be in contact with fresh concrete will not be damaged. Discard damaged forms.

END OF SECTION 03100

DIVISION 3 - CONCRETE
Section 03200 - Concrete Reinforcement

PART 1. GENERAL

1.01 WORK INCLUDES

A. The complete installation of the reinforcing steel bars and accessories for cast-in-place concrete.

1.02 RELATED SECTIONS

A. Section 03100 - Concrete Formwork.

B. Section 03300 - Cast-in-Place Concrete.

1.03 REFERENCES

A. ACI 301 - Structural Concrete for Buildings.

B. ACI 318 - Building Code Requirements For Reinforced Concrete.

C. ACI SP-66 - American Concrete Institute - Detailing Manual.

D. ASTM A615 - Deformed and Plain Billet Steel Bars for Concrete Reinforcement.

E. CRSI - Concrete Reinforcing Steel Institute Manual of Practice.

1.04 SUBMITTALS

A. Submit under provisions of Section 01010.

B. Shop Drawings: Indicate bar sizes, spacings, locations, and quantities of reinforcing steel, and bending and cutting schedules. Contract drawings shall not be reproduced as the basis for shop drawings.

C. Manufacturer's Certificate: Certify that products meet or exceed specified requirements.

1.05 QUALITY ASSURANCE

A. Perform Work in accordance with CRSI Manual of Standard Practice.

B. Submit certified copies of mill test report of reinforcement materials analysis.

1.06 COORDINATION

A. Coordinate with placement of formwork, formed openings and other work.

PART 2. PRODUCTS

2.01 REINFORCEMENT

A. Reinforcing Steel: ASTM A615, 60 ksi yield grade; deformed billet steel bars.

2.02 ACCESSORY MATERIALS

A. Tie Wire: Minimum 16 gage, annealed steel wire, epoxy coated when used with epoxy-coated reinforcement.

B. Chairs, Bolsters, Bar Supports, Spacers: Sized and shaped for strength and support of reinforcement during concrete placement conditions.

C. Special Chairs, Bolsters, Bar Supports, Spacers Adjacent to Weather Exposed Concrete Surfaces: Plastic coated steel type; size and shape as required.

2.03 FABRICATION

A. Fabricate concrete reinforcing in accordance with CRSI Manual of Standard Practice and ACI SP-66.

B. Splice reinforcement on at locations indicated on drawings. Indicate location of splices on shop drawings.

PART 3. EXECUTION

3.01 PLACEMENT

A. Place, support and secure reinforcement against displacement. Do not deviate from required position. Clean reinforcement of foreign particles or coatings.

B. Accommodate placement of formed openings.

C. Conform to ACI 318 code for concrete cover over reinforcement.

3.02 FIELD QUALITY CONTROL

A. Contractor shall notify the Owner's Representative at least 24 hrs. in advance of concrete placement. Placement of reinforcing shall occur in such sequence that the Owner's Representative has sufficient time to inspect the correctness of the reinforcing within the placement area. The Owner's Representative retains the right to require necessary revisions be made before concrete is placed.

END OF SECTION 03200

DIVISION 3 - CONCRETE
Section 03300 - Cast-In-Place Concrete

PART 1. GENERAL

1.01 WORK INCLUDES

A. The complete installation of cast-in-place concrete structures, including joint sealants.

1.02 RELATED SECTIONS

A. Section 03100 - Concrete Formwork: Formwork and accessories.

B Section 03200 - Concrete Reinforcement.

C. Section 03400 – Concrete Embedment Liner

1.03 REFERENCES

A. ACI 301 – Structural Concrete for Buildings.

B. ACI 302 - Guide for Concrete Floor and Slab Construction.

C. ACI 304 - Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete.

D. ACI 305R - Hot Weather Concreting.

E. ACI 306R - Cold Weather Concreting.

F. ACI 308 - Standard Practice for Curing Concrete.

G. ACI 318 - Building Code Requirements for Reinforced Concrete.

H. ASTM C31 - Concrete Test Specimens.

I. ASTM C33 - Concrete Aggregates.

J. ASTM C94 - Ready-Mixed Concrete.

K. ASTM C150 - Portland Cement.

L. ASTM C260 - Air Entraining Admixtures for Concrete.

M. ASTM C494 - Chemical Admixtures for Concrete.

1.04 SUBMITTALS

A. Product Data: Provide data on joint devices, attachment accessories, admixtures.

1.05 QUALITY ASSURANCE

A. Perform Work in accordance with ACI 301.

B. Acquire cement and aggregate from same source for all work.

C. Conform to ACI 305R when concreting during hot weather.

D. Conform to ACI 306R when concreting during cold weather.

1.06 COORDINATION

A. Coordinate this Section with other Sections which require embedment of components in cast-in-place concrete.

1.07 PRODUCT DATA

A. Submit proposed mix design to Owner's Representative for review prior to commencement of work. Identify source and provide material certificates for cement, fine and coarse aggregates. Provide recent laboratory gradation for fine and coarse aggregates and mix design information in accordance with ACI 301.

B. Submit Construction joint plan.

PART 2. PRODUCTS

2.01 CONCRETE MATERIALS

A. Cement: ASTM C150, Type I - Normal Portland Type, Gray Color.

B. Fine and Coarse Aggregates: ASTM C33.

C. Water: Potable.

2.02 ADMIXTURES

A. Air Entrainment: ASTM C260.

B. Chemical: ASTM C494. Maximum 0.05% Chloride Ion Contents.

C. The use of calcium chloride in any concrete is not permitted.

2.03 ACCESSORIES

A. Non-Shrink Grout: Premixed compound consisting of non-metallic aggregate, cement, water reducing and plasticizing agents; capable of developing minimum compressive strength of 2,400 psi in 48 hours and 7,000 psi in 28 days.

B. Curing Compound: Dress and Seal No. 18 by L&M Construction Chemicals, MB-429 by Master Builders, or Sikagard Cure/Hard by the Sika Corporation.

C. Epoxy Grouted Adhesive Anchors: Hilti, Red Head, Simpson, or Rawl.

2.04 CONCRETE MIX

A. Mix concrete in accordance with ACI 304. Deliver concrete in accordance with ASTM C94.

B. Select proportions for normal weight concrete in accordance with ACI 301.

C. Provide normal weight concrete of the following characteristics:

1. Compressive strength at 28 days: 4,000 psi.

2. Slump: 4 in. - A tolerance of up to 1 in. above the maximum shall be allowed for one batch in any five consecutive batches tested.

3. Water/cement ratios: 0.4 (max).

D. Use accelerating admixtures in cold weather only when approved by Owner's Representative. Use of admixtures will not relax cold weather placement requirements.

E. Use set-retarding admixtures during hot weather only when approved by Owner's Representative.

F. Water-reducing admixtures may be used in all concrete except footings and in strict compliance with the manufacturer's directions.

G. Add air-entraining agent to concrete mix for air content of 6% (± 1%).

PART 3. EXECUTION

3.01 EXAMINATION

A. Verify requirements for concrete cover over reinforcement.

B. Verify that anchors, seats, plates, reinforcement and other items to be cast into concrete are accurately placed, positioned securely, and will not cause hardship in placing concrete.

3.02 PLACING CONCRETE

A. Place concrete in accordance with ACI 301.

B. Notify Owner's Representative minimum of 24 hours prior to commencement of operations.

C. Ensure reinforcement, inserts, and embedded parts are not disturbed during concrete placement.

D. Maintain records of concrete placement. Record date, location, quantity, air temperature, and test samples taken.

E. Place concrete continuously between predetermined expansion, control, and construction joints.

F. When air temperature is between 80°F and 90°F, reduce the mixing and delivery time specified in ASTM C94 from 1-1/2 hours to 75 minutes. When the air temperature is above 90°F, reduce the mixing and delivery time to 60 minutes.

G. Cold weather concreting. Comply with ACI 306 except as follows:

1. In freezing weather, provide suitable means for maintaining concrete temperature at a minimum of 70°F for three days, or 50°F for five days after placing.

2. Cooling of concrete to outside temperature: Not faster than 1° per hour for first day and 2° per hour thereafter until outside temperature is reached.

3. Maximum temperature of concrete produced with heated aggregated, heated water, or both, at any time during its production or transportation: 90°F.

4. Do not mix chemicals or other foreign materials in concrete to prevent freezing or to accelerate hardening of concrete, unless approved in writing by Owner's Representative.

H. Hot weather concreting. Comply with ACI 305R.

1. ACI recommendations shall be observed when any combination of high air temperature, low relative humidity and wind velocity tend to impair the quality of fresh or hardened concrete.

2. Retarding and water reducing admixtures shall be approved in writing for each concrete mix design prior to placement.

3.03 CONCRETE FINISHING

A. Provide exterior concrete formed surfaces to be left exposed with smooth rubbed finish in accord with ACI 301. All other formed surfaces shall have fins, projections and offsets removed.

B. Provide Class A tolerances to exterior concrete slabs according to ACI 301.

1. Broom finish all exterior slabs. Broom out all tool marks.

C. Pitch slabs to drain.

3.04 CURING AND PROTECTION

A. Immediately after placement, protect concrete from premature drying, excessively hot or cold temperatures, and mechanical injury.

B. Maintain concrete with minimal moisture loss at relatively constant temperature for a period necessary for hydration of cement and hardening of concrete in accordance with ACI 308.

C. Cure and protect finished concrete slabs in accordance with ACI 308.

3.05 FIELD QUALITY CONTROL

A. Field inspection and testing will be performed in accordance with ACI 301 and under provisions of Section 01010, paragraph 8.0.

B. Testing firm will take cylinders, perform slump and air entrainment tests in accordance with ACI 301.

C. Provide free access to Work and cooperate with appointed firm.

D. Submit proposed concrete mix design to Owner's Representative firm for review 14 days prior to commencement of Work.

E. Testing frequency shall be as specified in Section 01010, paragraph 8, except that one additional test cylinder will be taken during cold weather concreting, cured on job site under same conditions as concrete it represents.

3.06 PATCHING

A. Defective Concrete: Concrete not conforming to required lines, details, dimensions, tolerances or specified requirements.

B. Repair or replacement of defective concrete will be determined by Owner's Representative and performed by the Contractor at no additional cost to the project.

C. Do not patch, fill, touch-up, repair, or replace exposed concrete except upon express direction of Owner's Representative for each individual area.

END OF SECTION 03300

DIVISION 3 - CONCRETE
Section 03400 - Concrete Embedment Liner

PART 1. GENERAL

1.01 WORK INCLUDES

A. Specifications and guidelines for manufacturing and installing high-density polyethylene embedment liners.

1.02 RELATED SECTIONS

A. Section 03100 - Concrete Formwork.

B. Section 03300 - Cast-in-Place Concrete.

1.03 REFERENCES

A. American Society for Testing and Materials (ASTM)

1. D 1505 Test Method for Density of Plastics by the Density-Gradient Technique
2. D 1603 Test Method for Carbon Black in Olefin Plastics
3. D 5199 Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
4. D 5596 Standard Test Method for Microscopic Evaluation of the Dispersion of Carbon Black in Polyolefin Geosynthetics
5. D 6693 Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes
6. D 1204 Standard Test Method for Linear Dimensional Changes of Nongrid Thermoplastic Sheeting or Film at Elevated Temperature
7. D 696 Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C With a Vitreous Silica Dilatometer
8. D 746 Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact
9. D 570 Standard Test Method for Water Absorption of Plastics
10. E 96 Standard Test Method for Water Vapor Transmission of Material

1.04 SUBMITTALS

A. All work for and in connection with the installation of the lining, field seaming and welding joints shall be completed in strict conformity with all applicable instructions and recommendations of the liner manufacturer.

B. Included with the shipment of liner, submit certified test reports that the liner and material are manufactured in accordance with standards specified herein.

1.05 QUALIFICATIONS

A. The HDPE liner specified in this section shall be furnished by a manufacturer who is fully experienced, reputable and qualified in the manufacturing of the materials. The manufacturer must at least 10 years of manufacturing experience.

B. Locking devices must be extruded to the sheet as a one step process.

C. Liner shall be GSE StudLiner as manufactured by GSE Lining Technology, Inc.

D. Liner shall be 8 feet in width.

E. Liner shall demonstrate a minimum pull-out strength of 14,000 psf.

1.06 COORDINATION

A. Coordinate with placement of formwork, formed openings and other work.

PART 2. PRODUCTS

2.01 ROLL DIMENSIONS

A. Embedment sheets shall be produced in rolls that are 8.0 ft (2.4 m) in width and a thickness range of 80 mils (2.0 mm) to 200 mils (5.0 mm) in thickness. Roll lengths vary according to thickness.

B. Locking studs of the same material as that of the liner shall be integrally extruded with the sheet. Stud spacing shall be on approximate 1.25 in (30 mm) centers, such that there are approximately 110 studs per square foot (1200 per square meter).

2.02 MATERIAL PROPERTIES

A. The material used in the embedment liner and in all welding strips shall be made from 97-98% virgin high density polyethylene and 1.5-3% carbon black or pigmentation for the purpose of an otherwise specified color.

B. Plasticizer shall not be added to the resin formulation.

C. Embedment sheet and welding strips shall be free of holes, pinholes, bubbles, blisters, excessive contamination by foreign matter, and nicks and cuts on roll edges.

D. The HDPE cap strips shall be made from HDPE, have good impact resistance and have an elongation sufficient to bridge up to 1/4 inch settling cracks.

E. Cap strips shall be approximately 4 inches wide or greater and shall be equivalent to that of the liner.

F. Material shall maintain a repairable state through it's lifecycle by methods approved and recommended by the manufacturer.

G. Embedment sheets shall have the following physical properties when tested in accordance with Table 1.

H. Raw resin shall have the following properties when tested in accordance with Table 2.

Table 1: Material Properties

Property	Test Method	Nominal Value				Testing Frequency
Thickness, mm (mil)	ASTM D 5199	2.00 (80)	3.00 (120)	4.00 (160)	5.00 (200)	Every 5th roll
Density, g/cm^3	ASTM D 1505	0.94	0.94	0.94	0.94	1/100,000 ft^2
Tensile Properties Strength@Yield,lb/in^2 (MPa) Elongation @ Break, %	ASTM D 6693 Type IV, Dumbell G.L.= 2.0in.	2,200 (14.5) 500	2,200 (14.5) 500	2,200 (14.5) 500	2,200 (14.5) 500	1/100,000 ft^2
Stud Pull-Out Strength[1], lb/ft^2 (kN/m^2)		>14,000 (669.89)	>14,000 (669.89)	>14,000 (669.89)	>14,000 (669.89)	1/ product
Carbon Black Content/ Pigment Content, % Black Liner Gray Liner	ASTM D 1603, mod. ASTM D 5630, mod.	2-3 1.5 – 2.5	2-3 1.5 – 2.5	2-3 1.5 – 2.5	2-3 1.5 – 2.5	1/100,000 ft^2
Carbon Black Dispersion[2]	ASTM D 5596	Note 2	Note 2	Note 2	Note 2	1/100,000 ft^2
Notched Constant Tensile Load, hours	ASTM D 5397	400	400	400	400	1/ formulation
Coefficient of Linear Thermal Expansion, per °C	ASTM D 696	1.20E-04	1.20E-04	1.20E-04	1.20E-04	1/ product
Low Temperature Brittleness, °C	ASTM D 746	-77	-77	-77	-77	1/ product
Dimensional Stability, % (each direction)	ASTM D 1204	± 1.0	± 1.0	± 1.0	± 1.0	1/ product
Water Absorption, %	ASTM D 570	0.1	0.1	0.1	0.1	1/ product
Water Vapor Transmission, (g/m^2/day)	ASTM E 96	<0.01	<0.01	<0.01	<0.01	1/ product

[1]Note: Concrete must have a compressive strength of at least 5,000 lb/in^2 (34,500 kPa).
[2]Note: Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view for category 3.

Table 2: Raw Material Properties

Property	Test Method	Value	Testing Frequency
Density, g/cm3	ASTM D 1505	0.932	1/ resin lot
Melt Flow, g/10 min	ASTM D 1238 (190/2.16)	≤ 1.0	1/ resin lot
OIT, minutes	ASTM D 3895 (1atm/200°C)	100	1/ formulation

2.03 MATERIAL SUPPLY

A. Embedment sheets shall be supplied in roll form, sheets, pre-fabricated tubes or panels.

B. Cap strips shall be supplied in 4 inch widths or greater.

PART 3. EXECUTION

3.01 PLACEMENT

A. Place, support and secure reinforcement against displacement. Do not deviate from required position. Clean reinforcement of foreign particles or coatings.

B. Accommodate placement of formed openings.

C. Conform to ACI 318 code for concrete cover over reinforcement.

3.02 FIELD QUALITY CONTROL

A. Contractor shall notify the Owner's Representative at least 24 hrs. in advance of concrete placement. Placement of the Concrete Embedment Liner shall occur in such sequence that the Owner's Representative has sufficient time to inspect the correctness of the placement within the concrete formwork area. The Owner's Representative retains the right to require necessary revisions be made before concrete is placed.

END OF SECTION 03200

AECOM

Appendix E: Operation & Maintenance Manual for #1 Ash Pond

Ameren Energy Generating

Coffeen Power Station

Operational Procedure

x-xxx-xxxx--xxx

Operation & Maintenance Manual for #1 Ash Pond

(Bottom Ash Recycle Pond)

Effective Date: xx/xx/xxxx

Reason for Change: New Procedure

Approved By: ***x*** Date: **xx/xx/xxxx**

x
John Romang

Responsible Department: Coffeen Power Station, Technical Services Department

- ☐ **This entire document shall be in the field during procedure performance.**
- ☐ **The following portions of this procedure shall be in the field during procedure performance: _____**
- ☐ **_____ from this procedure shall be in the field during procedure performance.**
- ☐ **No part of this procedure is required to be in the field during procedure performance.**

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1.0 Purpose

1.1 This procedure is intended to ensure the safe and environmentally responsible operation and use of the #1 Ash Pond (Bottom Ash Recycle Pond) at the Coffeen Power Station. The primary purpose of the #1 Ash Pond is for the removal of bottom ash by settling and the recirculation of slag tank water. The pond is used to supply water to the Unit 1 and Unit 2 ash handling systems via the recycle pumps.

2.0 Scope

2.1 This procedure applies to all onsite personnel and the Dam Safety Group staff.

3.0 Responsibilities

3.1 Outside Unit Operator – Checks the pond level and screens once a shift. Operates the facilities as described in this Operational Procedure. Reports any conditions noted during routine activities to the Shift Supervisor and Chemistry Department. Writes job requests if a problem is identified.

3.2 Shift Supervisor (SS) - Calls the Chemistry Department when structural concerns or overflow conditions are reported. Make entries into the shift electronic log book (e-log) indicating the concern and actions taken.

3.3 Dam Safety Inspector - Conducts weekly detailed dam safety inspections and provides a report with findings and recommendations. Make entries in e-log indicating the concern and actions taken.

4.0 Historical Information

4.1 The #1 Ash Pond was initially constructed to be a mixed ash deposition pond and was put in service in the mid-1960's. It is located east of the Main Building. It is a 23 acre pond with a maximum outer berm height of 41.5 feet above ground surface level (approximately elevation 637.5'). The pond overflow was located on the north east corner of the pond and discharged into the flume.

4.2 The #1 Ash Pond was converted to act as a closed loop system in the late **1970's** when the dewatering bins were installed. The mixed ash was removed and deposited into the #2 ash pond during the closure of #2 pond. The #1 Ash Pond berms were modified and an inner berms was added to the pond to aid in dropping out bottom ash solids. Exterior berm elevation is approximately 637.5 feet.

4.3 The #1 Ash Pond was equipped with an emergency overflow at the outlet structure. When the pond level reaches approximately 6.5 feet from the top of the berm, it will overflow into the flume. Overflow will be reported to the EPA. In 2011 there was an assessment of the overflow pipe which showed no obstructions or damage.

4.4 In **2006**, the bottom ash system was modified to directly sluice bottom ash into the pond, bypassing the retired dewatering bins. Bottom Ash is removed from the pond via an outside contractor on an as needed (typically daily) basis.

5.0 Water Supply

All water inlets to the pond are located on the west side of the pond.

The ash sluice lines (from the valve house) discharge to the pond. These lines are used to convey ash from the slag handling system to the #1 Ash Pond. These lines are the southern most of the pond inlets. HPSW system is routed to the pond (valve house sparger valves, floor drains at Unit 1 cyclone level).

The Slag Tank Overflow sump pumps discharge into the pond at the concrete culvert located directly east of the of the lime/soda ash silo. Also in this area, a small stainless line extends thru the concrete. This is the discharge of the sludge pumps at the Waste Treatment System in the Recycle Pump House building.

The recycle pump flow control valves discharge to the pond through a line located at the northwest corner of the pond. Also in the vicinity of this line is the discharge pipe of the recycle pump house sump pumps.

Water from the Unit 1 and Unit 2 oil water separators are typically routed to the pond via the Slag Tank Overflow Pump (STOP) House sumps. Water entering these sumps are floor and roof drains in the plant and the yard area immediately to the north of the main building.

6.0 Operations Requirements

Pond Level - Plant personnel shall monitor the level of the #1 Ash Pond on a daily basis. Pond level is maintained at approximately 1.0' to 1.5' at the water level staff gauge located on the pond side of the screens. The staff gauge has elevation 629.0' as the 0 elevation.

At 2.0' water level (elevation 631.0 feet), the pond overflows resulting in a sampling and analysis requirement for Total Suspended Solids and Oil and Grease with reporting of the results to the IEPA. If the pond is found at or above 2.0' on the pump side staff gauge, contact Chemistry immediately.

Water can be added to the pond from either the Unit 1 or Unit 2 Low Pressure Service Water (LPSW) headers via piping that discharges to the slag tank overflow trench.

Water can be drained from the pond via the water supply pipe to the dewatering bins. Opening this valve drains water from the recycle header which will remove water from the #1 Ash Pond.

Recycle Pump Intake Structure – Suction to the recycle pumps is supplied from the intake structure located at the west end of the north leg of the pond. This is the only water discharge point from the pond. Water level staff gauges are located upstream and downstream of the trash screens for determination of the screen differential. At 0.5' differential, the screens should be cleaned. Level sensors are also installed upstream and downstream of the screens. Digital displays of the upstream and downstream levels are located along the north side of the catwalk leading out to the screen enclosure. These level sensors will generate a high screen differential alarm in the Control Room DCS. Check screen differential (should clean screens at 6 inches differential.) When the screens become plugged, suction to the recycle pumps is reduced. Call shift supervisor to report if screens needs to be cleaned.

Oil Boom – Plant personnel shall monitor the oil boom that is provided upstream of the intake structure. Check condition of oil booms across pond, at discharge, and across pond inlet. Booms should be replaced when they become oil saturated or damaged. Also check that booms have not come unattached from one another. Write JR to change out booms or to reconnect booms when required.

Emergency Conditions – If a condition arises where there is a possibility of an embankment failure, then the following procedures will be followed:

1. Notify the Supervising Engineer Dam Safety immediately.

7.0 Dam Safety Requirements

7.1 Dam Safety Inspections - The plant's impoundment and flood prevention structures shall be inspected and maintained in a manner to ensure safe and environmentally responsible operations. A regular maintenance program shall be performed and shall consist of the following inspection items:

1. Earth embankments: Walk the crest, side slopes, and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlement, slumps, slides, and animal burrows. Frequency of inspection: Weekly.
2. Vegetation: Grass should be a thick vigorous growth to stabilize the earth embankment soils and prevent erosion form occurring. There should be NO trees on the earth embankment and none within a minimum of 20 feet of the embankment toe or other structures. Mowing frequency: Semiannually.
3. Well Readings: Record level of wells on the crest and toe of the berm. Frequency: Quarterly.
4. Special Inspections – Special inspections of the levees and ash pond berms shall be performed after earthquakes, floods, water level exceedance in the ponds, or heavy rainfall events. Inspection and report shall be equal to an annual inspection level of detail. Water level in the pond should be noted after a heavy rainfall. Dam Safety staff shall accompany plant personnel on special inspections. Frequency: As required.

8.0 Maintenance Log

8.1 Dam & Berm Inspector shall enter on e-log under the Dam Safety tab all weekly inspections, any usual occurrences, and maintenance performed.

9.0 Contact Numbers

Plant Environmental Supervisor: John Romang / 217-534-7629
Plant Dam & Berm Inspector: Vito Passariello/ 217-534-7664
Plant Control Room: 217-534-7668 / 217-534-7669
Supervising Engineer Dam Safety: Steve Bluemner / 314-554-6298
Dam Safety Staff Contact: Mike Wagstaff / 314-554-6296

10.0 References

AECOM

Appendix F: Operation and Maintenance Manual, Gypsum Management FacilityOperation (2015)

Operation and Maintenance Manual
Coffeen Energy Center
Gypsum Management Facility
Montgomery County, Illinois

IDNR Permit # DS2014019
Dam Permit # IL50578 & IL50579

Prepared For:

ILLINOIS POWER GENERATING COMPANY
Coffeen Energy Center
134 CIPS Lane
Coffeen, Illinois 62017

Prepared By:

HANSON PROFESSIONAL SERVICES INC.
1525 South Sixth Street
Springfield, Illinois 62703

Amended By:

DYNEGY OPERATING COMPANY
1500 Eastport Plaza Drive
Collinsville, Illinois 62234

Original: February 2008
Amended: March 2015

OPERATION AND MAINTENANCE MANUAL
COFFEEN ENERGY CENTER
GYPSUM MANAGEMENT FACILITY
MONTGOMERY COUNTY, ILLINOIS

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SECTION 1.0
GENERAL

This operation and maintenance (O&M) manual outlines objectives, proposed policies, responsibilities, and procedures for Coffeen Energy Center personnel who are responsible for the management of the Coffeen Energy Center Gypsum Management Facility (GMF). The GMF incorporates two reservoirs, the Gypsum Pond and the Recycle Pond, for processing and storing gypsum.

1.1 REASONS FOR DEVELOPMENT AND DISSEMINATION OF THE O&M MANUAL

The State of Illinois Rivers, Lakes and Streams Act, (615 ILCS 5) Paragraph 23a includes the statement "The Department is authorized to carry out inspections of any dam within the State, and to establish standards and issue permits for the safe construction of new dams and the reconstruction, repair, operation and maintenance of all existing dams." (emphasis added).

Part 3702 of Section 17 of the Illinois Administrative Code, Chapter I entitled the "Construction and Maintenance of Dams" details the requirements to obtain a permit for the construction, operation, and maintenance of a dam. Section 3702.40 b) includes the following statements:

> "4) An applicant for a Class I or II dam shall submit an operational plan specifying the method and schedule for the operation of the dam and the routine operating procedures to keep the dam in good working order, including an emergency warning plan." and
>
> "5) As a condition of each permit, the dam owner shall submit a maintenance plan detailing the procedures and schedules to be followed to maintain the dam and its appurtenances in a reasonable state of repair."

Thus, it is a requirement of all dam owners who have dams which fall under the jurisdiction of the Illinois Department of Natural Resources Office of Water Resources (IDNR-OWR) to operate and maintain them safely.

As a dam owner, Illinois Power Generating Company (IPGC) Coffeen Energy Center is responsible for the safety of the public and for maintaining the structures at the facility for both safety and economy. The overall public interest is served by providing a document to serve as a basis for the safe and economical operation and maintenance of the dam during both emergency and day-to-day conditions.

1.2 GENERAL RESPONSIBILITIES CONCERNING DAMS

IPGC is responsible for the operation and maintenance of the Gypsum Pond Dam and the Recycle Pond Dam. These responsibilities include general maintenance (mowing, removing debris from decants, placing riprap where needed, etc.), operation, inspection and emergency action decisions.

SECTION 2.0
DEFINITIONS

Appurtenant Works - The structures or machinery auxiliary to dams which are built to operate and maintain dams; such as outlet works, spillways, gates, valves, channels, etc.

Boil - A stream of water discharging from the ground surface downstream of the dam carrying with it a volume of soil which is distributed around the hole formed by the discharging water.

Berm - A horizontal step or bench in the sloping profile of an embankment dam.

Breach - A break, gap, or opening (failure) in a dam which releases impoundment water.

Dam - A barrier built for impounding or diverting the flow of water.

Dike (Levee) - An embankment, usually applied to embankments or structures built to protect land from flooding.

Drain, Layer or Blanket - A layer of pervious material in a dam to facilitate the drainage of the embankment including such items as a toe drain, a weephole, and a chimney drain.

Drawdown - The resultant lowering of the water surface level due to the release of water from the impoundment.

Embankment - Fill material, usually rock or earth, placed with sloping sides.

Earthen Dam - Any dam constructed of excavated natural materials.

Emergency Action Plan - A predetermined plan of action to be taken to reduce the potential for property damage and loss of lives.

Failure - An incident resulting in the uncontrolled release of water from the dam.

Freeboard - The vertical distance between a stated water level and the top of the dam.

Gate or Valve - In general, a device in which a leaf or member is moved across the waterway to control or stop the flow.

Groin - The junction of the upstream or downstream face of the dam with the valley wall.

Maintenance - The upkeep, involving labor and materials, necessary for efficient operation of dams and their appurtenant works.

Operation - The administration, management, and performance needed to operate the dam and appurtenant works.

Operation and Maintenance Inspection - Inspections conducted by the dam operator. These inspections are frequent visual "Walk-around" inspections of the dam surface and appurtenant works.

Outlet - An opening through which water can freely discharge for a particular purpose from an impoundment.

Phreatic Surface - The upper surface of saturation in an embankment.

Piping - The progressive development of internal erosion by seepage, appearing downstream as a hole or seam, discharging water that contains soil particles.

Riprap - A layer of large stones, broken rock or precast blocks placed in a random fashion usually on the upstream slope of an embankment dam, on a reservoir shore, or on the sides of a channel as a protection against wave and ice action.

Silt/Sediment - Soil particles and debris in an impoundment.

Slump/Slide Area - A portion of earth embankment which moves downslope, sometimes suddenly, often with cracks developing.

Spillway System - A structure or structures over or through which flows are discharged. If the flow is controlled by gates, it is considered a controlled spillway. If the elevation of the spillway crest is the only control of the flows, it is considered an uncontrolled spillway.

Emergency Spillway - A spillway designed to operate very infrequently, only during exceptionally large floods, usually constructed of materials expected to erode slowly.

Principal Spillway - The main spillway which controls both normal and flood flows and is usually constructed of non-erodable materials.

Auxiliary Spillway - A spillway which works in conjunction with the principal spillway to control flood flows and is usually constructed of non-erodable materials.

Stilling Basin - A basin constructed to dissipate the energy of fast flowing water, such as from a spillway, and to protect the streambed from erosion.

Toe of Embankment - The junction of the face of the dam with the ground surface in the floodplain upstream or downstream of the dam.

SECTION 3.0
INFORMATION ABOUT THE DAMS

3.1 LOCATION

The Gypsum Pond Dam and Recycle Pond Dam are located in the NW 1/4 of Section 11, Township 7 North, Range 3 West of the Third Principal Meridian in Montgomery County, Illinois. More specifically, the dams are located approximately 1.5 miles south of Coffeen, Illinois. A map showing the location of the dams is included in Appendix A.

3.2 DESCRIPTION OF DAM AND APPURTENANCES

The gypsum pond perimeter earthen dam, the gypsum pond "gypsum" dam, and the recycle pond dam will all be regulated in accordance with 17 Illinois Administrative Code (IAC) Part 3702, Construction and Maintenance of Dams. The gypsum pond perimeter earthen dam, which will be lined with a dual high density polyethylene (HDPE) geomembrane system, will have a maximum embankment height of 13 ft and a maximum impounding capacity of 442 acre-ft (measured at the top of earthen dam elevation 632 ft). There will be an additional 123 acre-ft of incised storage. The total volume of gypsum stored within the completed gypsum pond dams will be approximately 2,478 acre-ft.

The dam for the recycle pond, which will be lined with a 60 mil HDPE geomembrane, will have a maximum embankment height of 16 ft and a maximum impounding capacity of 243 acre-ft (measured at the top of dam elevation 629 ft). There will be an additional 99 acre-ft of incised storage.

The gypsum pond will be divided into two sub-cells for the containment of scrubber sludge (gypsum). Discharges to the site will switch back and forth between the two sub-cells so that one sub-cell can be dewatered and raised while the other is in use. There will be two fixed decant pipes constructed in the gypsum stack – one for each sub-cell - which will discharge to stilling wells located adjacent to the perimeter ditches. The control elevation on the decant pipes will be maintained 5.0 ft below the lowest point on the stack cell crest. The decant pipes will enable the cells to be dewatered after storm events so that a minimum of 5.0 ft of freeboard will be maintained in each cell. A minimum of 4.7 ft of freeboard is required above the decant inlet to contain the Probable Maximum Flood (PMF) storm event in addition to peak wind generated waves.

The gypsum pond dam perimeter ditches will be located on the interior sides of the earthen dam. Runoff from the stack will be conveyed through the ditches to a transfer channel which will discharge into the recycle pond. The ditches will be trapezoidal in shape with a 15 ft bottom width, a maximum depth of 9 ft and a longitudinal slope of 0.0005 ft/ft. Side slopes will be 3H:1V. During operation, the ditches will be monitored for erosion. If erosion of the designed ditch geometry occurs, a geogrid will be used for stabilization.

The transfer channel between the gypsum pond dam and the recycle pond have a trapezoidal cross-section with 3H:1V side slopes will be lined with HDPE. The 500 ft long transfer channel will transition from a 32-ft bottom width at an invert elevation of 623.0 ft at the upstream end to a 60-ft bottom width at an invert elevation of 622.0 ft at the downstream end. The transfer channel will be fitted with stop logs capable of raising the discharge control elevation to 625.0 ft. To prevent degradation of the HDPE liner due to flow velocities, the transfer channel and a portion of the recycle pond dam will incorporate an additional sacrificial layer of HDPE.

The emergency spillway for the recycle pond will consist of three 6 ft by 6 ft precast reinforced concrete risers (drop inlets) with a top elevation of 624 ft (5 ft below the top of the dam). The recycle pond's HDPE liner will attach to the exterior sides of each riser. A 4-ft diameter HDPE outlet conduit will be constructed at each riser with an upstream invert of 615.0 ft and a downstream invert of 613.0 ft. Assuming a normal pool elevation of 624 ft (control elevation of the risers), the emergency spillway has been designed to pass the 24-hour PMF storm event with adequate freeboard to prevent overtopping of the recycle pond crest by wind generated waves. The emergency spillway has been provided in the event of accident or catastrophic rainfall only. It is not expected to be activated during the life of the facility. As designed, all discharges from the system will be through the pump house located on the southeast corner of the recycle pond.

3.3 SIZE AND HAZARD CLASSIFICATION

If a worst case failure of the gypsum pond dam were to occur, and the entire volume of the stack is released easterly into Coffeen Lake, the Coffeen Lake reservoir has adequate freeboard to accept this additional volume without overtopping the dam during flood events up to and including the 60 percent PMF. However, the power plant and several residences could potentially be impacted if the gypsum stack dam were to fail in a westerly direction. Considering the regulatory criteria established in Part 3702, the gypsum stack perimeter earthen dam and the gypsum stack "gypsum" dam are classified as intermediate-size Class I (high hazard potential) dams.

A failure of the recycle pond dam would discharge water to Coffeen Lake but it is not anticipated to result in loss of life or any significant economic damage. Breach analyses indicate that a failure of the recycle pond dam during a PMF event would be expected to result in an increase in the Coffeen Lake water surface elevation of not more than ½ inch. Accordingly, the recycle pond dam is classified as a small-size Class III (low hazard potential) dam.

3.4 PURPOSE OF THE DAMS

The dams will be used to dewater, store and dispose of flue gas desulphurization sludge (gypsum) from the Coffeen Power Station (the Plant). Gypsum will be transported to the Gypsum Pond Dam in slurry form (approximately 20 percent solids) and allowed to settle. Clarified process water will then be decanted to the recycle pond and returned to the Plant for reuse via a pipeline.

3.5 PERTINENT DATA

Pertinent data about the dams, appurtenant works, and reservoirs are presented in Table 3-1 and Table 3-2.

Table 3-1 Pertinent Data for the Gypsum Pond Earthen Dam
(Based on the Construction of 2 Gypsum Cells)

Perimeter Ditches		
Bottom Width	15.00	feet
Top Width	73.50	feet
Depth	9.00	feet
Outer Side Slope	3:1	H:V
Inner Side Slope	3:1	H:V
Upstream Invert	624.85	feet
Downstream Invert	623.00	feet
Ditch slope	0.00050	ft/ft
Bank Full Cross-sectional Area	378.00	sf
Length of Each Ditch (Centerline)	3710.00	feet
Bank Full Volume of Each Ditch	32.19	acre-ft
Total Ditch length (Centerline)	7420.00	feet
Total Ditch Bank Full Volume	64.39	acre-ft

Transfer Channel		
Bottom Width	32.00	feet
Top Width	86.00	feet
Depth	9.00	feet
Upstream Invert	623.00	feet
Downstream Invert	622.00	feet
Weir Elevation	625.00	feet
Weir Length (at 2 ft height)	44.00	feet
Dam		
Top of Dam Elevation	632	feet
Reservoir Surface Area	77.29	acres
Total Watershed Area	77.29	acres
Dam Length	7720	feet
Dam Height	13	feet

1.0 PMF Storm Event		
Storm Duration	24	hours
Peak Outflow Discharge	1100.7	cfs
Total Discharge Volume	228.83	acre-ft
Peak WSEL in Perimeter Ditches	629.89	feet
Freeboard over Max WSEL	2.11	feet
Wave Runup/Wind Setup	2.06	feet
Adequate Freeboard?	**YES**	

0.5 PMF Storm Event		
Storm Duration	24	hours
Peak Outflow Discharge	541.1	cfs
Total Discharge Volume	122.41	acre-ft
Peak WSEL in Perimeter Ditches	628.23	feet
Freeboard over Max WSEL	3.77	feet
Wave Runup/Wind Setup	2.06	feet
Adequate Freeboard?	**YES**	

100-yr Storm Event - Critical Duration		
Storm Duration	12	hours
Peak Outflow Discharge	92.6	cfs
Total Discharge Volume	50.91	acre-ft
Peak WSEL in Perimeter Ditches	626.07	feet
Freeboard over Max WSEL	5.93	feet
Wave Runup/Wind Setup	2.06	feet
Adequate Freeboard?	**YES**	

100-yr Storm Event - 24 Hour Duration		
Storm Duration	24	hours
Peak Outflow Discharge	62.9	cfs
Total Discharge Volume	57.01	acre-ft
Peak WSEL in Perimeter Ditches	625.84	feet
Freeboard over Max WSEL	6.16	feet
Wave Runup/Wind Setup	2.06	feet
Adequate Freeboard?	**YES**	

Note: The Critical Storm Duration is the duration of the rainfall event which produces the highest reservoir water surface elevation in the Gypsum Stack Perimeter Ditches for the given storm frequency. In each case, the starting normal pool elevation of the Recycle Pond is considered to be at elevation 624 ft.

Table 3-2 Pertinent Data for the Recycle Pond Dam
(Based on the Construction of 2 Gypsum Cells)

Dam		
Top of Dam Elevation	629	feet
Invert of Reservoir Elevation	605	feet
Reservoir Area at Invert	11.55	acres
Reservoir Area at Top of Dam	17.07	acres
Total Reservoir Volume	341.91	acre-ft
Volume at Elevation 624 ft	259.60	acre-ft
Total Watershed Area	94.36	acres
Dam Length	3600	feet
Dam Height	16	feet

3 Spillways- 6ft x 6ft inlet w/ 4ft dia outlet pipe		
Weir Length	22	feet
Weir Elevation	624.00	feet
Outlet Conduit Length	120	feet
Outlet Conduit Diameter (Inside)	48	inch
Upstream Invert	615	feet
Downstream Invert	614	feet
Outlet Conduit Slope	0.00833	

1.0 PMF Storm Event - Normal Pool at Elev. 624 ft		
Storm Duration	24	hours
Peak Inflow	1261.6	cfs
Peak Outflow	586.9	cfs
Peak Storage	315.47	acre-ft
Peak WSEL (HEC-HMS)	627.45	feet
Freeboard over Peak WSEL	1.55	feet
Wave Runup/Wind Setup	1.20	feet
Adequate Freeboard?	**YES**	

1.0 PMF Storm Event - Normal Pool at Elev. 609 ft		
Critical Storm Duration	24	hours
Peak Inflow	1261.6	cfs
Peak Outflow	289.7	cfs
Peak Storage	280.65	acre-ft
Peak WSEL (HEC-HMS)	625.34	feet
Freeboard over Peak WSEL	3.66	feet
Wave Runup/Wind Setup	1.20	feet
Water Released from Dam?	**YES**	

0.5 PMF Storm Event - Normal Pool at Elev. 624 ft		
Storm Duration	24	hours
Peak Inflow	608.4	cfs
Peak Outflow	413.6	cfs
Peak Storage	286.48	acre-ft
Peak WSEL (HEC-HMS)	625.69	feet
Freeboard over Peak WSEL	3.31	feet
Wave Runup/Wind Setup	1.20	feet
Adequate Freeboard?	**YES**	

0.5 PMF Storm Event - Normal Pool at Elev. 613 ft		
Critical Storm Duration	24	hours
Peak Inflow	608.4	cfs
Peak Outflow	0	cfs
Peak Storage	255.83	acre-ft
Peak WSEL (HEC-HMS)	623.75	feet
Freeboard over Peak WSEL	5.25	feet
Wave Runup/Wind Setup	1.20	feet
Water Released from Dam?	**NO**	

100-yr Storm Event - Normal Pool at Elev. 624 ft		
Critical Storm Duration	12	hours
Peak Inflow	113.2	cfs
Peak Outflow	95.8	cfs
Peak Storage	269.36	acre-ft
Peak WSEL (HEC-HMS)	624.63	feet
Freeboard over Peak WSEL	4.37	feet
Wave Runup/Wind Setup	1.20	feet
Adequate Freeboard?	**YES**	

100-yr Storm Event - Normal Pool at Elev. 619 ft		
Critical Storm Duration	24	hours
Peak Inflow	76.6	cfs
Peak Outflow	0	cfs
Peak Storage	258.48	acre-ft
Peak WSEL (HEC-HMS)	623.94	feet
Freeboard over Peak WSEL	5.06	feet
Wave Runup/Wind Setup	1.20	feet
Water Released from Dam?	**NO**	

Note: The above variation in normal pool elevations for the Recycle Pond is for the purpose of documenting the water surface elevation which must be maintained in the recycle pond in order to prevent the release of water from the GMF for the above described storm events.

SECTION 4.0
OPERATIONS ACTIVITIES

4.1 INTRODUCTION

The operations plan describes the proposed operation of the Coffeen Gypsum Management Facility (GMF) which includes the gypsum pond and the recycle pond.

4.2 SITE OPERATIONS AND PERSONNEL

4.2.1 Site Operations

The GMF will receive gypsum slurry 24 hours per day, seven days per week. Routine facility maintenance and construction activities will generally be conducted during day shift hours. The crest widths for both the gypsum stack earthen dam and the recycle pond dam are 20 ft. In addition, multi-directional ramps are being provided for both structures so that they are readily accessible by inspection, maintenance and gypsum recovery equipment.

The Plant is a restricted access location. Additional fencing around the perimeter of the active sedimentation cells of the gypsum stack and the recycle pond will be erected to prevent unauthorized access to the GMF, which is also under surveillance by security personnel.

4.2.2 Personnel

The proposed GMF will be owned and operated by Ameren Energy Generating Company (Ameren). Corporate offices are located in St. Louis, Missouri. Overall responsibility for the GMF operation lies with Ameren management personnel.

4.3 GYPSUM MANAGEMENT FACILITY STARTUP

The major components of the proposed GMF consist of:

- The gypsum stack dam/impoundment;
- The recycle pond;
- The earthen transfer channel that connects the two structures and through which process water will be decanted from the gypsum stack into the recycle pond; and
- The recycle pond decant and pumphouse through which process water will be returned to the Plant for reuse.

Both the recycle pond and the gypsum stack dam will be constructed before gypsum is placed within the gypsum stack dam/impoundment.

Upon startup, it is likely that the gypsum stack impoundment will have no more than a few feet of water in the bottom to prevent the high density polyethylene (HDPE) geomembrane from moving. The gypsum slurry (approximately 20 percent solids) will be pumped from the

Plant to the gypsum stack via piping. The piping will be HDPE with a suitable pressure rating for the intended hydraulic and static head. The HDPE pipe will discharge the slurry into the impoundment, and gypsum will settle by gravity.

It will take approximately 10 months before the gypsum stack impoundment is filled to elevation 623 ft, the point where process water may begin flowing into the recycle pond via the HDPE-lined earthen channel connecting the two structures. As soon as water begins to fill the recycle pond, it will be pumped back to the Plant for reuse.

4.4 WATER BALANCE

The capacity of the recycle pond has been designed to accommodate all precipitation runoff from the entire gypsum pond/recycle pond area during a 2-week complete maintenance outage at the Coffeen Power Station (the Plant) followed by a 12-week outage of one of the two units. The runoff and excess water accumulated during this time can be stored within the recycle pond without discharging. The design is based on the maximum 3.5 month precipitation that has occurred in the area since 1950. This occurred in April, May, June and half of July, 1957 and consisted of 28.83 inches of rainfall.

The water balance has been carried out for the expected life of the Site. During the first nine or ten months of operation, the water balance is positive, meaning that there is more water entering the gypsum stack/recycle pond system through process water and precipitation than is leaving the system through process water return and evaporation. However, there is 15 ft of freeboard between the pump discharge and the emergency spillway. With proper water-level management, the water surface will remain well below discharge elevation. After this initial startup period, the water balance is negative, meaning that other water sources will need to be continually added to the process water makeup stream to maintain the volume necessary for transport of the gypsum slurry.

The water balance is of particular concern since the entire system is designed to be a closed loop with no discharges. *(As previously noted, the recycle pond has been designed with an emergency spillway, but this is only to protect the structures in the event of an unforeseen accident or catastrophic rainfall event.)* Table 3.5-2 lists the maximum water surface elevation allowed in the recycle pond in order to prevent the discharge of water for the 100-year storm event and the 0.5 PMF storm event.

4.5 GYPSUM MANAGEMENT FACILITY OPERATION

4.5.1 Routine Operations

Gypsum slurry will initially be discharged at the southwestern corner of the gypsum pond impoundment. Settled gypsum will gradually create a plane of material sloping gently towards the north end of the impoundment. Depending on the slope of the settled gypsum, the discharge pipe may be moved to other corners of the impoundment to evenly distribute the material. Care must be taken during the initial filling period so to ensure that the sand layer covering the ring drains is not disturbed. If necessary, the sand may be armored with larger washed aggregate or

the impoundment may be gradually filled with water to cover the sand prior to the discharge of gypsum slurry into the impoundment.

Once the gypsum plane reaches approximately elevation 627 ft (5 ft below the earthen dam crest), a track excavator or similar piece of equipment will be used to create the first gypsum berm and to form the perimeter ditch. Each gypsum berm will be approximately 10 ft in height and will effectively create a two-compartment impoundment within its perimeter. Gypsum for construction of the gypsum berm will be obtained from the settled material on the inside of the berm, creating an inner ditch. Gypsum slurry will then be discharged alternately into the inner ditch of each compartment. Gypsum will settle out into the inner ditch and clarified process water will flood the compartment to a depth of several feet. This water will be decanted to the perimeter ditch by way of an HDPE decant pipe which will discharge to a stilling well located at the toe of the gypsum stack.

As each compartment fills with settled gypsum, the discharge piping will be moved to the alternate compartment. The compartment, or sub-cell, that is not in service will be allowed to dewater and another gypsum berm will be constructed on top of the previous gypsum berm, effectively raising the gypsum stack another 10 ft. This alternating cycle of gypsum discharge, compartment dewatering and berm construction will continue. Gypsum will be deposited in the stack with an average dry density of approximately 74 lb/ft^{3}. Drawing No. C-10201-25 provides a visual description of this process.

4.5.2 Piezometer Installation and Monitoring

The side slopes of the gypsum pond will be constructed with 3:1 side slopes. After consolidation of the settled gypsum over time, the final slopes should approach 3.75:1. The stability of each gypsum pond slope is critically dependent on the location of the phreatic surface which is anticipated to develop within the stack. Ring drains are intended to lower the phreatic surface so that it is located an adequate distance from the surface of the slope in order to maintain slope stability. In order to monitor the phreatic surface within the stack, piezometers will be installed on each side of the gypsum pond. The piezometers will be installed every 15 vertical feet up the slope (45 horizontal feet based on 3:1 side slopes) and will extend to a depth of at least 15 feet below the anticipated phreatic water surface elevation as shown in Figure 4-1. At the time of installation, each piezometer will be labeled with the "critical elevation" corresponding to the anticipated phreatic surface elevation at that location. The anticipated phreatic surface elevation is the water surface elevation which was used in the slope stability analysis of the gypsum pond. The water level in each piezometer will be read and recorded on a monthly basis. If at any time a reading is recorded higher than "critical elevation" for that specific peizometer, the design engineer must be contacted immediately for evaluation of the reading. Any readings above the "critical elevation" may be indicative of improper ring drain function and/or slope instability which could lead to a failure of the gypsum stack. Therefore, it is critical that the piezometers are installed in accordance with the construction plans and specifications and monitored in accordance with this manual. It may be necessary to install additional subdrainage to maintain the phreatic surface at the desired level within the gypsum stack.

Figure 4-1 Anticipated Phreatic Surface in Gypsum Pond

Refer to figure at the end of the report text.

4.6 DAM INSPECTIONS

The inspection program includes two types of dam inspections. The first is regularly conducted by the dam operator and is referred to as an Operation and Maintenance Inspection. The second type of inspection, referred to as the Engineering Inspection, is conducted by a qualified engineer approved by IPGC. All engineering inspection reports must be signed and sealed by an Illinois Registered Professional Engineer.

The dam operator will perform monthly Operation and Maintenance Inspections of the gypsum pond perimeter earthen dam and the gypsum berms and side slopes during the operating life of the structure. During these inspections, the gypsum stack ditches and the transfer channel will also be examined for signs of erosion and liner degradation. The "operating life of the structure" will be considered to cease upon covering of the gypsum with an HDPE/soil cover. Engineering Inspections will be conducted on an annual basis during the operating life of the structure and will continue after covering of the gypsum pond until authorization to abandon the structure is received from IDNR/OWR.

4.6.1 Operation and Maintenance Inspection

Occasional "walk-around" inspections of the dams and appurtenant works are to be made by the dam operator. During these inspections, a checklist of items to be maintained and items to be observed should be recorded. Appendix A provides an example of the Operation and Maintenance Inspection Checklist to be utilized for these inspections. **If any of the following items are found to be unusual or are cause for concern, the Shift Supervisor should be notified and the Emergency Action Plan should be immediately consulted for guidance on an appropriate course of action.**

Frequency: Operation and maintenance inspections will be performed by the dam operator on a monthly basis and also during and after unusual events such as heavy rainfall or an earthquake.

Inspection Items: During each inspection the following items should be noted in particular.

1. Water Level - Maximum reservoir levels as a result of heavy rainfall should be recorded.

2. Earth Embankment - Walk the crest, side slopes and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlement, slumps, slides, and animal burrows. These are described as follows:

    - Surface Erosion - Removal of vegetative cover by water action or pedestrian or vehicle usage forming deep ruts or gullies.

    - Seepage - The passage of water through and/or underneath the earth embankment abutment and natural groundline or at the contact between the embankment and

outlet works. It can be indicated by cattails or other wet environmental vegetation, erosion, channelization, or slumping on the embankment face.

- Cracks - Deep cracks usually indicate the movement of the dam and/or the foundation and can be in either the longitudinal (along the length of the dam) or transverse (across the dam) directions. Cracking can be an indicator of the beginning of slumps. Shallow cracks may develop during the summer when the surface soils of the embankment become severely dried and are usually of no concern in regard to the safety of the dam.

- Settlement - Settlement is indicated by depressions or low spots and can be signs of consolidation of the dam or foundation or the loss of material beneath the settlement area.

- Slumps/Slides - A slow or sudden movement of the earth embankment slope on either face toward the toe of the dam.

- If seepage indicates the presence of soil particles, or if deep cracks, settlement, slumps, or slides are noticed, a qualified engineer should be contacted immediately for consultation.

- Animal Burrows - Animal burrows result in a loss of earth embankment material and can provide seepage paths for water through the embankment.

3. Gypsum Embankment - Walk the crest, side slopes and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlement, slumps, slides and animal burrows. The descriptions for these are the same as for earth embankment.

4. Vegetation - Grass should be a thick vigorous growth to stabilize the earth embankment soils and prevent erosion from occurring. Note the height of the grass; if greater than 1 foot a mowing of the area should be scheduled before the next inspection. There should be NO trees on the earth embankment and NONE within a minimum of 20 feet of the embankment toes or other structures. The gypsum embankment will not be seeded and is not expected to have any vegetation.

5. Gypsum Stack piezometers should be inspected for any damage or loss of function. Damaged piezometers must be promptly repaired or replaced since their function is critical to ensuring stability of the gypsum stack.

6. The water level in each Gypsum Stack piezometer must be measured and recorded during each monthly inspection. If the water level in any piezometer is above the "critical elevation" as discussed in Section 4.5.2 of this plan, the Ameren Technical Services Superintendent should be notified and the **Emergency Action Plan should be immediately consulted for guidance on an appropriate course of action**.

7. Gypsum Pond LD/LCRS Drains - The change in location or amount of flows discharging from the Leak Detection/Leachate Collection Recovery System (LD/LCRS) should be recorded. If a significant change has occurred, a qualified engineer should be contacted for consultation.

8. Gypsum Stack Ring Drains - The change in location or amount of flows discharging from the Ring Drains should be recorded. If a significant change has occurred, a qualified engineer should be contacted for consultation.

9. Gypsum Stack Fixed Decant – Check the alignment and supports for the pipe. Record the amount of flows discharging from the pipe and any erosion or scour around the discharge point.

10. Gypsum Stack Perimeter Ditch – The perimeter ditch should have a consistent prismatic shape for the entire length. Inspect the perimeter ditch for evidence of erosion, sediment deposition and irregularity in channel geometry, especially in the vicinity of siphon, decant or ring drain outfall structures. If irregularities are noted, repairs should be scheduled and completed.

11. Drawdown Facilities - Check to make sure that the drawdown stop logs in the transfer ditch are undamaged, operating well and allowing for the free flow of water over them. Confirm during inspections the valves are opened and closed at least quarterly.

12. Transfer Channel - Check for any debris or other obstructions which may block or restrict the free flow of water. Check for any pools or undulation of the floor of the channel.

13. Recycle Pond Decant - Check for any debris or other obstructions around the Recycle Pond decant which may block or restrict the free flow of water. The emergency dewatering valve should be lubricated. If there is no return water in the pipe, the emergency dewatering valve should be exercised. Record the physical and operating conditions of the system.

14. Recycle Pond Drop Inlet Spillways - Check for any debris or other obstructions around the inlet crest and at the bottom of the drop inlet which may block or restrict the free flow of water. Check for the development of any rusty areas on the concrete, and seepage, cracking, breaking, or spalling of the concrete. Check for settlement or cracking of the crest. Check for any debris in the pipes which may restrict the flow of water. Check for any tears or leaks in the HDPE liner covering the concrete.

15. Recycle Pond Rip Rap Basin - Check for any debris or other obstructions in the riprap basin which may block or restrict the free flow of water. Check to make sure that the rip rap is remaining in a uniform position. Freeze/thaw action or flow over the rip rap may tend to lift or fracture, thus requiring replacement or leveling to maintain the necessary level of protection. NO trees or woody vegetation should be growing through the rip rap.

16. Fences - Check for damage, accumulated debris, operation of gates and locks, and adequacy of locations (this may change with time as people access the area or development occurs in the area).

17. Perimeter - Check the perimeter of the dams for a distance of at least 100 feet beyond the toe for signs of seepage or boils.

18. HDPE Liner – Wherever exposed, the HDPE Liner should be inspected for tears, gouges, protrusions under the liner and abrasion.

Records: A log book of activities occurring at the dam is to be kept current by the dam operator. The log book should be reviewed during the Engineering Inspection. This book should contain at the least the following documentation:

1. Completed operation and maintenance inspection checklists
2. Readings from all piezometers on the Gypsum Stack
3. Additional visual observations
4. A list of maintenance performed
5. A list of any unusual occurrences at the dam
6. Copies of the engineering inspection reports

4.6.2 Engineering Inspection

The engineering inspection is to be conducted by a qualified engineer approved by Ameren. The inspection will provide a thorough evaluation of the dam condition and appurtenances. Appendix B is an example of the inspection report form which is to be utilized for these inspections.

Frequency: The Gypsum Pond Dam is a Class I, High Hazard Potential dam and is to be inspected by an Illinois Registered Professional Engineer at least once per year. The Recycle Pond Dam is classified as a Class III, Low Hazard Potential dams and is to be inspected by an Illinois Registered Professional Engineer at least once every five years.

Inspection Items: The engineer will thoroughly inspect all of the items noted in Section 4.6.1 Operation and Maintenance Inspection.

Records: The Dam Inspection Report form from IDNR-OWR "Guidelines and Forms for Inspection of Illinois Dams" (a copy of which is included in Appendix B), will be completed by the inspecting engineer and will be signed and sealed by an Illinois Registered Professional Engineer. This report will document problem areas and deficiencies; recommend remedial actions for problem areas; and establish time requirements for dealing with the problems. The original report will be retained in Dynegy Operating Company (DOC) files, and a copy of the report will be submitted to the Illinois Department of Natural Resources, Office of Water Resources.

4.6.3 Review of Emergency Action Plan

The emergency action plan should be reviewed annually to assure that all contacts, addresses and telephone numbers are current. Changes in the adjacent land use should also be noted and may dictate the need for revisions to the plan. Changes to the plan should be made as appropriate but only with the concurrence of the Montgomery County Emergency Services and Disaster Agency and of the Illinois Department of Natural Resources, Office of Water Resources. Copies of any revisions should also be forwarded to all personnel and known emergency responders that possess previous versions the plan.

SECTION 5.0
MAINTENANCE ACTIVITIES

Timely repairs are a must after problem areas have been identified. The dam operator is to perform the work required to correct items noted in the operation and maintenance inspections and engineering inspections. Such items include repairing erosion of the gypsum slopes, mowing, seeding, tree and brush removal, replacing rip rap, repairing fences and locks, clearing debris, etc. The maintenance activities specified in the following sections are minimum requirements. NOTE: NO alterations or repairs to structural elements should be made without the assistance of the Ameren Chief Dam Safety Engineer and the concurrence of the Illinois Department of Natural Resources, Office of Water Resources.

Debris: Remove all trash, logs and other debris which may obstruct flow into the principal spillway pipes and drop inlets, or block passage from their discharge channels.

Rip Rap: Replenish rip rap as needed to provide adequate protection against erosion.

Vegetation Control

1. Maintain a good grass cover on the embankment by seeding, fertilizing and mulching areas which are refilled, barren, or thinly vegetated. Seeding mixtures used for maintenance reseeding shall result in a cover compatible with adjacent cover. The seeding mixture specified at the time of the dam's construction was IDOT Standard Specifications Class 1A (Salt Tolerant Lawn Mixture) as follows:

   IDOT Class 1A Salt Tolerant Lawn Mixture
   Bluegrass ..... 60 lb/acre
   Perennial Ryegrass ..... 20 lb/acre
   Dawsons Red Fescue ..... 20 lb/acre
   Scaldis Hard Fescue ..... 20 lb/acre
   Fults Salt Grass ..... 60 lb/acre

2. Grassed areas such as the embankment and the areas beyond the embankment toes for a distance of at least 20 feet should be mowed at least twice annually or at any time the height of the grass exceeds 1 foot.

3. All erosion areas will be filled and compacted, reseeded, fertilized and mulched to establish a thick erosion resistant cover.

4. Remove all trees and brush growing on the dam embankment to prevent development of a root system which could provide seepage paths. Herbicides utilized for tree and brush control are discussed in Appendix D.

5. Keep the riprap basin clear of weeds, brush, and trees.

6. Clear all brush and trees for a distance of approximately 20 feet beyond the toe of each dam.

Animal Damage: Fill rodent holes and other animal burrows with compacted clayey soil and reseed. If rodents become a nuisance, an effective rodent control program as approved by the Illinois Department of Natural Resources District Wildlife Biologist should be implemented.

Signs: All warning signs shall be maintained (repaired, painted, or replaced) as needed.

Gypsum Slopes: Erosion of the gypsum slopes will be evident with the presence of erosion rills. Erosion rills should be filled with additional gypsum material and graded to conform with the design slope.

Piezometers: All piezometers on the gypsum stack shall be inspected for signs of damage or displacement. Non-functioning piezometers shall immediately be replaced.

APPENDIX A
LOCATION MAP

APPENDIX B
OPERATION AND MAINTENANCE INSPECTION CHECKLIST

OPERATION AND MAINTENANCE INSPECTION CHECKLIST

Dam Name (circle one): Gypsum Pond Dam Recycle Pond Dam

Date: Time:

Name of Inspector:

Reservoir Elevation: feet

ITEM	NO	YES	IF YES
Record Piezometer Readings for Gypsum Stack. Are any readings above the critical level? (see section 4.5.2 of O&M Manual)			Contact Manager, Environment & Chemistry and notify Hanson Professional Services
Note the condition of the Piezometers on the Gypsum Stack. Any damage?			Contact Manager, Environment & Chemistry
Deep Surface Cracks			Contact Manager, Environment & Chemistry
Slump or Slide on the upstream or downstream face			Contact Manager, Environment & Chemistry
Erosion from runoff, wave action or traffic			Repair and stabilize
Embankment, abutment or spillway seepage			Contact Manager, Environment & Chemistry
Seepage or flows of muddy water			Contact Manager, Environment & Chemistry
Uneven settlement			Contact Manager, Environment & Chemistry
Trees, brush or burrow holes on the embankment or in the riprap basin			Remove trees and brush, fill holes
Transfer channel or Spillway pipes blocked			Clear immediately
Damage to stop logs			Repair or replace
Damage to HDPE Liner			Repair and schedule engineer inspection
Settlement or displacement of Gypsum Pond fixed decant pipes or outlets			Schedule engineer inspection
Discharge from Gypsum Pond LD/LCRS Drains?			Record discharge rate for each outlet (time to fill bucket)
Discharge from Gypsum Pond Ring Drains?			Record discharge rate for each outlet (time to fill bucket)
Gypsum Stack Perimeter Ditch erosion			Schedule repair
Problems with Recycle Pond spillways			Contact Manager, Environment & Chemistry
Problems with Recycle Pond decant			Contact Manager, Environment & Chemistry
Height of grass (inches)		inches	If more than 1 foot, schedule mowing
Damage to fencing, gates and locks or other access restriction measures			Contact Manager, Environment & Chemistry
Confirm drawdown facilities are opened and closed at least quarterly.			Contact Manager, Environment & Chemistry

Comments:

APPENDIX C
ENGINEERING INSPECTION FORMS

Dam Inspection Report

Name of Dam

Dam Identification Number

Permit Number

Class of Dam

Location NW 1/4 Section 11 Township 7N Range 3W 3rd P.M.

Owner

Name

Telephone Number (Day)

Street

Telephone Number (Night)

County Montgomery

City

Zip Code

Type of Dam

Type of Spillway

Date(s) Inspected

Weather When Inspected

Temperature When Inspected

Pool Elevation When Inspected

Tailwater Elevation When Inspected

Inspection Personnel:

Name Title

Name Title

Name Title

Name Title

Professional Engineer's Seal

The Department of Natural Resources is requesting information that is necessary to accomplish the statutory purpose as outlined under the River, Lakes and Streams Act, 615 ILCS 5 (1994 State Bar Edition). Submittal of this information is REQUIRED. Failure to provide the required information could result in the initiation of non-compliance procedures as outlined in Section 702.160 of the "Rules for Construction and Maintenance of Dams". This form has been approved by the State Forms Management Center.

R000822

CONDITION CODES

EC - Emergency Condition. A serious dam safety condition exists that needs immediate action. Emergency measures implemented as instructed by Chief Dam Safety Engineer; such as, pool draw down, work stoppage, plant stoppage.

NE - No evidence of a problem

GC - Good condition

MM - Item needing minor maintenance and/or repairs within the year, the safety or integrity of the item is not yet imperiled

IM - Item needing immediate maintenance to restore or ensure its safety or integrity. Remediation should be completed within 1 month.

EC - Emergency condition which if not immediately repaired or other appropriate measures taken could lead to failure of the dam

OB - Condition requires regular observation to ensure that the condition does not become worse

NA - Not applicable to this dam

NI - Not inspected - list the reason for non-inspection under deficiencies

EC - Emergency Condition. A serious dam safety condition exists that needs immediate action. Emergency measures implemented as instructed by Chief Dam Safety Engineer; such as, pool draw down, work stoppage, plant stoppage.

R000823

GYPSUM STACK - EARTH EMBANKMENT

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Surface Cracks			
Vertical and Horizontal Alignment of Crest			
Unusual movement or Cracking at or Beyond Toe			
Sloughing or Erosion of Outer Embankment Slopes			
Upstream Face Slope Protection (HDPE Liner)			
Seepage			
Animal Damage			

R000824

GYPSUM STACK - EARTH EMBANKMENT

(Continued)

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Vegetative Cover			

R000825

GYPSUM STACK - GYPSUM EMBANKMENT

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Surface Cracks			
Vertical and Horizontal Alignment of Crest			
Unusual movement or Cracking at or Beyond Toe			
Sloughing or Erosion of **Outside** Embankment Slopes			
Sloughing or Erosion of **Inside** Embankment Slopes			
Seepage			
Animal Damage			

R000826

GYPSUM STACK - GYPSUM EMBANKMENT

(Continued)

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Condition of Piezometers on Gypsum Stack			
Piezometer Readings on Gypsum Stack Above Critical Level?			

R000827

GYPSUM STACK – PERIMETER DITCH

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Ditch Geometry (15 ft bottom width, 3:1 slopes, 8-9 ft depth)			
Concrete Apron at ring drain outlets			
Ring Drain Discharge Pipes			
Stilling Wells for Fixed Decants			

R000828

TRANSFER CHANNEL - (between gypsum stack and recycle pond)

[ ] Drop Inlet Structure [X] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Debris			
Side Slope Stability			
HPDE Liner			
HDPE Liner Welds			
Stop Logs			
Differential Settlement			

R000829

RECYCLE POND - EMBANKMENT

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Surface Cracks			
Vertical and Horizontal Alignment of Crest			
Unusual movement or Cracking at or Beyond Toe			
Sloughing or Erosion of Outer Embankment Slopes			
Upstream Face Slope Protection (HDPE Liner)			
Seepage			
Animal Damage			

R000830

RECYCLE POND - EMBANKMENT

(Continued)

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Vegetative Cover			

R000831

RECYCLE POND - PRINCIPAL SPILLWAY (Left, Looking Downstream)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Alignment of Structure Walls			
Construction Joints			
Differential Settlement			
Erosion, Spalling, Cavitation			
Joint Separation			
Seepage Around or into Conduit			
Surface Cracks			

R000832

RECYCLE POND - PRINCIPAL SPILLWAY (Left, Looking Downstream)

(Continued)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Structural Cracks			

R000833

RECYCLE POND - PRINCIPAL SPILLWAY (Center)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Alignment of Structure Walls			
Construction Joints			
Differential Settlement			
Erosion, Spalling, Cavitation			
Joint Separation			
Seepage Around or into Conduit			
Surface Cracks			

R000834

RECYCLE POND - PRINCIPAL SPILLWAY (Center)

(Continued)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Structural Cracks			

R000835

RECYCLE POND - PRINCIPAL SPILLWAY (Right, Looking Downstream)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Alignment of Structure Walls			
Construction Joints			
Differential Settlement			
Erosion, Spalling, Cavitation			
Joint Separation			
Seepage Around or into Conduit			
Surface Cracks			

R000836

RECYCLE POND - PRINCIPAL SPILLWAY (Right, Looking Downstream)

(Continued)

[X] Drop Inlet Structure [ ] Overflow Spillway Structure [ ] Gated

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Structural Cracks			

R000837

RECYCLE POND - ENERGY DISSIPATOR

[X] Principal Spillway [ ] Outlet Works Type: FHWA HEC-14, Riprap Basin

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Riprap			
Outlet Channel			
Debris			

R000838

RECYCLE POND - DECANT STRUCTURE

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Alignment			
Connection to Bollard			
Debris in Inlets			
Condition of Pipe			
Condition of Liner Beneath Pipe			
Connection to Ballast			
Connection of Pipe Boot to Liner			

RECYCLE POND - DECANT STRUCTURE

(continued)

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE
Seepage Around or into Conduit			

R000840

RECYCLE POND – WATER LEVEL GAGE STRUCTURE

ITEM	CONDITION	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES & SCHEDULE

APPENDIX D
HERBICIDES

HERBICIDES

Site personnel should check with the Illinois Department of Natural Resources, Regional Fisheries Biologist and the Regional Wildlife Biologist before using any herbicide. Read the product label prior to use and follow the use directions and precautions accordingly.

On March 1, 1979 the U.S. Environmental Protection Agency (U.S.E.P.A.) halted the use of the herbicide 2, 4, 5-T in parks and recreation areas. The use of silvex (2, 4, 5-TP) around water has also been banned.

The Agronomy Department at the University of Illinois and the Aquatic Biology Section of the Department of Natural Resources, Office of Scientific Research and Analysis indicate that the herbicides containing the 2, 4-D or 2, 4-DP are legal for use in parks and recreation areas and effective for controlling brush and woody growth. Some examples of approved herbicides are:

1. Tordon RTU by DOW Chemical. (Can be obtained with blue dye.)
2. WEEDONE 170 by Union Carbide
3. WEEDONE, 2, 4-DP by Union Carbide
4. A 1% to 2% solution of ROUNDUP
5. Garlon by DOW Chemical
6. Banvel by Sandoz

Your distributor may carry brand name herbicides other than those listed above. Be certain that the product does not contain the ingredients 2, 4, 5-T or 2, 4, 5-TP. An example of an unacceptable product is ESTERON 2, 4, 5 by DOW Chemical.

APPENDIX E
CONSTRUCTION DRAWINGS

AECOM

Appendix G: Photos of 2015 Sloughing Repairs



Figure G.1. Photo of 2015 sloughing prior to repairs.



Figure G.2. Photo of 2015 sloughing prior to repairs.



Figure G.3. Photo of 2015 sloughing area after repairs.



Figure G.4. Photo of 2015 sloughing area after repairs.

ATTACHMENT E


COFFEEN ASH
POND NO. 2
ID #: W1350150004-02
ILLINOIS POWER
GENERATING COMPANY

ATTACHMENT H

Natural Resource Technology
AN OBG COMPANY

OBG | There's a Way

November 21, 2017

Mr. Rick Diericx
Managing Director – Environmental Compliance Group
Dynegy Operating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234-6135

Subject: Response to IEPA Comments – Coffeen Station Inactive Ash Pond No. 2
Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2
NRT Project No. 2380

Dear Mr. Diericx:

Natural Resource Technology, Inc., an OBG Company (NRT) is providing this letter to Dynegy Operating Company (Dynegy) in response to comments received from the Illinois Environmental Protection Agency (IEPA) dated October 27, 2017 regarding the *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2* (Closure Plan; AECOM, January, 2017) at Illinois Power Generating Company Coffeen Power Station, in Coffeen, IL.

This Response to Comments will serve as Addendum 1 to the Closure Plan dated January 2017. For ease of review, IEPA comments are presented below in italics, followed by responses. Supplemental information to support the responses, when required, is included as Attachments 1-3. This document provides responses to all IEPA comments numbered 1 - 8.

Comment 1

It is mentioned multiple times in the closure and post-closure care plans that there are coal mines in the vicinity at depth. Please provide additional information on the locations and depths of the coal mines in the vicinity of Ash Pond No. 2.

Response: The Truax-Traer Coal Company and the Consolidation Coal Company extracted coal underlying Ash Pond No. 2 from 1964 to 1983 (Attachment 1 – Mine Index 871). The mine was originally known as the "Hillsboro" Mine and after Consolidation Coal Company took over the mining operation it was renamed "Consolidation No. 63, Hillsboro". Herrin No. 6 Coal was mined from depths of 500-510 feet below ground surface. The coal seam was 5.8-7.1 feet thick and an estimated 26,800,000 tons of coal were removed from the mine during the operational period (see Reference 1) with an extraction ratio of approximately 25% based on an estimate of volume removed from the recorded mine maps. A Mine Workings Map dated 1969 is overlaid on an aerial of Ash Pond No. 2 and included in Attachment 1 (Figure 1 – Overlay of Historic Mine). Comparison of the mine extents from 1969 with the extent of the mine included in Reference 1and shown on the Coal Mines in Illinois, Coffeen Quadrangle map included in Attachment 1 indicates there was no additional mining below Ash Pond No. 2 between 1969 and 1983 when the mine closed. As stated in Mine Index 871 (Attachment 1) the Coal Section of the Illinois State Geologic Survey (ISGS) has been assured that the extents included in Reference and Attachment 1 are final and complete.

Comment 2

The Agency requests the addition of a groundwater monitoring well on the east side of Inactive Ash Pond No. 2.

Response: NRT has evaluated the site conditions in the area east of Ash Pond No. 2 and has determined that there is no feasible access to install a monitoring well outside of the embankment because of steep slopes, heavy vegetation, and the presence of wetlands. In addition, several borings along the east side of Ash Pond No. 2 (B403A, P010, and G402) did not encounter the uppermost aquifer during drilling. Given significant access concerns and the limited nature of the aquifer NRT does not recommend installation of a monitoring well.

However, if required or deemed necessary in the future by the IEPA, a boring could be advanced through the berm following completion of closure construction activities to determine if the uppermost aquifer (Hagarstown) is present. Assuming the uppermost aquifer is present, a well could be installed through the berm if requested.

Comment 3

The two new groundwater monitoring wells to the west of the Inactive Ash Pond No. 2 are approved.

Response: A schedule for installation of the wells will be developed following approval of this Closure Plan. Appropriate documentation will be submitted to the IEPA upon completion of installation.

Comment 4

Will changes need to be made to the NPDES permit as part of the implementation of the closure plan?

Response: Yes, an application to modify the Coffeen NPDES permit (IL0000108) is being prepared to authorize the discharge of "dewatering" wastewaters from Ash Pond No. 2 to Coffeen Lake. The application will include an Antidegradation Assessment for Coffeen Lake in support of that modification request.

Comment 5

Calibration of the MODFLOW model was completed using only November 2016 groundwater elevations. Further calibration using more groundwater elevation data over a larger span of time should be completed.

Response: November 2016 groundwater elevations were used to calibrate the MODFLOW model because this was the first and only complete data set available for model development that included groundwater elevations from monitoring wells set in the uppermost aquifer, including wells G406 and G407 installed in August 2016. In order to address IEPA concerns about the efficacy of the groundwater elevation data range used for the model calibration, a comparison of observed versus predicted groundwater elevation values and groundwater flow directions will be provided in post-closure annual reports to assess model performance. If the predictive model does not adequately represent groundwater elevation and flow directions, the model will be recalibrated using available groundwater elevation data collected after November 2016. Similarly, post-closure groundwater quality data will be compared to transport model predictions to assess model performance in post-closure annual reports.

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Comment 6

In the Application for a GMZ, it is noted that the problem with groundwater was identified via sampling in 2015. The Agency notes that the Coffeen Power Station received a Violation Notice in 2012 for groundwater standards violations in groundwater around Inactive Ash Pond No. 2.

Response: The GMZ application was revised to include reference to Violation Notice W-2012-00064 (Attachment 2).

Comment 7

Also in the GMZ application, no other remedies to groundwater violations are considered other than to state they are not deemed practical or cost effective. Please discuss other remedies considered and why they are not practical for mitigation relative to the nature of the subsurface or cost-effective.

Response: The GMZ Application was revised to include the following text (Attachment 2):

> "Previous experience at similar sites developing and evaluating alternative remedial options and determining costs indicates capping is often the most cost-effective and cost-efficient remedy. Therefore, dewatering and capping were initially evaluated. Based on the results of the evaluation and predictive modeling, the selected remedy successfully mitigates groundwater impacts. Groundwater monitoring will continue to be performed to evaluate the effectiveness of the remedy. If the selected remedy is not demonstrated as successful through collection of data and comparison to predictive values and applicable groundwater quality standards, then other remedial options will be evaluated."

Comment 8

All monitoring wells must be sampled for the parameters listed in 35 IAC 620.410 (a) and (d), with the exception of perchlorate. Statistical analysis for each well's parameters using approved methods listed in 40 CFR 257 should be included.

Response: Tables 2 - 5 of the Groundwater Monitoring Plan, which was included as Appendix B of the Closure Plan, have been revised to include all parameters of 35 IAC 620.410 (a) and (d) with the exception of perchlorate. Revised tables are included in Attachment 3. Note these tables also include aluminum and proposed changes to groundwater standards which are included in IEPA's Proposed Changes to 35 IAC Part 620.

Please don't hesitate to contact us if you have any questions regarding these responses to comments and associated attachments provided herein.

Sincerely,
NRT | An OBG Company

Nathaniel R. Keller, PG
Hydrogeologist

Stu J. Cravens, PG
Principal Hydrogeologist

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Attachments:

Attachment 1: Comment 1 – Historic Mine Documentation
Attachment 2: Comment 2 – Revised GMZ Application
Attachment 3: Comment 8 – Revised Tables 2,3,4, and 5 from Appendix B: Groundwater Monitoring Plan

cc: Ms. Amy Zimmer – IEPA, Hydrogeology and Compliance Unit
Mr. Tom Davis, PE - Dynegy, Inc.
Mr. Jason Frierdich, PE – Dynegy, Inc.
Mr. Matt Ballance, PE – Dynegy, Inc.
Mr. Vic Modeer, PE – Dynegy, Inc.
Mr. John Romang, - Illinois Power Generating Company

References:

1 Obrad, Jennifer M., 2011. Directory of Coal Mines in 7.5-Minute Quadrangle Series, Coffeen Quadrangle Montgomery and Bond Counties. The Board of Trustees of the University of Illinois.

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Attachment 1

Comment 1-
Historic Mine Documentation

Mine Index 871
Consolidation Coal Company, Hillsboro Mine (Consolidation No. 63 Mine)

Type: Underground Total mined-out acreage shown: 4,841

SHAFT, SLOPE, DRIFT or TIPPLE LOCATIONS

Type	County	Township-Range	Section	Quarters-Footage
Man shaft	Montgomery	7N 3W	14	SW NE NW
Air shaft	Montgomery	7N 2W	18	SE NE NE
Hoist & air shaft	Montgomery	7N 3W	14	NE NW NW

GEOLOGY

Seam(s) Mined	Depth (ft)	Thickness (ft) Min	Max	Ave	Mining Method
Herrin	500-510			5.83-7.17	RPP

Geologic Problems Reported: Roof problems were widespread, the sites characterized by slickensided fault planes that cut irregularly through the roof shales and claystones. Small clay dikes were also associated with this small-scale faulting. Floor heaving was slight, but had been a larger problem in the past.

PRODUCTION HISTORY

Company	Mine Name	Years	Production (tons)
Truax-Traer Coal Company	Hillsboro	1964-1970	5,605,812
Consolidation Coal Company	Consolidation No. 63, Hillsboro	1971-1983	21,173,542
			26,779,354

Last reported production: July 1983

SOURCES OF DATA

Source Map	Date	Original Scale	Digitized Scale	Map Type
Company, Coal Section files	2-1-1983	1:12000	1:2170	Final *

* The map date is before mine closure, but the Coal Section has been assured that the workings shown on the map are indeed final. The mined area shown on the accompanying map is the approximate size expected for the reported production. This suggests that the mine outline is complete.

Annotated Bibliography (data source, brief description of information)

Coal Reports - Production, ownership, years of operation, mine type, depth, thickness.
Directory of Illinois Coal Mines (Montgomery County) - Mine names, mine index, ownership, years of operation.
Mine notes (Montgomery County) - Shaft location, seam, depth, thickness, geologic problems.
Company map, Coal Section files, 1983 Line Project - Shaft locations, mine outline, mining method.



Natural Resource Technology
AN ODEC COMPANY

PROJECT NO: 2380

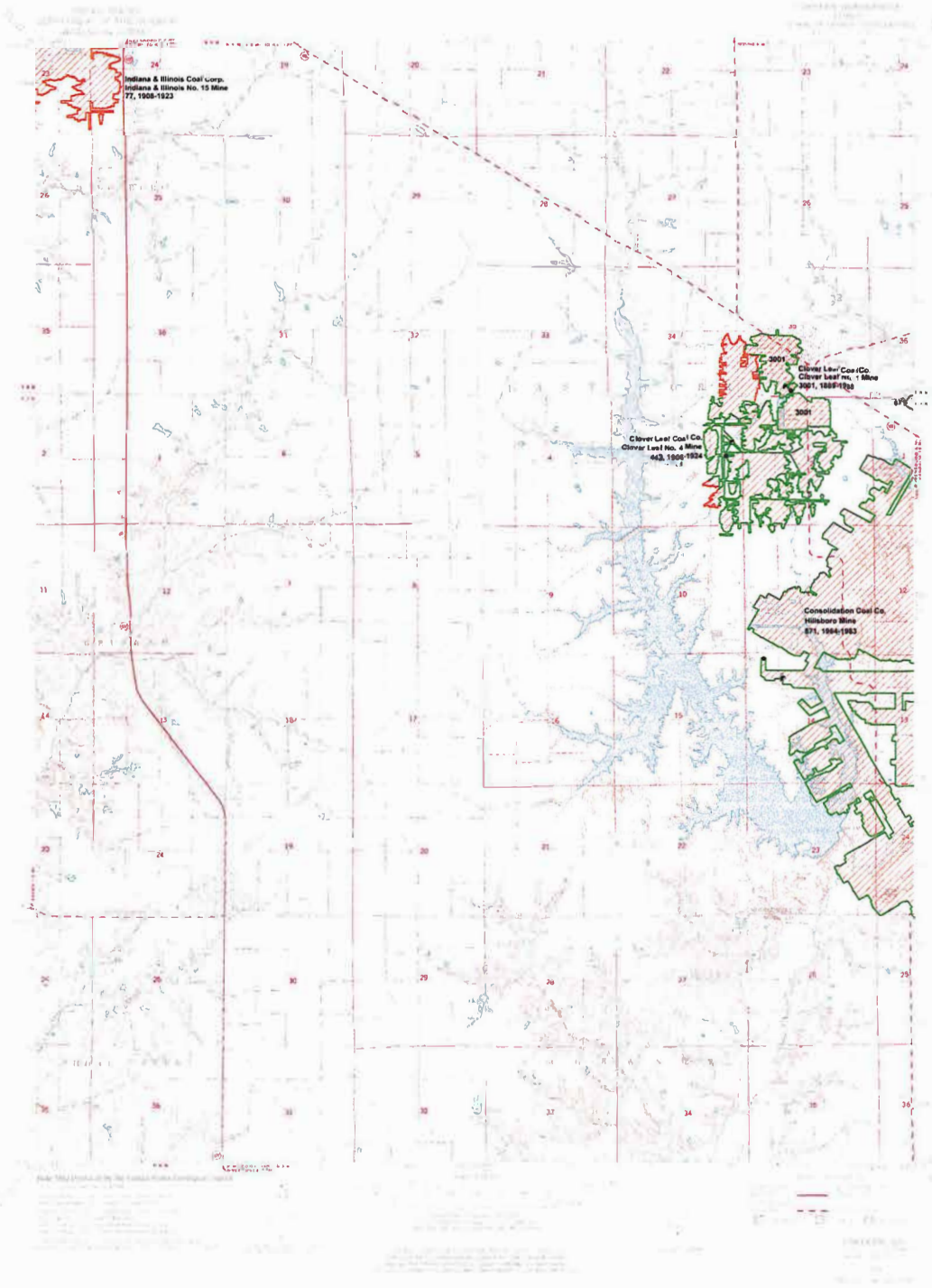
FIGURE NO: 1

OVERLAY OF HISTORIC MINE

RESPONSE TO IEPA COMMENTS - CLOSURE AND POST-CLOSURE CARE PLAN FOR THE COFFEEN ASH POND NO. 2
COFFEEN POWER STATION
COFFEEN, ILLINOIS

DRAWN BY/DATE:
SDS 11/8/17
REVIEWED BY/DATE:
NRK 11/8/17
APPROVED BY/DATE:
SJC 11/10/17

R000857



Coal Mines in Illinois
Coffeen Quadrangle
Montgomery & Bond Counties, Illinois

This map accompanies the Coal Mines Directory for the Coffeen Quadrangle. Consult the directory for a complete explanation of the information shown on this map.

Mining Method

- Room & Pillar (RP)
- Room & Pillar Basic (RPB)
- Modified Room & Pillar (MRP)
- Room & Pillar Panel (RPP)
- Blind Room & Pillar (BRP)
- Checkerboard Room & Pillar (CRP)
- High Extraction Retreat (HER)
- Longwall (LW)
- Underground, Method Unknown
- Strip Mine
- Auger Mine
- General Area of Mining

Source of Mine Outline

- Final Mine Map
- Not Final Mine Map
- Undated Mine Map
- Incomplete Mine Map
- Secondary Source Map

Tipple, Shaft, Slope, Drift Locations

- Strip Mine Tipple - Active
- Strip Mine Tipple - Abandoned
- Mine Shaft - Active
- Mine Shaft - Abandoned
- Mine Slope - Active
- Mine Slope - Abandoned
- Mine Drift - Active
- Mine Drift - Abandoned
- Air Shaft
- Uncertain Location
- Uncertain Type of Opening

Location



Mine Annotation
(space permiting)
Company
Mine Name
ISGS Index No., Years of Operation

Disclaimer

Please check the Coal Section at the Illinois State Geological Survey's web site at http://www.isgs.illinois.edu for the most up-to-date version of these products.

Note that each quadrangle scale mined-out overlay map requires the use of the associated text directory for full explanation of map features and mine attributes. Also note that some quadrangles have multiple seams mining and therefore more than one map may be available for a particular quadrangle. Please take care to check for multiple maps, as extensive mining may exist in the other seams.

The maps and digital files used for these studies were compiled from data obtained from a variety of public and private sources and have varying degrees of completeness and accuracy. This compilation map presents reasonable interpretation of the geology of the area and is based on available data. Locations of some mine features may be off by 500 feet or more due to errors in the original source maps, the compilation process, digitizing, or a combination of these factors. These data are not intended for use in site-specific screening or decision-making. Use of these documents does not eliminate the need for detailed studies to fully understand the geology of a specific site. The Illinois State Geological Survey, Institute of Natural Resource Sustainability, or the University of Illinois make no guarantee, expressed or implied, regarding the correctness of the interpretations presented in this data set and accept no liability for the consequences of decisions made by others on the basis of the information presented here.

These maps were designed for use at 1:24,000. Enlarging the map may reduce accuracy, and the original scale of the source maps used to compile the outlines shown varies from 1:400 to 1:150,000, as well as mine locations are known only from text descriptions. See the accompanying mine directory for the original scale of the source map used for a specific mine to check accuracy of a given portion of the map. Areas with no mines shown may still be undermined; see the undocated mines list at the back of each mine directory.

The shape of the U.S.G.S. topographic base map was projected from the original UTM to Lambert Conformal Conic

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Institute of Natural Resource Sustainability
Illinois State Geological Survey
615 E. Peabody Dr.
Champaign, IL 61820

Mine Outlines Compiled by
Jennifer M. Obrad

November 21, 2011

Attachment 2

Comment 2 – Revised GMZ Application

Title 35, Illinois Admin. Code, Part 620 – APPENDIX D
Confirmation of an Adequate Corrective Action Pursuant to 35 Ill. Adm. Code 620.250(a)(2)

Pursuant to 35 Ill. Adm. Code 620.250(a) if an owner or operator provides a written confirmation to the Agency that an adequate corrective action, equivalent to a corrective action process approved by the Agency, is being undertaken in a timely and appropriate manner, then a groundwater management zone may be established as a three-dimensional region containing groundwater being managed to mitigate impairment caused by the release of contaminants from a site. This document provides the form in which the written confirmation is to be submitted to the Agency.

Note 1. Parts I and II are to be submitted to IEPA at the time that the facility claims the alternative groundwater standards. Part III is to be submitted at the completion of the site investigation. At the completion of the corrective process, a final report is to be filed which includes the confirmation statement included in Part IV.

Note 2. The issuance of a permit by IEPA's Division of Air Pollution Control or Water Pollution Control for a treatment system does not imply that the Agency has approved the corrective action process.

Note 3. If the facility is conducting a cleanup of a unit which is subject to the requirements of the Resource Conservation and Recovery Act (RCRA) or the 35 Ill. Adm. Code 731 regulations for Underground Storage Tanks, this confirmation process is not applicable and cannot be used.

Note 4. If the answers to any of these questions require explanation or clarification, provide such in an attachment to this document.

Information provided in the following technical documents is referenced within this form:

- AECOM, 2016c. Revised 30% Closure Design Package for Coffeen Power Station Ash Pond No. 2. April 16, 2016.
- Natural Resource Technology, Inc., 2016a. Hydrogeologic Characterization Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016b. Groundwater Monitoring Plan. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016c. Groundwater Model Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016d. Hydrostatic Modeling Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.

A legal description and map of the proposed GMZ is provided in Appendix A of this GMZ Application. The GMZ will extend vertically through all water-bearing strata through the Hagarstown Member and upper weathered portions of the Vandalia Till Member at an estimated elevation ranging from approximately 604 to 608 ft MSL.

Part I. Facility Information

Facility Name: Coffeen Power Station

Facility Address: 134 CIPS Lane, Coffeen, IL 62017

County: Montgomery

Standard Industrial Code (SIC): 4911

1. Provide a general description of the type of industry, products manufactured, raw materials used, location and size of the facility. ***Electric power generation and coal combustion residual (CCR) disposal. Ash Pond 2 is located within the Coffeen Power Station which encompasses approximately 4,000 acres including a 1,100-acre lake.***

2. What specific units (operating or closed) are present at the facility which are or were used to manage waste, hazardous waste, hazardous substances or petroleum?

	YES	NO
Landfill	X	
Surface Impoundment	X	
Land Treatment		X
Spray Irrigation		X
Waste Pile		X
Incinerator		X
Storage Tank (above ground)	X	
Storage Tank (underground)	X	
Container Storage Area	X	
Injection Well	X	
Water Treatment Units	X	
Septic Tanks	X	
French Drains	X	
Transfer Station		X
Other Units (please describe)		

3. Provide an extract from a USGS topographic or county map showing the location of the site and a more detailed scaled map of the facility with each waste management unit identified in Question 2 or known/suspected source clearly identified. Map scale must be specified and the location of the facility must be provided with respect to Township, Range and Section. ***Facility is located in Sections 10 and 11, Tier 7 N, Range 3 W, of the 3rd PM. Figure 1 has the facility located on a USGS topographic map (7½ minute).***

4. Has the facility ever conducted operations which involved the generation, manufacture, processing, transportation, treatment, storage or handling of "hazardous substances" as defined by the Illinois Environmental Protection Act? Yes ☒ No ☐
   If the answer to this question is "yes" generally describe these operations. ***Storage and handling of anhydrous ammonia, sulfuric acid, 50% sodium hydroxide, and chlorine gas.***

5. Has the facility generated, stored or treated hazardous waste as defined by the Resource Conservation and Recovery Act? Yes ☒ No ☐
   If the answer to this question is "yes" generally describe these operations. ***Small quantity TSD.***

6. Has the facility conducted operations which involved the processing, storage or handling of petroleum? Yes ☒ No ☐ If the answer to this question is "yes" generally describe these operations. ***Store, load, and unload diesel fuel and kerosene.***

7. Has the facility ever held any of the following permits?

   a. Permits for any waste storage, waste treatment or waste disposal operation. Yes ☒ No ☐
      If the answer to this question is "yes", identify the IEPA permit numbers. ***IL0000108 and 1998-289- UIC.***

   b. Interim Status under the Resources Conservation and Recovery Act (filing of a RCRA Part A application). Yes ☐ No ☒
      If the answer to this question is "yes", attach a copy of the last approved Part A application.

   c. RCRA Part B Permits. Yes ☐ No ☒
      If the answer to this question is "yes", identify the permit log number.

8. Has the facility ever conducted the closure of a RCRA hazardous waste management unit? Yes ☐ No ☒

9. Have any of the following State or federal government actions taken place for a release at the facility?

   a. Written notification regarding known, suspected or alleged contamination on or emanating from the property (e.g., a Notice pursuant to Section 4(q) of the Environment Protection Act)? Yes ☒ No ☐
      If the to this question is "yes", identify the caption and date of issuance. ***Violation Notice No. W-2012-00064 was issued on June 27, 2012 for boron, manganese, sulfate, and total dissolved solids concentrations which exceeded Class I GW Standards at APW-2/G402.***

   b. Consent Decree or Order under RCRA, CERCLA, EPAct Section 22.2 (State Superfund), or EPAct Section 21(f) (State RCRA). Yes ☐ No ☒

   c. If either of Items a. or b. were answered by checking "yes", is the notice, order or decree still in effect? Yes ☒ No ☐ ***Concentrations remain above Class I GW Standards which is why this GMZ is being requested.***

10. What groundwater classification will the facility be subject to at the completion of the remediation?

    Class I ☒ Class II ☐ Class III ☐ Class IV ☐

    If more than one Class applies, please explain.

11. Describe the circumstances which the release to groundwater was identified. ***Groundwater sampling at Ash Pond 2 was initiated in 2015. Exceedances of Class I groundwater quality standards in monitoring wells associated with Ash Pond 2 include the parameters arsenic, boron, lead, manganese, sulfate, and total dissolved solids.***

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true and accurate.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

PART II: Release Information

1. Identify the chemical constituents release to the groundwater. Attach additional documents as necessary.

Chemical Description	Chemical Abstract No.
Arsenic	*7440-38-2*
Boron	*7440-42-8*
Lead	*7439-92-1*
Manganese	*7439-96-5*
Sulfate	*14808-79-8*
Total Dissolved Solids	*10052*

2. Describe how the site will be investigated to determine the source or sources of the release. ***Ash Pond 2 has been investigated as described in the Hydrogeologic Characterization Report (Natural Resource Technology, Inc. [NRT], 2016a).***

3. Describe how groundwater will be monitored to determine the rate and extent of the release. ***The monitoring network to monitor the rate and extent of the release is described in the Groundwater Monitoring Plan (NRT, 2016b).***

4. Has the release been contained on-site at the facility? ***The release is contained within the facility boundary. Migration of CCR constituents is limited by Coffeen Lake, which acts as a groundwater discharge area and hydraulic barrier.***

5. Describe the groundwater monitoring network and groundwater and soil sampling protocols in place at the facility. ***The groundwater monitoring network and sampling protocols are described in the Groundwater Monitoring Plan (NRT, 2016b).***

6. Provide the schedule for investigation and monitoring. ***The site investigation is complete and groundwater monitoring will continue for the required/permitted frequency and monitoring period as described in the Groundwater Monitoring Plan Section 4.2: Sampling Schedule (NRT, 2016b).***

7. Describe the laboratory quality assurance program utilized for the investigation. ***Laboratory quality assurance is described in the Groundwater Monitoring Plan Sections 4.4: Laboratory Analysis and 4.5: Quality Assurance (NRT, 2016b). The quality assurance/quality control procedures described in the Groundwater Monitoring Plan will be supplemented by the selected Illinois EPA-approved laboratory's QA Manual.***

8. Provide a summary of the results of available soil testing and groundwater monitoring associated with the release at the facility. The summary or results should provide the following information: dates of sampling; types of samples taken (soil or water); locations and depths of samples; sampling and analytical methods; analytical laboratories used; chemical constituents for which analyses were performed; analytical detection limits; and concentrations of chemical constituents in ppm (levels below detection should be identified as "ND"). ***A narrative summary of the results of groundwater monitoring is discussed in the Hydrogeologic Characterization Report Section 3: Groundwater Quality (NRT, 2016a). Analytical data summary tables and graphs are available in the Hydrogeologic Characterization Report Appendix F: Groundwater Quality Data and Appendix G: Water Quality Trend Graphs (NRT, 2016a). Lab reports for all monitoring events have previously been submitted to the Agency.***

PART II: Release Information (Continued)

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of knowledge and belief, true and accurate and confirm that the actions identified herein will be undertaken in accordance with the schedule set forth herein.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

Part III: Remedy Selection Information

1. Describe the selected remedy. ***The remedy includes ash dewatering, relocating/reshaping the CCR within Ash Pond 2 to achieve acceptable grades, construction of a geomembrane cover system and establishing a vegetative cover to minimize long-term erosion (AECOM, 2016).***

2. Describe other remedies which were considered and why they were rejected. ***Previous experience at similar sites developing and evaluating remedial alternatives and costs indicate capping is often the most cost effective and cost-efficient. Therefore, dewatering and capping were initially evaluated. Based on the results of the evaluation and modeling, the selected remedy successfully mitigates groundwater impacts. If the selected remedy is not shown successful through collection of data and comparison to predictive values, then other remedial options will be evaluated.***

3. Will waste, contaminated soil or contaminated groundwater be removed from the site in the course of this remediation? Yes ☐ No ☒
   If the answer to this question is "yes", where will the contaminated material be taken?

4. Describe how the selected remedy will accomplish the maximum practical restoration of beneficial use of groundwater. ***The dewatering and installation of a geomembrane cover system will control the potential for water infiltration into the closed CCR unit and will allow drainage of surface water off of the cover system. These actions will reduce leachate generation and migration and groundwater quality will improve over time, as described in the Groundwater Model Report (NRT, 2016c).***

5. Describe how the selected remedy will minimize any threat to public health or the environment. ***The currently defined extent of the release does not threaten public health. As discussed in the Hydrogeologic Characterization Report Section 2.5 (NRT, 2016a), there are currently no impairments to groundwater usage on the Coffeen Power Station property or surrounding properties associated with Ash Pond 2. No impairments to groundwater usage resulting from establishment of the proposed GMZ are anticipated. CCR dewatering and the geomembrane cover system will reduce leachate generation and migration from Ash Pond 2 and minimize CCR constituents entering the environment, as described in the Groundwater Model Report (NRT, 2016c).***

6. Describe how the selected remedy will result in compliance with the applicable groundwater standards. ***The in place closure of Ash Pond 2, as proposed, will result in a reduction of leachate production, decreasing CCR constituent concentrations and contraction of the groundwater plume. A Groundwater Model Report (NRT, 2016c), included in Appendix D of AECOM 2016, suggests that the geosynthetic cover system will control recharge and subsequent leachate generation within the limits of the Site and reduce concentrations of boron below Class I standards. Concentration reductions are expected to begin approximately one year after completion of the cover system.***

7. Provide a schedule for design, construction and operation of the remedy, including dates for the start and completion. ***A schedule for implementing the remedies is included in Section 1.3 in AECOM, 2016.***

8. Describe how the remedy will be operated and maintained. ***The operation and maintenance of the remedy is described in Section 3: Post-Closure Care Plan (AECOM, 2016).***

9. Have any of the following permits been issued for the remediation?

   a. Construction or Operating permit from the Division of Water Pollution Control. Yes ☐ No ☒

   b. Land treatment permit from the Division of Water Pollution Control. Yes ☐ No ☒
      If the answer to this question is "yes", identify the permit number.

   c. Construction or Operating permit from the Division of Air Pollution Control. Yes ☐ No ☒

If the answer to this question is "yes", identify the permit number.

10. How will groundwater at the facility be monitored following completion of the remedy to ensure that the groundwater standards have been attained? ***Groundwater monitoring procedures are described in Section 4 of the Groundwater Monitoring Plan (NRT, 2016b).***

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true and accurate and confirm that the actions identified herein will be undertaken in accordance with the schedule set forth herein.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

Attachment 3

Comment 8 – Revised Tables 2,3,4, and 5 from Appendix B: Groundwater Monitoring Plan

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Table 2. Proposed Monitoring Well Network and Analyses
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Boring/ Well ID	Ground Surface at Time of Install	Measuring Point Elevation (2015)	Top of Screen Elevation	Bottom of Screen Elevation	Screen length	Screen Top	Screen Bottom	Proposed Analyses for IEPA Monitoring	Additional Monitoring Programs Performed at Well	Other Analyses (USEPA CCR Rule or IEPA)
G270	622.92	625.92	609.79	605	5	16.1	20.9	IEPA 620.410 (a), and (d), no perchlorate[3]	Ash Pond 2 & GRP - CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G281	623.82	626.36	608.31	603.66	5	18.1	22.7		Ash Pond 2 CCR	
G401	623.03	625.57	608.67	604.24	4	16.9	21.3			
G402	610.56	613.37	600.60	590.6	10	12.8	22.8			
G403	623.81	626.47	610.70	606.03	5	15.8	20.4			
G404	613.10	615.67	606.68	601.93	5	9.0	13.7			
G405	620.90	623.63	611.89	607.14	5	11.7	16.5			
G406	621.86	621.86	608.30	603.49	5	13.6	18.4		None	None
G407	618.35	621.32	604.57	599.74	5	16.8	21.6			
G410[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G411[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G154	623.52	626.35	609.26	604.76	5	17.1	21.6		SW Pond - IEPA	IEPA Approved Parameters
G279	629.19	632.04	606.79	602.40	4	25.3	29.6		GRP - IEPA and CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G280	622.95	625.85	610.16	605.32	5	15.7	20.5			

Notes:

[1] Proposed wells to be installed upon approval of Closure Plan and GMZ application

[2] Field parameters include: pH, oxidation -reduction potential, specific conductance, temperature, and dissolved oxygen

[3] Groundwater samples collected for metals analyses will be field filtered.

Groundwater quality analyses including methods and sampling details are included in Table 4.

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Table 3. Background Groundwater Quality and Applicable Groundwater Quality Standards
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Parameters (totals)[6]	Sampling Program	IL Class I Std[1] (mg/L)	Background Concentration[2] for IEPA (mg/L)	Applicable Groundwater Standard[3] for IEPA (mg/L)	Maximum[5] (mg/L)	Minimum[5] (mg/L)
Aluminum (d)[4]	IEPA	3.5	tbd	tbd	0.1	<0.005
Antimony	CCR, IEPA	0.006	tbd	tbd	<0.003	<0.003
Arsenic	CCR, IEPA	0.01	tbd	tbd	**0.25**	<0.001
Barium	CCR, IEPA	2.0	tbd	tbd	0.24	0.014
Beryllium	CCR, IEPA	0.004	tbd	tbd	0.0018	<0.001
Boron	CCR, IEPA	2.0	tbd	tbd	**17**	<0.01
Calcium	CCR	NS	tbd	tbd	450	<0.1
Cadmium	CCR, IEPA	0.005	tbd	tbd	0.008	<0.001
Chloride	CCR, IEPA	200	tbd	tbd	160	1.5
Chromium	CCR, IEPA	0.1	tbd	tbd	0.034	<0.004
Cobalt	CCR, IEPA	1, 0.002[4]	tbd	tbd	0.28	<0.001
Copper (d)	IEPA	0.65, 0.2[4]	tbd	tbd	0.021	<0.001
Cyanide	IEPA	0.2	tbd	tbd	<0.005	<0.003
Fluoride	CCR, IEPA	4	tbd	tbd	1.06	0.031
Iron (d)	IEPA	5	tbd	tbd	**13**	<0.005
Lead	CCR, IEPA	0.0075	tbd	tbd	**0.220**	<0.001
Lithium	CCR	NS	tbd	tbd	0.057	<0.01
Manganese(d)	IEPA	0.15	tbd	tbd	**1.02**	<0.018
Mercury	CCR, IEPA	0.002	tbd	tbd	0.00093	<0.0002
Molybdenum	CCR, IEPA	NS	tbd	tbd	0.043	<0.001
Nickel (d)	IEPA	0.1	tbd	tbd	0.035	<0.003
Nitrate-N	IEPA	10	tbd	tbd	8.8	<0.01
Selenium	CCR, IEPA	0.05	tbd	tbd	0.027	<0.001
Silver (d)	IEPA	0.05	tbd	tbd	<0.005	<0.003
Sulfate	CCR, IEPA	400	tbd	tbd	**2,500**	2.3
Thallium	CCR, IEPA	0.002	tbd	tbd	0.0013	<0.001
TDS (d)	CCR, IEPA	1,200	tbd	tbd	**3,900**	320
Vanadium (d)	IEPA	0.049, 0.00049[4]	tbd	tbd	**0.025**	<0.003
Zinc (d)	IEPA	5	tbd	tbd	0.59	<0.002
Field pH	CCR, IEPA	6.5 - 9.0	tbd	tbd	8.03	**5.80**
Radium 226/228	CCR, IEPA	20/20, 5[4]	tbd	tbd	4.46	0.185

Notes:
All parameters are totals unless noted. Standards apply to dissolved or total concentrations
(d) Dissolved
tbd = To Be Determined for Illinois EPA monitoring program; CCR Appendix III and IV parameters based on future monitoring , started in November 2015
Bold = Background Concentration exceeds Class I Groundwater Standard
Red = Exceeds Applicable Groundwater Standard
NS = No Class II Groundwater Standard
USEPA (t) = background concentration for parameter [total] required under USEPA program (40 CFR Part 257)

[1] IPCB 620 Class I: Potable Resource Groundwater Standard
[2] Background Concentration to be calculated following 8 sampling events at all wells in accordance with 40 CFR 257
[3] Applicable Groundwater Standard is the higher of the Background Concentration and the Class I Groundwater Standard (or the lower if compared to the pH lower limit)
[4] Standards listed are proposed changes to 35 Ill. Adm. Code Part 620 by Illinois EPA
[5] Groundwater concentrations based on historical results for wells in the proposed sampling program
[6] Groundwater samples collected for metals analysis as required by IL620.410 will be field filtered

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Table 4. Sampling and Analysis Summary
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Parameter	Analytical Method[5]	Number of Samples	Field Duplicates[1]	Field Blanks[2]	Equipment Blanks[2]	MS/MSD[3]	Total	Container Type	Minimum Volume[4]	Preservation (Cool to 4 °C for all samples)	Sample Hold Time from Collection Date
Metals - Appendix III [(1)]											
Boron (total and dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO_3 to pH<2	6 months
Calcium	6020	7	1	0	0	1	9	plastic	600 mL	HNO_3 to pH<3	6 months
Metals - Appendix IV [(2)] and Additional Metals											
Other Metals [(3)] (total and dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Manganese (d)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Lithium	6020	7	1	0	0	1	9	plastic	600 mL	HNO3 to pH<2	6 months
Mercury	7470A or 6020	14	2	0	0	1	17	plastic	400 mL	HNO_3 to pH<2	28 days
Inorganic Parameters - Appendix III [(1)] and Other Inorganic Parameters											
Cyanide	SM 4500-CN or C – EPA 335.4	14	2	0	0	1	17	amber	50 mL	NaOH, Cool to 4 °C	14 days
Fluoride	9214	14	2	0	0	1	17	plastic	300 mL	Cool to 4 °C	28 days
Chloride	9251	14	2	0	0	1	17	plastic	100 mL	Cool to 4 °C	28 days
Nitrate-N	EPA 300.0	14	2	0	0	1	17	plastic	10 mL	Cool to 4 °C	48 hours
Sulfate	9036	14	2	0	0	1	17	plastic	50 mL	Cool to 4 °C	28 days
Total Dissolved Solids	SM 2540 C	14	2	0	0	1	17	plastic	200 mL	Cool to 4 °C	7 days
Radium - Appendix IV [(2)]											
Radium 226	9315 or EPA 903	14	0	0	0	1	15	plastic	1000 mL	HNO3 to pH<2	6 months
Radium 228	9320 or EPA 904	14	0	0	0	1	15	plastic	1000 mL	HNO_3 to pH<2	6 months
Field Parameters											
pH [(1)]	SM 4500-H+ B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Dissolved Oxygen	SM 4500-O/405.1	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Temperature	SM 2550	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Oxidation/Reduction Potential	SM 258O B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Specific Conductivity	SM 2510 B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Turbidity [(4)]	SM 2130 B	14	NA	NA	NA	NA	14	flow-through cell or hand-held turbidity meter	NA	none	immediately

Notes:

[(1)] USEPA Appendix III Parameters (boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids (TDS))

[(2)] USEPA Appendix IV Parameters
(antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, radium 226 and 228 combined)

[(3)] Other Metals = aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, molybdenum, nickel, silver, selenium, thallium, vanadium, zinc

[(4)] If turbidity exceeds 10 NTUs, a duplicate sample filtered through a .45 micron filter may be collected for metals analysis in addition to the unfiltered sample. Both samples would be submitted for analysis.

NA = not applicable

HNO_3 = nitric acid

°C = degrees Celsius

mL = milliliter

1. Field duplicates will be collected at a frequency of one per group of 10 or fewer investigative water sample. Field duplicates will not be collected for radium analysis.
2. Field blanks will be collected at the discretion of the project manager; Equipment blanks will be collected at a rate of 1 per sampling event if non-dedicated equipment is used.
3. Matrix Spike/Matrix Spike Duplicate (MS/MSD) samples will be collected at a frequency of one per group of 20 or fewer investigative water samples per CCR unit/multi-unit. Additional volume to be determined by laboratory.
4. Sample volume is estimated and will be determined by the laboratory.
5. Analytical method numbers are from SW-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as apropriate.

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Table 5. Summary of Detection Limits for Proposed Monitoring Program Class I Groundwater Standards
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Constituent	Unit	Analytical Methods [1]	USEPA MCL [2] (ug/L)	IL Class I Std [7] (ug/L)	RL [4] (ug/L)	MDL [4] (ug/L)
Metals[8]						
Aluminum (d)	µg/L	6020	200 [3]	3500	10	0.85
Antimony	µg/L	6020	6	6	1	0.25
Arsenic	µg/L	6020	10	10	1	0.25
Barium	µg/L	6020	2000	2000	1	0.4
Beryllium	µg/L	6020	4	4	1	0.5
Boron	µg/L	6020	NS	2000	25	10
Boron(d)	µg/L	6020	NS	2000	2.3	10
Cadmium	µg/L	6020	5	5	1	0.25
Calcium	µg/L	6020	NS	NS	125	100
Chromium	µg/L	6020	100	100	1	0.3
Cobalt	µg/L	6020	NS	1000, 2	1	0.25
Copper (d)	µg/L	6020	NS	650, 200	3	0.025
Cyanide	µg/L	4500	200	200	5	0.85
Iron (d)	µg/L	6010	300 [3]	5,000	10	0.88
Lead	µg/L	6020	NS	7.5	1	0.25
Lithium	µg/L	6020	NS	NS	1	0.5
Manganese (d)	µg/L	6020	50 [3]	150	1	0.055
Mercury	µg/L	6020 or 7470A	2	2	0.2	0.051
Molybdenum	µg/L	6020	NS	NS	1	0.25
Nickel (d)	µg/L	6020	NS	100	5	0.075
Nitrate- N	µg/L	300	10000	10000	30	8
Selenium	µg/L	6020	50	50	1	0.9
Silver (d)	µg/L	6020	100 [3]	50	55	0.028
Thallium	µg/L	6020	2	2	1	0.25
Vanadium (d)	µg/L	6020	NS	49, 0.49	5	0.27
Zinc (d)	µg/L	6020	5000 [3]	5	6	0.495
Inorganics						
Fluoride	mg/L	9214	4	4	0.1	0.05
Chloride	mg/L	9251	250 [3]	200	5	1
Sulfate	mg/L	9036	250 [3]	400	10	5
Total Dissolved Solids	mg/L	SM 2540 C	500 [3]	1200	20	10
Other						
Combined Radium 226/228	pCi/L	9315/9320 or EPA 903/904	5	20/20, 5	-- [5]	-- [6]
Field						
pH	SU	SM 4500-H+ B	NS	6.5-9.0	NA	NA
Oxidation/Reduction Potential	mV	SM 2580 B	NS	NS	NA	NA
Dissolved Oxygen	mg/L	SM 4500-O/405.1	NS	NS	NA	NA
Temperature	°C	SM 2550	NS	NS	NA	NA
Specific Conductivity	µS/cm	SM 2510 B	NS	NS	NA	NA
Turbidity	NTU	SM 2130 B	NS	NS	NA	NA

Notes:

NS = No standard
ug/L = micrograms per liter
mg/L = milligrams per liter
pCi/L = picoCuries per liter
µS/cm = microSiemens per centimeter
NTU = nephelometric turbidity unit
(d) = dissolved analysis
RL = Reporting limit as established by the laboratory
MDL = Method detection limit as established by the laboratory
SM = Standard Methods for the Examination of Water and Wastewater

1. Analytical method numbers are from SW-846 unless otherwise indicated.
2. USEPA MCL = United States Environmental Protection Agency Maximum Contaminant Level.
3. USEPA SMCL = United States Environmental Protection Agency Secondary Maximum Contaminant Level.
4. Reporting limits and method detection limits will vary depending on the laboratory performing the work.
5. All radium results will be reported (values may be positive or negative) and will include uncertainty and the calculated MDC.
6. Laboratories calculate a minimum detectable concentration (MDC) based on the sample.
7. 35 IAC 620.410 standards are listed including proposed changes submitted to the IL Pollution Control Board

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HYDROGEOLOGIC SITE CHARACTERIZATION REPORT

Ash Pond 2
Coffeen Power Station
Coffeen, Illinois

January 24, 2017

NATURAL RESOURCE TECHNOLOGY

ENVIRONMENTAL CONSULTANTS

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HYDROGEOLOGIC SITE CHARACTERIZATION REPORT

ASH POND 2
COFFEEN POWER STATION
COFFEEN, ILLINOIS

Project No. 2380

Prepared For:

Illinois Power Generating Company
Coffeen Power Station
134 Cips Lane
Coffeen, IL 62107

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January 24, 2017

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1 INTRODUCTION

1.1 Overview

This Hydrogeologic Site Characterization Report was prepared by Natural Resource Technology, Inc. (NRT) in support of a Closure Plan for Ash Pond 2 located at the Coffeen Power Station (CPS, Site) which is owned by Illinois Power Generating Company (IPGC). This report and the Closure Plan will apply specifically to this Coal Combustion Residuals (CCR) surface impoundment (Ash Pond 2), and not to any of the other impoundments present on the Site which include the following: Ash Pond 1, Ash Landfill, Gypsum Stack Pond, and Recycle Pond. However, information gathered to evaluate these other CCR units regarding geology, hydrogeology, and groundwater quality is included, where appropriate.

Numerous hydrogeologic investigations have been performed concerning the CCR Units located at the Site. The information presented in this site characterization report includes recent data collected to comply with the Federal CCR Rule (40 CFR Part 257) as well as comprehensive data collection and evaluations from prior hydrogeologic investigation reports (recent to oldest), including, but not limited to, the following:

- ***Corrective Action Plan. Hanson, April 16, 2016.*** A plan to remediate groundwater exceedances around Ash Pond 2 and other units. Proposed plan includes reduction in leachate within Ash Pond 2, enhanced cover system on Ash Pond 2, and a Groundwater Management Zone (GMZ).

- ***Revised 30% Closure Design Package for Coffeen Power Station Ash Pond No. 2. AECOM, April 2016.*** A 30% design package for closure of Ash Pond 2 including the design basis and summary in addition to preliminary construction costs and schedule.

- ***Uppermost Aquifer Considerations. Hanson, April 2016.*** A discussion of the construction of the gyspum pond and relation to the uppermost aquifer in the vicinity of the site.

- ***Addendum to the 30% Design Data Package for Dynegy Coffeen Power Station; GMF Gypsum Stack Pond. AECOM, January 27, 2016.*** A geotechnical program consisting of CPT soundings to obtain information for compliance with requirements of the federal CCR Rule.

- ***30% Design Data Package for Dynegy Coffeen Power Station; Ash Ponds Nos. 1 and 2 CCR Units. AECOM, January 14, 2016.*** A geotechnical program consisting of installation of auger borings, CPT soundings, piezometers and soil testing to obtain information for compliance with requirements of the federal CCR Rule.

- ***G153 Assessment. Hanson, January 15, 2015.*** An investigation and evaluation of elevated concentrations of sulfate and manganese near the Southwest Storm Water Detention Pond (SW Pond).

- ***Phase 1 Hydrogeological Assessment Report, Coffeen Energy Center, Montgomery County, IL. Natural Resource Technology, inc., March 2013.*** An investigation and assessment of the potential for impacts to water quality from unlined impoundments at the Coffeen Power Station. Included a survey to identify wells within 2,500 feet of the Site.

- ***Section_3 Hydrogeologic Report. Hanson, August, 2009,*** A summary of the geology and hydrogeology in the area of the proposed Ash Landfill, Gypsum Stack Pond, and Recycle Pond.

In conjunction with this report, a Groundwater Monitoring Plan and a Groundwater Management Zone Application are being prepared to support the closure of Ash Pond 2. In addition, a groundwater flow and transport model was developed to evaluate the effect of various ash pond closure scenarios on groundwater quality and to predict the fate and transport of CCR leachate components. Modeling has also been conducted to enable estimation of the time required for hydrostatic equilibrium of groundwater to be achieved beneath Ash Pond 2.

1.2 Site Location and Background

Ash Pond 2 is one of five CCR units at the CPS, located approximately 2 miles south of the City of Coffeen in Montgomery County, Illinois (Figure 1). The power plant and the CCR Units are situated on a peninsula between two lobes of Coffeen Lake which was created in 1963 by damming a portion of the East Fork of Shoal Creek (IDNR, 2014). The lake covers approximately 1,100 acres and provides cooling water for the CPS.

Ash Pond 2 is located within Section 11 Township 7 North and Range 7 East. The city of Coffeen is approximately 2 miles north of the CPS and the city of Hillsboro, IL is about 8 miles to the northwest. The CPS is located in an agricultural area. Historically, several coal mines were operated at depth in the vicinity of the site as well as a US Minerals processing facility located to the north. The CPS property is bordered by Coffeen Lake on the west, east, and south, and by agricultural land to the north.

Ash Pond 2 was first investigated in 2010, as requested by the Illinois Environmental Protection Agency(Illinois EPA). Results of the investigation (NRT, 2013) indicated the presence of CCR constituents in groundwater in the vicinity of Ash Pond 1 and 2 as well as exceedances of Class I Groundwater Standards for arsenic, boron, lead, sulfate, manganese, iron,sulfate, total dissolved solids, and pH. Additional wells were installed in 2015 to comply with the Federal CCR Rule (40 CFR Part 257), and define the extent of Class I exceedances associated with Ash Pond 2. Based on the groundwater results of wells installed in 2015, Hanson submitted a Corrective Action Plan (CAP, Hanson, 2016a) to define the proposed remedy. Ash Pond 2 will be closed by leaving CCR in place using an alternative geomembrane cover system, following partial dewatering of the pond. This design will control the potential for slope failure and water infiltration into the closed CCR unit and will allow for drainage of surface water off of the cover system (AECOM, 2016a).

Illinois EPA responded to Dynegy regarding the CAP with a draft letter including comments and Dynegy and Illinois EPA met on July 20, 2016 to discuss the CAP and proposed remedy. Following the discussion, Illinois EPA in a letter dated August 9, 2016 provided the following comments (summarized):

1. Investigation may be required to define the source and extent of exceedances from Ash Pond 2.
2. A vertical component is required for the GMZ.
3. The GMZ contains portions of CCR units not proposed to close, GMZ must be revised to include only areas where CAP for Ash Pond 2 will mitigate impacts.
4. Hydraulic conductivity of foundation layer needs to be evaluated to determine if CAP is appropriate.
5. A groundwater monitoring plan,specific to Ash Pond 2 must be submitted with CAP.
6. Modeling is required to demonstrate corrective action will be successful, and at what point in the future.
7. Evaluate the impacts of the corrective action on Coffeen Lake, with respect to applicable surface water standards.

The Closure Plan, to which this Hydrogeologic Characterization Report, the Groundwater Monitoring Plan, Groundwater Model Report, and Hydrostatic Model Report are attached, provide the information necessary to address these comments and justify the selected corrective action.

1.3 Site History

CPS began operation in 1972 and CCR from the coal fired units was disposed of in Ash Pond 1. Ash Pond 2 was also utilized in the early 1970's and Ash Pond 1 was reconstructed in 1978. Both of these units were used until the mid-1980's. Currently, two coal fired units at Coffeen generate 945 MW of electricity with CCR being handled and filled in Ash Pond 1, the Ash Landfill, the Gypsum Stack Pond, and the Recycle Pond.

Ash Pond 2, which is the sublect of this closure, has a surface area of approximately 60 acres with berms up to 47 feet higher than the surrounding land surface. Ash Pond 2 was removed from service and capped in the mid 1980's. Prior to capping, this pond was identified as Outfall 004 in the facility NPDES operating permit, IL0000108. A 2-foot clay and soil cap was placed on the surface of the pond with contouring and drainage provided to direct storm water to four engineered revetment down drain structures (NRT, 2013).

Other CCR units (not the subject of this Closure Plan) at CPS include the following:

- Ash Pond 1 (active unlined impoundment) covers an area of approximately 23 acres, has berms up to 41 feet above the surrounding land surface, and a volume of 300 acre-feet. It primarily receives bottom ash and low volume wastes from floor drains in the main power block building. Several years ago, air heater wash and boiler chemical cleaning wastes were directed to Ash Pond 1 but this practice was discontinued. This impoundment (also known as

the Bottom Ash/ Recycle Pond) is a reclaimed ash pond that was reconstructed utilizing the existing earthen berms with reinforcement, as provided by Water Pollution Control Permit 1978-EA-389 issued by the Agency on May 26, 1978. The bottom ash is periodically removed for beneficial uses by a third-party contractor.

- A Gypsum Management Facility (GMF), consisting of a 77-acre Gypsum Stack Pond and 17-acre Recycle Pond, receives blowdown from the air emission scrubbers and has been in operation since 2010. Construction of the GMF was in accordance with Water Pollution Control Permit 2008-EA-4661 and features a composite HDPE liner with 3-feet of recompacted soil at 1 x 10^{-7} cm/s. Both GMF ponds have a groundwater underdrain system. The Gypsum Stack Pond system was actively pumped during construction, but is currently not used. The Recycle Pond underdrain is a passive, gravity drained system.

- Fly ash is managed in a composite lined landfill constructed in 2010. The Ash Landfill has an active groundwater underdrain system that is currently being actively pumped. Additionally, the Ash Landfill leachate collection system is restricted by rule to no more than 1 foot of leachate on the composite liner.

- An Illinois EPA groundwater monitoring program is in effect for the GMF (under Bureau of Water) and Ash Landfill (under Bureau of Land).

- The SW Pond is not a CCR unit; it manages stormwater from around the Ash Landfill. It is managed under NPDES Permit #2011-EB-1289.

2 GEOLOGY AND HYDROGEOLOGY

Since 2010, several site investigations have been completed in the vicinity of the CCR units. The initial site investigation near Ash Pond 2 (Geotechnology, 2010) included the installation of one well near the southeast corner of the unit. Significant investigation has been completed north of the unit prior to permitting of the Ash Landfill, Gypsum Stack Pond, and Recycle Pond. Following promulgation of the Federal CCR Rule (40CFR 257), additional investigation was completed by AECOM (2016a, 2016b)) to obtain geotechnical information and NRT (2013) to install additional wells for groundwater monitoring. The most recent investigation was completed in 2016 by NRT to better define the vertical and horizontal extent of impacts and refine the GMZ proposed in the CAP. The data collected from recent investigations as well as historical work is incorporated in this report to develop an accurate site conceptual model.

2.1 Regional Geology

2.1.1 Unlithified Deposits

Pleistocene deposits of unlithified glacial diamictons, lacustrine/alluvial deposits, and windblown loess overlie Pennsylvanian-age bedrock throughout central Illinois. The most extensive glacial deposits are those from the Illinoian Stage which cover much of the state and are present at the Site. Diamictons deposited by glacial activity during the more recent Wisconsian Stage does not extend into the Coffeen area. Windblown (aeolian) deposits, the Peoria and Roxana Silts, cover the glacial deposits over a majority of the state. These units are fine-grained deposits blown from river valleys by prevailing winds. The Quaternary units are described briefly below (Hensel and Johnson, 1996), and in detail later in this section.

The Illinois State Geologic Survey has mapped loess thickness at the CPS at less than 5 ft. The Peoria Silt is generally classified and described as light yellow-tan to gray, fine sandy silt. The Roxana Silt is predominately silt-sized material, but can be sandier in localized areas and the base of this unit is often colluvium of silt, and sand (Hensel and Johnson, 1996).

Till members of the Glasford Formation include the Smithboro Member, the Mulberry Grove Member, the Vandalia Member, and the Hagarstown Member (oldest to youngest). The Smithboro Member is described as a gray, compact, silty till. The Smithboro is bounded below by the Yarmouth Soil. The Mulberry Grove Member is intermittent at the Site, and is described as a calcareous gray silt and fine sand containing some fossil mollusks. The Vandalia Member is described as a sandy till with thin lenticular bodies of silt, sand, and gravel. It is calcareous, except where weathered, generally gray, and moderately compact. The Hagarstown Member is bounded at the top by the Sangamon Soil. The member consists of gravelly till, poorly sorted gravel, well sorted gravel, and sand (Willman and Frey, 1970).

2.1.2 Bedrock

The site and surrounding areas are underlain by rocks belonging to the Pennsylvanian Bond Formation (Kolata, 2005). Detailed descriptions of the Pennsylvanian strata of Illinois were published by Willman et al. (1975). The Bond Formation includes all strata from the base of the Shoal Creek Limestone Member or the LaSalle Limestone Member to the top of the Millersville Limestone Member or the Livingstone Limestone Member. It is overlain by the Mattoon Formation and underlain by the Modesto Formation. It varies from less than 150 feet thick in eastern Illinois to over 300 feet thick in southeastern Illinois, averaging about 250 feet. The Bond Formation is characterized by a high percentage of limestone and calcareous clays and shales. It is bound by thick limestone members (up to 50 feet), the thickest and purest limestones in the Pennsylvanian System of Illinois. Gray shales constitute the greatest part of the formation, although thick channel sandstones are developed locally.

The elevation of the bedrock surface in the area ranges from 450 to 500 feet above mean sea level (Herzog et al., 1994). The bedrock surface slopes gently towards the west into a minor bedrock valley that runs north-south. Well logs indicate that the lithology of the uppermost bedrock is predominantly shale (Zeizel, 1959).

2.2 Site Geology

Quaternary deposits in the Coffeen area consist mainly of glacial diamictons and outwash deposits that were deposited during Illinoian and Pre-Illinoian glaciations. A hydrogeologic investigation was conducted in 2006 and 2007 by Hanson to characterize the site geology as part of an application for an Initial Facility Report and Operating (Subpart B) Permit, and Hanson issued a Hydrogeologic Report as part of those applications in 2009. The following geologic descriptions are based on the findings of these investigations and supplemented with data near Ash Pond 2 collected from recent investigations performed to meet requirements of the CCR Rule.

Figure 3 and Table 1 display and summarize the monitoring wells present on site, and Appendix A includes boring logs and well construction logs used for this report. Appendix B includes reports for both laboratory and field hydraulic conductivity tests for recent testing completed in 2015 and 2016 in addition to test results from piezometers within the Ash Pond. The major unconsolidated materials present at the site include the following (listed from ground surface down).

2.2.1 Ash/Fill

Ash is present within Ash Pond 2 at thicknesses up to approximately 36 feet as measured in OW-4, but ash is generally only 24 to 29 feet thick as shown in the boring logs for OW1, OW-2, OW-3, and OW-5 (Appendix A). A majority of Ash Pond 2 overlies the Loess/ Silt unit which comprises the Upper Confining Unit (next Subsection). The remaining areas of Ash Pond 2 overlie the Vandalia Till where former

drainage features were present prior to construction and filling (Figure 4). Field hydraulic conductivity tests from piezometers screened within the ash (Appendix B2) resulted in a geometric mean of 1.5×10^{-3} cm/sec indicating a relatively permeable ash unit.

2.2.2 Roxana Silt / Peoria Silt (Loess Unit)

The Roxana Silt and Peoria Silt are stratigraphically distinct units, but are difficult to differentiate in the area of the Coffeen Power Station. In this report, the combined silts will be called the Loess Unit. The Loess Unit extends from beneath the topsoil, which is derived from the loess, to the the top of the Hagarstown (Beds) Member. Thicknesses range from a minimum of <1.0 ft as observed in G401 and G403 located adjacent to and west/southwest of Ash Pond 2, to a maximum of <6 feet as measured in a boring advanced within the footprint of the landfill prior to construction (MW14S). Actual thickness of the Loess Unit is difficult to evaluate due to the illuviation of the model soil horizon. Around Ash Pond 2, the thickness is presumed to be less than four feet. The loess has been variously classified as silt or clayey silt, with minor amounts of sand. The loess often exhibits mottling, concretions, and some fracturing and may be saturated, dependent on the seasonal variation in groundwater levels.

The Loess Unit is generally considered unsaturated and the upper-most aquifer is recharged by precipitation that percolates through this unit. The laboratory tests from recent geotechnical analysis reported vertical hydraulic conductivity values ranging from 1.3×10^{-8} to 5.0×10^{-7} cm/sec, with a geometric mean of 1.0×10^{-7} cm/sec (Table 2). This unit was likely removed from within the footprint of Ash Pond 2 either through erosion or based on ash pond design grades of 616.5 ft. Construction of the landfill and GMF units required the excavation and removal of this layer.

2.2.3 Hagarstown Member

The Hagarstown Member (consisting of gravelly clay till and sandy materials in contact with the Vandalia, (also referred to as Hagarstown Beds) has been separated into two units for this discussion; the first unit, consisting of the gravelly clay till and the second consisting of sandy material overlying the Vandalia Member. The clay till portion had varying thicknesses ranging from 1.9 feet (G404) to over 12 feet as observed in the borings for G401 and G403, located adjacent to, south and west of the Pond. This unit underlies 95% of the pond and in general the clayey portion is at least 9 feet thick (Figure 4). The thickness of the sandy portion of the Hagarstown is generally less than 3 feet, and near Ash Pond 2 it is generally 1 to 2 feet thick as seen in borings for G401, G404, and G405. The composition of the sandy portion of the Hagarstown unit varies across the site and was classified as gravelly till, poorly sorted gravel, well sorted gravel, sand and silty sand. The elevation of the top of the Hagarstown is mapped in Figure 5 and the general thicknesses are illustrated on Figure 6. As displayed in Figure 5, the elevation of the top of the Hagarstown generally declines as the unit approaches Coffeen Lake or other topographic drainage features.

The elevation of the bottom of the discharge channel south of Ash Pond 2 is approximately 600 ft, based on the Ash Pond design drawing. This implies that the channel intersects and cuts through the Hagarstown along the southern side of the Ash Pond. Along the eastern edge, the creek is at an elevation of ~594 to ~590, indicating that the Hagarstown is also exposed. along the ravine slope.

During construction of the Ash Landfill, the Gypsum Pond, and the Recycle Pond, the Loess Unit and the Hagarstown Beds were excavated to facilitate construction by limiting groundwater flow into excavations. The excavations were backfilled with structural fill and an underdrain system was installed to mitigate inward hydraulic pressure and potential liner uplift damage before the CCR units were filled. The Ash Landfill underdrain system remains active. The Recycle Pond is a gravity drain system, and the Gypsum Pond remains in place, but the system is inactive.

The hydraulic characteristics of the Hagarstown Member indicate the unit has a moderate hydraulic conductivity. The results of single-well field permeability tests have hydraulic conductivity values ranging from 3.1×10^{-5} to 1.6×10^{-3} cm/sec, with a geometric mean of 2.9×10^{-4} cm/sec (Table 3). In several locations (i.e., G402, G403, and G404) this unit is very thin, or was not observed in the boring as shown on the boring logs (Appendix A); however, field hydraulic conductivities are similar to those measured in wells screened across the Hagarstown Beds, indicating that at these locations the upper Vandalia is hydraulically similar to the Hagarstown Beds and is likely connected to and continuous with the Hagarstown. The hydraulic conductivity values measured within wells screened across the Hagarstown Beds are significantly higher than both the overlying Roxana/Peoria Silts and lower Vandalia (Till) Member.

2.2.4 Vandalia Member

The Vandalia (Till) Member is a sandy/silty till with thin, discontinuous lenses of silt, sand, and gravel. The Vandalia Till was encountered in all borings advanced at the site. The Vandalia Till ranged in thickness from 11.7 ft in SB-10 (drilled near MW10S) in the northern portion of the CPS, to 31.0 ft in SB-12 (near MW12S between the Gypsum Stack Pond and the Recycle Pond). Based on Borings G45D and G46D, the Vandalia Till is approximately 7 feet thick in the southeast corner (G46D) to 18 feet thick along the northern edge of the Ash Pond 2 (G45D).The elevation of the top of the Vandalia Till is depicted in Figure 7. Below Ash Pond 2 the elevation ranges from approximately 608.5 to 598 ft. Similar to the observed top elevation of the Hagarstown Beds, the top of the Vandalia unit declines in elevation near Coffeen Lake and topographic drainage features. This unit is relatively thick throughout the site, with an average thickness of of over 15 feet (Hanson 2009).

Results from laboratory tests completed for vertical hydraulic conductivity indicate the Vandalia unit has a very low vertical hydraulic conductivity. The laboratory tests reported hydraulic conductivity values ranging from 6.8×10^{-9} to 4.5×10^{-6} cm/sec, with a geometric mean of 4.9×10^{-8} cm/sec (Table 2). Field

hydraulic conductivity tests completed in temporary piezometers (T408 and T409) indicate horizontal conductivities of 9.0 x 10^{-7} and 3.4 x 10^{-5} cm/sec, respectively (Table 3). The maximum value was measured in a sand seam within the Vandalia Till, but likely is not representative of the diamicton because sand seams are infrequent and discontinuous.

2.2.5 Mulberry Grove Member

The Mulberry Grove (Silt) Member typically consists of a thin, lenticular unit of gray sandy silt (Willman et al., 1975). It represents the interval between the retreat of the glacier that deposited the Smithboro Member and the advance of the glacier that deposited the Vandalia Member. At the site, the Mulberry Grove Member is represented by pockets (generally less than 2 ft thick) of gray sandy silt. This unit was absent in many borings through the central portion of the site from south to north. Where sampled, the Mulberry Grove Member ranged in thickness from 0.5 ft in Borings SB-12 (MW12D) to 4.9 ft in Boring SB-11 (MW11D), both of which are located near the Gypsum Pond (Hanson 2009). The Mulberry Grove Silt was not encountered in the two deep borings, G45D and G46D, advanced near Ash Pond 2.

The laboratory tests reported vertical hydraulic conductivity values of 1.6 x 10^{-6} and 1.9 x 10^{-6} cm/sec, with a geometric mean of 1.7 x 10^{-6} cm/sec. These silts appear to be deposited in depressions found in the surface of the underlying Smithboro Member.

2.2.6 Smithboro Member

The Smithboro (Till) Member is described as a gray, compact, silty, clayey diamicton. The Smithboro Member ranges in thickness from 6.7 ft in Boring SB-05 (near MW05S) to 21.2 ft in Boring SB-02 (near MW02S) located northwest of the landfill. Figure 8 displays the top elevation of the Smithboro Till. As shown on the figure the top of the unit ranges in elevation from 596 to 590 ft below Ash Pond 2. Borings advanced in the vicinity of Ash Pond 2 did not did not penetrate the full thickness of the Smithboro Till.

Laboratory and field conductivity testing indicate the Smithboro Member has a low hydraulic conductivity. Laboratory test reported vertical hydraulic conductivity values ranging from 1.1 x 10^{-9} to 1.0 x 10^{-7} cm/sec with a geometric mean of 1.3 x 10^{-8} cm/sec (Table 2). Horizontal hydraulic conductivities calculated from single well tests performed in wells G45D and G46D were 4.0 x 10^{-8} and 4.9 x 10^{-7} cm/sec, respectively (Table 3).

2.2.7 Yarmouth Soil

The Yarmouth was not encountered in the area of Ash Pond 2 as borings did not extend through the Smithboro. Historical borings in the northern portion of the site which encountered the Yarmouth were summarized previously (Hanson 2009). The Yarmouth Soil is described as the weathered zone on the

Kansan drift, but in some places it consists of accretionary deposits of fine sediment and organic material that accumulated in poorly drained areas on the surface of the Kansan deposits. The Yarmouth Soil was absent in Borings SB-18 and SB-04. Where encountered, the Yarmouth Soil ranged in thickness from 0.8 ft in Boring SB-13 to 5.1 ft in Boring SB-08.

The Yarmouth Soil (considered the deep water-bearing zone) possesses a moderate to moderately low hydraulic conductivity. The single-well permeability tests conducted by Hanson (2009) reported moderate hydraulic conductivity values ranging from 1.3×10^{-4} to 1.7×10^{-3} cm/sec, with a geometric mean of 4.4×10^{-4} cm/sec.

2.2.8 Lierle Clay Member

The Lierle Clay was not encountered in the areas of Ash Pond 2 because borings were terminated in the Smithboro Till. Historical borings in other portions of the CPS which encountered the Lierle were summarized previously (Hanson 2009). The Lierle Clay Member is the upper-most member of the Kansan Stage Banner Formation. It is described as an accretion-gley with clay, silt and some sand. It was encountered by Hanson (2009) in all but a few borings on site (i.e., SB-02 and SB-11), and was the target formation for completion ofsome boreholes. No boring penetrated the full thickness of the Lierle Clay.

The Lierle Clay has a very low hydraulic conductivity. The laboratory tests reported very low vertical hydraulic conductivity values ranging from 3.4×10^{-9} to 1.3×10^{-8} cm/sec, with a geometric mean of 3.6×10^{-9} cm/sec.

2.2.9 Bedrock

The site is underlain by the Pennsylvanian-age Bond Formation, which is characterized by Willman et al., (1975) as having a high percentage of limestone and calcareous clays and shales. Bedrock was not encountered in any borings advanced onsite so site specific information is not available.

2.3 Hydrogeology

One monitoring well was initially installed in 2010 near Ash Pond 2: however, a significant number of wells were installed around the CCR Units prior to and following their construction. In 2015 additional wells and piezometers were installed within and around Ash Pond 2 to meet requirements of the CCR Rule. This discussion focuses on Ash Pond 2 but utilizes historical results from wells at surrounding units, where appropriate, to evaluate the sitewide hydrogeology.

A summary of the current monitoring well networks and construction details is included in Table 1, and recent AECOM piezometers are summarized in Table 4. Since 2006 the hydrogeology of the site has been characterized and described through multiple investigations. This section discusses recently

collected information, focusing on the existing well network and piezometers installed in 2015 and 2016 around Ash Pond 2 as well as appropriate historical data from other units onsite.

2.3.1 Groundwater Occurrence and Elevations

Leachate is present within the ash, and groundwater is present within all geologic units at the CPS; however, the Hagarstown Beds are considered the uppermost aquifer (groundwater monitoring unit or Illinois EPA aquifer) at the site. Hydraulic conductivities of the Hagarstown Beds are generally one to two orders of magnitude higher that the surrounding materials and support the designation of the Hagarstown Beds (and in areas the Upper Vandalia Till) as the Uppermost Aquifer (groundwater monitoring unit). Near Ash Pond 2 (i.e., G402 and G403) the Hagerstown was either very thin or not observed in the boring; however, hydraulic conductivity tests in these wells indicate similar hydraulic conductivities to the Hagarstown Member, indicating that the weathered Upper Vandalia Member is likely part of the Uppermost Aquifer and hydraulicly connected in these areas.

Measured groundwater elevations typically range from about 602 ft near discharge zones along the edges of Coffeen Lake and the Unnamed Creek, to 623 ft in upgradient wells along an approximate center line of the site between the two lobes of the lake (i.e., groundwater divide). Based on the elevation of Coffeen Lake (normal pool elevaton of 590 ft), Unnamed Creek (~590 ft), southern discharge channel (~604 ft) and lowest observed elevation of the Hagarstown Beds (602.6 ft) it is likely that groundwater seeps exist along the shoreline of the lake and slopes near these drainage features. Groundwater elevations are generally consistent and appear to be controlled by discharge as seeps along the shoreline of Coffeen Lake. Geologic cross-sections illustrate the occurrence of the Hagarstown Beds in Figures 9 to 11.

A summary of groundwater elevations from existing wells is included in Table 5 and hydrographs for representative well locations are included in Appendix C. Table 6 summarizes water elevations from piezometers located within and adjacent to Ash Pond 2 and Ash Pond 1. Table 6 also includes elevations from AECOM piezometer (P012) which is screened below the impoundment in the Hagarstown Beds.

Ash leachate is present within Ash Pond 2 and the elevations within the impoundment are significantly above groundwater elevations measured outside the impoundment in the Hagarstown Beds (i.e., observation wells [OW] versus monitoring wells G401 to G405. Within the impoundment, measurements collected from OW-1 through OW-5 indicate the CCR porewater elevation ranges between 635 and 637 (Table 7), while wells outside and below the impoundment range from approximately 604 ft (G402) to 625 ft (P012), indicating the groundwater elevation in the Hagarstown Beds is generally 10 to 15 feet lower than those measured within the impoundment. The leachate appears to be perched above the lower permeability Loess Unit and/or Hagarstown Member gravelly clay till, which locally acts as an aquitard. Leachate head elevations decrease significantly across the impoundment berms and seeps

observed on the berms are likely derived from flow along the ash/aquitard interface. These seeps have been observed adjacent to well locations G404 and G405 along the north impoundment berm and G406 at the southwest corner of Ash Pond 2. The presence of a surface water control channel adjacent to and along the north berm, the ravine to the east, and the southern discharge channel all limit the lateral extent of ash leachate movement.

2.3.2 Groundwater Flow

Potentiometric surface maps prepared from elevation data measured in monitoring wells indicate groundwater elevations can be variable but flow directions are generally consistent. Groundwater generally flows from the center of the site both to the east to the Unnamed Creek, and westward towards Coffeen Lake. Near Ash Pond 1 flow appears to be radial based on mounding created by that unit. In the vicinity of Ash Pond 2 there appears to be a component of radial flow due to water elevations within the ash pond. However, flow within the underlying Hagarstown Beds appears to be east to the Unnamed Creek and south to the discharge flume (water elevation of approximately 604 ft). As shown in Figure 4, ash is in contact with the Hagarstown Member in two areas on the eastern side of the impoundement. Given the elevated heads measured in Ash Pond 2, the predominant flow of water from the ash into the Hagarstown Member likely occurs in these former ravines and migrates within the Hagarstown eastward, beneath the constructed berms, and discharges through seeps into the Unnamed Creek. As previously noted, seeps were also observed along the north and south sides of Ash Pond 2. The horizontal gradient between wells G405 and G404, as measured in May 2016 and November 2016, is 0.007. Representative potentiometric surface maps are shown in Figure 12 and Figure 13.

Construction of the Ash Landfill, Gypsum Stack Pond, and Recycle Pond required removal of the Hagarstown Beds, in effect removing the aquifer beneath the footprint of these units (Hanson 2016b). The groundwater flow dynamics beneath/around the Ash Landfill and GMF Units is affected by several factors, including: removal of the Hagarstown Member from beneath the Units; presence of the construction dewatering systems around the units; and the lateral variability of lithology within the Hagarstown Member. It is uncertain whether these constructed units significantly limit lateral groundwater flow, either by creating no flow zones or by capturing groundwater via their dewatering systems. Potentiometric contours included in Figures 12 and 13 project flow beneath the units.

2.3.3 Vertical Groundwater Gradients

Nested monitoring wells G405D / T408 / G45D and G406 / T409 / G46D were installed in August 2016 to determine the vertical extent of impacts near Ash Pond 2. Based on the water elevations measured in these wells in November 2016, vertical gradients are upward between the Vandalia and Hagarstown Beds and range from 0.009 to 0.42 ft/ft. Between the Vandalia and Smithboro Tills vertical gradients are

significantly downward, ranging from 1.46 to 2.44 ft/ft. A summary of vertical gradients is included in Table 8.

2.3.4 Groundwater Discharge to Coffeen Lake and the Unnamed Creek

The flow of groundwater to both the Unnamed Creek and Coffeen Lake (via the discharge flume) was estimated using a number of general conservative assumptions regarding creek flow and lake levels. Calculations are included in Appendix D, and the results are summarized as follows:

- Flow from Ash Pond 2 through the Hagarstown along the eastern edge of the impoundment is approximately 0.034 cubic feet per second (cfs), or 2 cubic feet per minute (cfm); and estimated flow in the Unnamed Creek based on its geometry is approximately 43.3 cfs (2,600 cfm).
- Flow from Ash Pond 2 from the Hagarstown into the discharge channel along the southern edge is approximately 0.032 cfs (1.9 cfm), and flow in the discharge channel based on average daily flow (based on the NPDES permit) is approximately 773 cfs (46,400 cfm).

2.4 Conceptual Site Model

The geology and hydrogeology described above is summarized and grouped into the following hydrostratigraphic units for the remaining discussion in this report:

- Ash Unit – Saturated CCR within the various CCR Units
- Upper Confining Unit – Low permeability clays and silts, including the Loess Unit and the upper clayey till portion of the Hagarstown Member
- Uppermost Aquifer (Groundwater Monitoring Zone) – Thin (generally less than 3 feet), moderate permeability sand, silty sand, and sandy silt/clay units which include the Hagarstown Member and the upper Vandalia Member (where weathered).
- Lower Confining Unit – Thick (generally greater that 15 feet), very low permeability sandy silt till or clay till that includes the unweathered lower Vandalia Member, Mulberry Grove Member (discontinous), and Smithboro Member.

Mounding of water within saturated ash in the impoundment creates a component of radial flow. The extent of this groundwater movement appears to be limited, as the elevated heads overlying the Upper Confining Unit dissipate across the Ash Pond 2 berms. Potentially impacted water from the seeps observed along the berms may partially infiltrate through the Upper Confining Unit and/or run off toward the Lake or Unnamed Creek.

The Uppermost Aquifer underlying Ash Pond 2 consists of the Hagarstown Member and the weathered (upper) portions of the Vandalia Member, which is being monitored to define the extent of CCR constituents derived from Ash Pond 2. The Uppermost Aquifer is confined except where the Hagarstown Member is exposed along the eastern side of the impoundment within the former ravine (Figure 4). Based

on hydraulic conductivity values (10^{-3} to 10^{-4} cm/sec) measured in the monitoring wells screened in the Hagarstown Member, groundwater at CPS has previously been classified as Class I in accordance with 35 IAC 620 (Hanson, 2009).

CCR within Ash Pond 2 is underlain by the Upper Confining Unit beneath the majority of the impoundment footprint. However, in former drainage features present prior to construction the saturated ash is in contact with the Hagarstown Beds and underlain by the Vandalia Member. Given the relatively high permeability of the Hagarstown Beds, leachate from Ash Pond 2 infiltrates into this unit, migrates through/under the eastern berm (where the Hagarstown Member is continuous below the berm) and discharges along the slope, as evidenced by the observation of seeps (Figure 4).

Groundwater within the Hagarstown Beds beyond the boundary of Ash Pond 2 flows predominantly to the east and south. Both the southern discharge flume and the Unnamed Creek intersect and cutoff the Hagarstown unit, eliminating further migration of potentially impacted groundwater. Impacted groundwater may also migrate to the north and northwest in the Hagarstown, potentially under the influence of the passive (gravity drain) underdrain system associated with the Recycle Pond and active underdrain system associated with the Landfill.

2.5 Potable Water Well Inventory

A potable water well inventory was completed in 2013 during the Phase I Hydrogeological Assessment (NRT, 2013). Public records were searched to identify water supply wells located within 2,500 feet of the unlined impoundments. The Coffeen property boundary is located in Township 7 North, Range 8 West, and the unlined impoundments are located in the southwest quarter of Section 11. The 2,500 foot boundary spans across Sections 10, 11, 14, and 15. All wells within Sections 10, 11, 14, and 15 are shown on Figure E1 and tabulated in Appendix E.

The following sources of information were queried to identify well locations.

- Illinois State Geological Survey's Illinois Water Well (ILWATER) Internet Map Service
- Illinois State Water Survey Domestic Well Database
- Illinois EPA's web-based Geographic Information System (GIS) files

Twenty-six water well records were identified within the four sections surrounding the unlined impoundments, and are numbered 1 through 26 on Figure E1. Based on state records there are two non-community water supply (NCWS) wells, one industrial/commercial well, ten monitoring wells (associated with the White and Brewer facility), and 13 farm/domestic water wells within the four section search area (Appendix E). The Coffeen Power Station does not have a water supply well. The two NCWS wells, points 25 and 26, are located within Sections 10 and 15 and outside of the 2,500 feet boundary of

the impoundments (Figure E1 and Appendix E). There are no maximum setback zones (as defined by 35 IAC 671) for these two NCWS wells.

All except one of the wells identified in the well search are east or west of Coffeen Lake, which is a hydraulic divide for potentially impacted groundwater. The only water well located between the east and west branches of the lake is well 22, which was reportedly installed in 1981 and completed in sand and gravel at a depth of 39 feet. This well was observed during the original Hydrogeologic Investigation and removed by the Contractor during construction of the Recycle Pond (Rhonald Hasenyager, Hanson Professional Services, Inc.; personal communication).

Public water supply (PWS) wells within a ten mile radius of the Coffeen CCP impoundments were identified via a search of the Illinois State Water Survey's Illinois Water Inventory Program (IWIP) database (not available on-line) by RAPPS (2009). Three wells belonging to the Village of Fillmore are located within the search radius, the closest one is approximately eight miles northeast of the impoundments.

3 GROUNDWATER QUALITY

3.1 Summary of Groundwater Monitoring

Groundwater monitoring at the Coffeen Power Station was initiated in 2006 prior to construction of the Gypsum Management Facilty and Landfill; however, consistent data collection near Ash Pond 2 began in November 2015 to comply with the CCR Rule. There are currently no IEPA monitoring requirements for Ash Pond 2. The following discussion presents an analysis of historical data collected from 2010 to 2012 (in well G402, formerly APW-2) and recent CCR data from November 2015 to 2016. Limited data from monitoring wells near the Landfill, Gypsum Stack Pond and Gypsum Recycle Pond are also included to evaluate historical trends. Groundwater data from monitoring wells near Ash Pond 1 are not included in this analysis.

Groundwater monitoring around Ash Pond 2 that was initiated in November 2015 included seven well locations. Sampling is conducted quarterly at 2 background wells and 5 downgradient wells for the following parameters:

Metals (totals)			
Antimony	Boron	Cobalt	Molybdenum
Arsenic	Cadmium	Lead	Selenium
Barium	Calcium	Lithium	Thallium
Beryllium	Chromium	Mercury	
Inorganics (totals)			
Fluoride	Chloride	Sulfate	Total Dissolved Solids
Field			
pH	Dissolved Oxygen	Specific Conductivity	Turbidity
Oxidation/Reduction Potential	Temperature		

In August 2016, four additional wells (G406, G407, G45D, G46D) were installed to further define the extent of impacts from Ash Pond 2 and refine the GMZ proposed in the CAP. Groundwater samples were collected in August and November, 2016 and results are included in this analysis. Data for the expanded parameter list for the federal CCR sampling will be reported in accordance with the groundwater monitoring plan included with the Closure Plan for Ash Pond 2.

3.2 Groundwater Monitoring Results and Analysis

Analytical results for Ash Pond 2 wells from 2010 (APW-2) through October 2016, and from 2008 to 2016 for select wells around the SW Pond and Recycle Pond are summarized in Appendix F. Statistics

showing the minimum and maximum concentrations detected in the groundwater samples is included for each well in Table 9. Table 9 also includes a comparison of groundwater data from wells to the Groundwater Quality Standards for Class I: Potable Groundwater. The well locations are shown on Figure 3. Note these results include both dissolved and total analytes, and are compared to 35 IAC 620 Class I Standards. Where possible, emphasis is placed on dissolved analyses, but totals are used when no dissolved analysis was available.

Parameters that have been detected in groundwater at concentrations exceeding the Class I groundwater quality standards include the following: arsenic, boron, lead, manganese, sulfate, and total dissolved solids (reported as residue on evapoaration or ROE). A summary of recent exceedances in 2015 and 2016 follows for the parameters of concern. Time-series graphs for each of the groundwater parameters at the 7 monitoring wells around Ash Pond 2 and select wells around the SW Pond and Recycle Pond are included in Appendix F including all historical results for these locations.

Arsenic

Arsenic exceeded the Class I standard (0.010 mg/L) in well G405 (November 2015), and G402 (November 2015, and February and May 2016) which are located at the toe of Ash Pond 2 on the north and southeast side, respectively. Results from other wells on-site are either non-detect or at concentrations well below the standard. However, arsenic is naturally occurring in Illinois groundwater. State agencies (IDNR, IDPH & IEPA, 2001) have noted that "arsenic concentrations that vary dramatically over a relatively short distance indicates that local conditions dictate arsenic concentration in groundwater, and it is difficult to make regional generalizations." Therefore, it is equally dificcult to make large-scale source determinations because of the concentration variations over these reported short distances.

Boron

Boron exceeded the 2 mg/L Class I standard during all events at wells G401 and G405, located south and north of Ash Pond 2, respectively. Exceedances were also measured in G402, southeast of the unit and G404 and the nearby Recycle Pond well G275, located northeast of the unit. Recently installed deep wells (G45D and G46D) did not exceed the Class I standard, indicating the impacts do not extend vertically through the Vandalia Till. West of the unit, G403 exhibits very low concentrations of CCR parameters which may be related to the relatively thin Hagarstown unit at this location (~0.2 ft). The groundwater elevation at G403 is also the highest measured value around Ash Pond 2, implying the impacted water does not flow toward this location. The highest concentrations of boron in groundwater have been detected in G405 and range from 15 to 17 mg/L. This concentration is significantly higher than other wells located adjacent to the Pond, and may be related to the shallow depth and increased

thickness of the Hagarstown Beds observed at this location. As discussed previously it is unclear if the seeps along the northern berm are infiltrating and resulting in localized increases in concentration.

Ash Pond 2 was closed/capped in the mid-1980's and it is expected that groundwater has reached equilibrium with respect to Ash Pond 2 (both concentrations and heads). Long term data collection at G402 (APW-2) supports this conclusion as boron concentrations have remained relatively stable (Appendix F). Results from sampling at G275 indicate highly variable concentrations of boron which may be related to the well's proximity to the Unnamed Creek, which exhibits significant seasonal fluctuations in discharge. Increasing trends are visible in results from G271, G273, and G274 (located north of the unit between the Recycle Pond and Ash Pond 2), although concentrations are significantly below the standard. The slight increases in concentration at these locations may be attributed to the construction of the Recycle Pond. As discussed in Subsection 2.3.2, construction of the Recycle Pond has likely impacted the groundwater flow dynamics in the area. The removal of the Hagarstown Member and the installation of the passive dewatering system may be allowing the northerly migration of contaminants toward the Recycle Pond monitoring system wells. Additional data is necessary to establish long term trends in boron concetrations at other monitoring wells near Ash Pond 2.

Lead

Lead was detected above standard (0.0075 mg/L) adjacent to Ash Pond 2 in G402 and G405. Concentrations above standard were also reported in G275, G276, G278, and G280 near the GRP. However, with the exception of G402, additional samples collected at these locations did not contain elevated lead concentrations, suggesting exceedances at these locations were anomalous and likely related to turbidity.

Sulfate

Sulfate, like boron, is a primary indicator of CCR leachate, and exceeded the 400 mg/L Class I standard at Ash Pond 2 wells G401, G402, G405, G406 (located around the perimeter of the Pond) and G407 (located approximately 1,000 feet west of the Pond). It also exceeds the standard at G271, G273, G275 and G279 adjacent to the Recycle Pond and north of Ash Pond 2, and G153 adjacent to the SW Pond and northwest of Ash Pond 2. At well G274 exceedances occurred in December 2012 and January 2013, but recent results indicate concentrations are below the standard. Sulfate, when present with elevated boron concentrations, is presumed to be indicative of potential impacts from a CCR unit. The highest concentrations of sulfate are detected in G401, which is located on the south side of Ash Pond 2. Sulfate concentrations generally correlate with boron concentrations with the exception of G271, G273, G279, and G407 where elevated sulfate is present without a significant boron presence. Increasing trends of boron in G71, G273, and G279 suggest that sulfate concentrations may be partially in response to effects from Ash Pond 2, but limited data from G407 (installed in August 2016) does not allow a similar analysis.

Current data does not suggest wells G153 and G407 are impacted by Ash Pond 2; however, without more data a definitive source of the sulfate in G153 and G407 cannot be determined.

Increasing trends are apparent at wells G153, G271, and G272. As discussed previously, increasing concentrations in G271 and G272 may be naturally occurring background in conjunction with changes in groundwater flow and geochemical conditions following construction of the Recycle Pond. It is unclear why sulfate concentrations are increasing in G153; it may be due to similar effects following construction of the Landfill and SW Pond. Sulfate concentrations in this well have been elevated since it was installed in 2011. Background well G270 had increased concentrations following installation in 2008 until December 2014; however, since then the concentration has stabilized and declined. Remaining wells exhibit stable concentration trends, although more data is needed for CCR wells installed in 2015 (G401 to G405).

Manganese

Manganese concentrations exceeded the Class I standard of 0.15 mg/L at monitoring wells G402, G404, G405, and G406 during 2015 and 2016. Wells G401, G402, and G403 are part of the CCR Rule monitoring program and have not been sampled for manganese (not an Appendix III or Appendix IV parameter). Wells around the SW Pond G151, G152, and G153 have exceeded the standard at least once during 2015-2016 and concentrations of manganese around the Recycle Pond are highly variable, however only G270 has exceeded the standard during 2015-2016. In locations where elevated manganese concentrations are present with both elevated boron and sulfate, it is likely related to effects of the impoundment(i.e. changes in geochemical conditions) but not necessarily directly from the CCR leachate. However, in some cases (i.e. G151, G152, G153, G270, and G407) the lack of elevated concentrations of boron (and in some cases sulfate, i.e. G151, G152, and G270) in groundwater indicates that the elevated manganese concentrations may be primarily associated with with changing geochemical factors (following construction of nearby CCR units and only secondarily related to the impoundment. Time concentration plots indicate decreasing manganese trends in groundwater from G270 and G273, no other trends are apparent in monitoring wells evaluated for this analysis.

Total Dissolved Solids

TDS concentrations regularly exceed the Class I standard of 1,200 mg/L at wells G401, G402, G405, G406, and G407 around Ash Pond 2 and also adjacent to the SW Pond (G153) and the GRP (G273 and G275). TDS reflects concentrations of major ions in groundwater and in the wells listed above sulfate concentrations make up the largest component of the TDS exceedances. TDS concentrations mirror trends observed in sulfate concentrations, with slightly increasing trends observed in G153, G271, and G272.

pH

The pH measured in G401 (south of the unit) fell below the lower limit (6.5 standard units, SU) during sampling in 2015 and 2016. Groundwater in this well appears to be impacted (based on boron and sulfate concentrations) and results from recent surface and source water sampling indicates the CCR leachate is slightly acidic, and is likely the source of acidity causing low pH values in groundwater. Monitoring well G402, also located south of the unit, exhibits simalr pH measurements but does not exceed the lower pH standard.

3.3 Impacted Groundwater Discharge to Surface Water

Based on the groundwater discharge calculations discussed in 2.3.4, and maximum concentrations of boron and sulfate detected in groundwater, the concentration of boron and sulfate loading into Coffeen Lake and the Unnamed Creek were calculated to determine if they exceed surface water standards. Calculations are included in Appendix D, and indicate that approximately 12.5 kg of boron are discharged to the creek each day, resulting in a calculated concentration of 0.115 mg/L. The estimated sulfate concentration is 1.9 mg/L.

In the discharge channel to the south, approximately 1.6 kg of boron is discharged via groundwater baseflow each day, resulting in a calculated concentration of 0.01 mg/L; the concentration of sulfate in the discharge flume is estimated at 50.1 mg/L. In both discharge areas the resulting concentrations are significantly below standards. Recent surface water sampling (Table 10) also confirms that Coffeen Lake is not impacted by Ash Pond 2 because measured concentrations of sulfate (~55 mg/L) and boron (≤280 ug/L) are well below standards and similar to background groundwater concentrations measured elsewhere onsite (i.e., at background wells G200 and R201).

4 CONCLUSIONS

Based on extensive site investigation and monitoring, the site has been characterized and a detailed site conceptual model has been developed. In conjunction with the hydrogeologic investigation, a groundwater model has also been developed to predict the effect of ash pond closure via capping on groundwater quality. The groundwater model report is being submitted under separate cover.

CPS and Ash Pond 2 overlie a significant thickness of glacially-derived deposits. The unlithified deposits which occur at Ash Pond 2 include the following hydrstratigraphic/geologic units:

- Ash Unit – Saturated CCR wIthin the various CCR Units
- Upper Confining Unit – Low permeability clays and silts, including the Loess Unit and the upper clayey till portion of the Hagarstown Member
- Uppermost Aquifer (Groundwater Monitoring Zone) – Thin (generally less than 3 feet), moderate to high permeability sand, silty sand, and sandy silt/clay units which include the Hagarstown Member and the upper Vandalia Member (where weathered).
- Lower Confining Unit – Thick (generally greater that 15 feet), very low permeability sandy, silt till, or clay till that include the unweathered Vandalia Member , Mulberry Grove Member (discontinous), and Smithboro Member.

CCR is underlain by the Upper Confining Unit in the majority of the Ash Pond 2 footprint and mounding of water within saturated ash in the impoundment creates a component of radial flow. However, the extent of this groundwater movement appears to be limited, as the elevated heads overlying the Upper Confining Unit dissipate across the Ash Pond 2 berms. Leachate seeps observed along the berms may partially infiltrate through the Upper Confining Unit and/or run off with surface water toward the Lake or Unnamed Creek. In localized areas on the east side of Ash Pond 2, former drainage features that ocurr within the pond footprint eroded through the Upper Confining Unit such that the CCR is in contact with the permeable portions of the Hagarstown Beds. In these areas, CCR leachate appears to migrate in the Hagarstown Beds and discharge through seeps along the ravine into the Unnamed Creek to the east.

The uppermost aquifer underlying Ash Pond 2 consists of the Hagarstown Member and the weathered portions of the Vandalia Member, which is being monitored to define the extent of CCR constituents derived from Ash Pond 2. Groundwater at CPS has previously been classified as Class I Potable Resource Groundwater. The uppermost aquifer is confined except where the Hagarstown Member is exposed along the eastern-side of the impoundment within the former ravine.

Groundwater within the Hagarstown Beds beyond Ash Pond 2 flows predominantly to the east and south. There is limited groundwater flow from Ash Pond 2 toward the west due to a thinning or lower hydraulic

conductivity of the Hagarstown Beds. Based on hydraulic conductivities and vertical gradients, horizontal groundwater flow in the overlying clays and underlying tills are negligible. Groundwater flow occurs primarily in the more permeable zones within the Hagarstown Beds. However, migration of impacts is limited to the east and south by the presence of the Unnamed Creek, Coffeen Lake and a surface water discharge flume, all three of which are areas of groundwater discharge and act as hydraulic barriers and/or groundwater divides.

Exceedances of Class I groundwater quality standards are present in monitoring wells at several locations around Ash Pond 2 for arsenic. boron, lead, manganese, sulfate, and total dissolved solids. The exceedances of Class I groundwater quality standards for arsenic, lead, manganese, sulfate, and TDS at several locations may be only partially attributed to Ash Pond 2, and are primarily a result of natural geochemical variations or background concentrations, specifically in wells where boron concentrations are low. The concurrent detection of elevated boron and sulfate concentrations are key indicators of the presence of CCR constituents related to Ash Pond 2.

Boron concentrations are generally stable with the exception of wells G271, G272, and G274 (located between Ash Pond 2 and the Recycle Pond), which have shown slight increases. However, concentrations remain significantly below the standard (2 mg/L). Increasing trends measured at these wells are attributed to the construction of the GRP north of the wells and the reduction of unimpacted groundwater flow towards these wells, or increased flow from Ash Pond 2, due to the underlying drainage system at the GRP.

Given the current groundwater data and Site information, groundwater quality is expected to improve following closure, as capping will reduce the infiltration of water and leachate generation from Ash Pond 2. Because CCR will remain in Ash Pond 2, a groundwater monitoring plan is being submitted with this Closure and Post-closure Care Plan. I.

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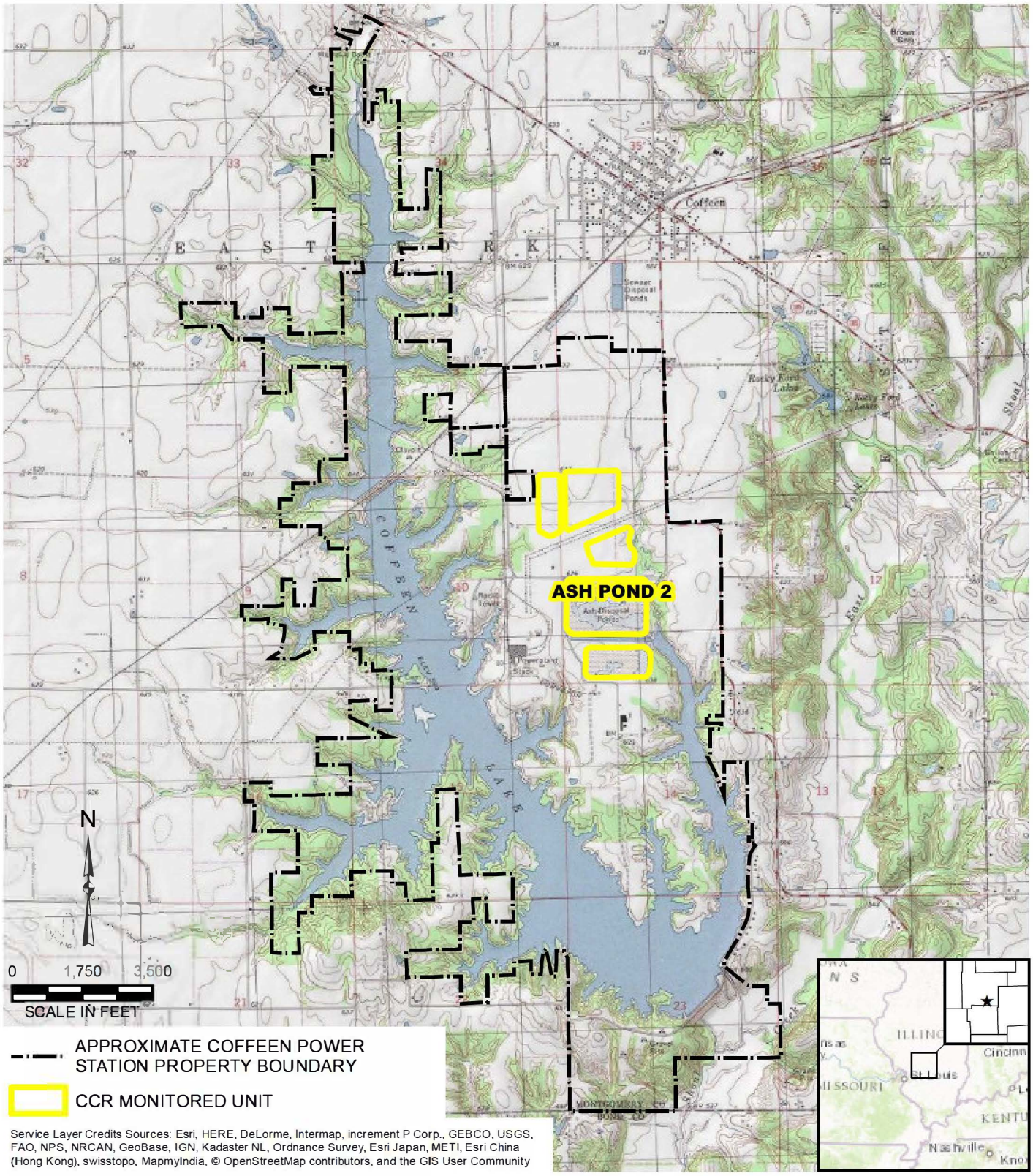
FIGURES



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SITE LOCATION MAP

HYDROGEOLOGIC CHARACTERIZATION REPORT
ASH POND 2
COFFEEN POWER STATION
COFFEEN, IL

PROJECT NO: 2380

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Natural Resource Technology

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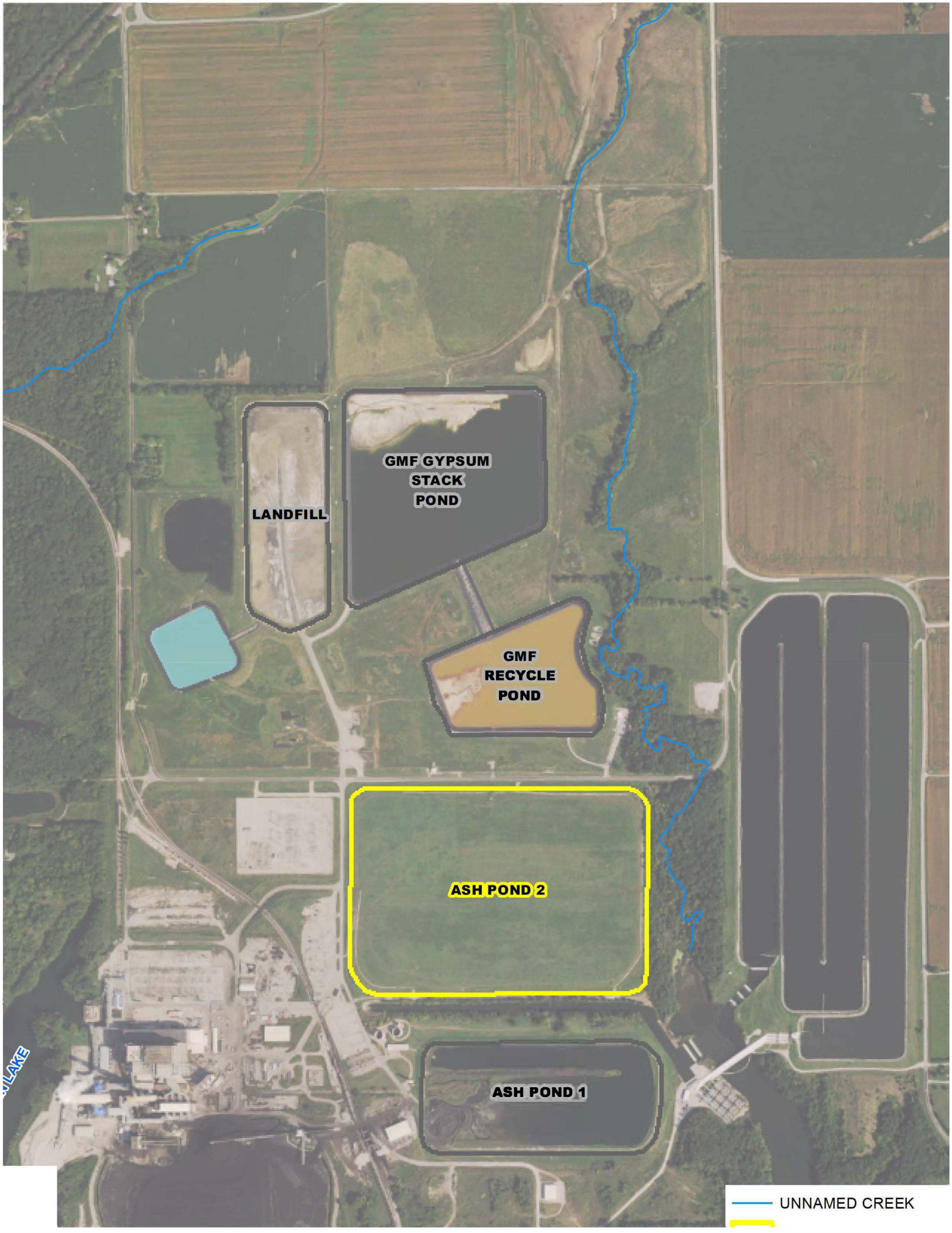
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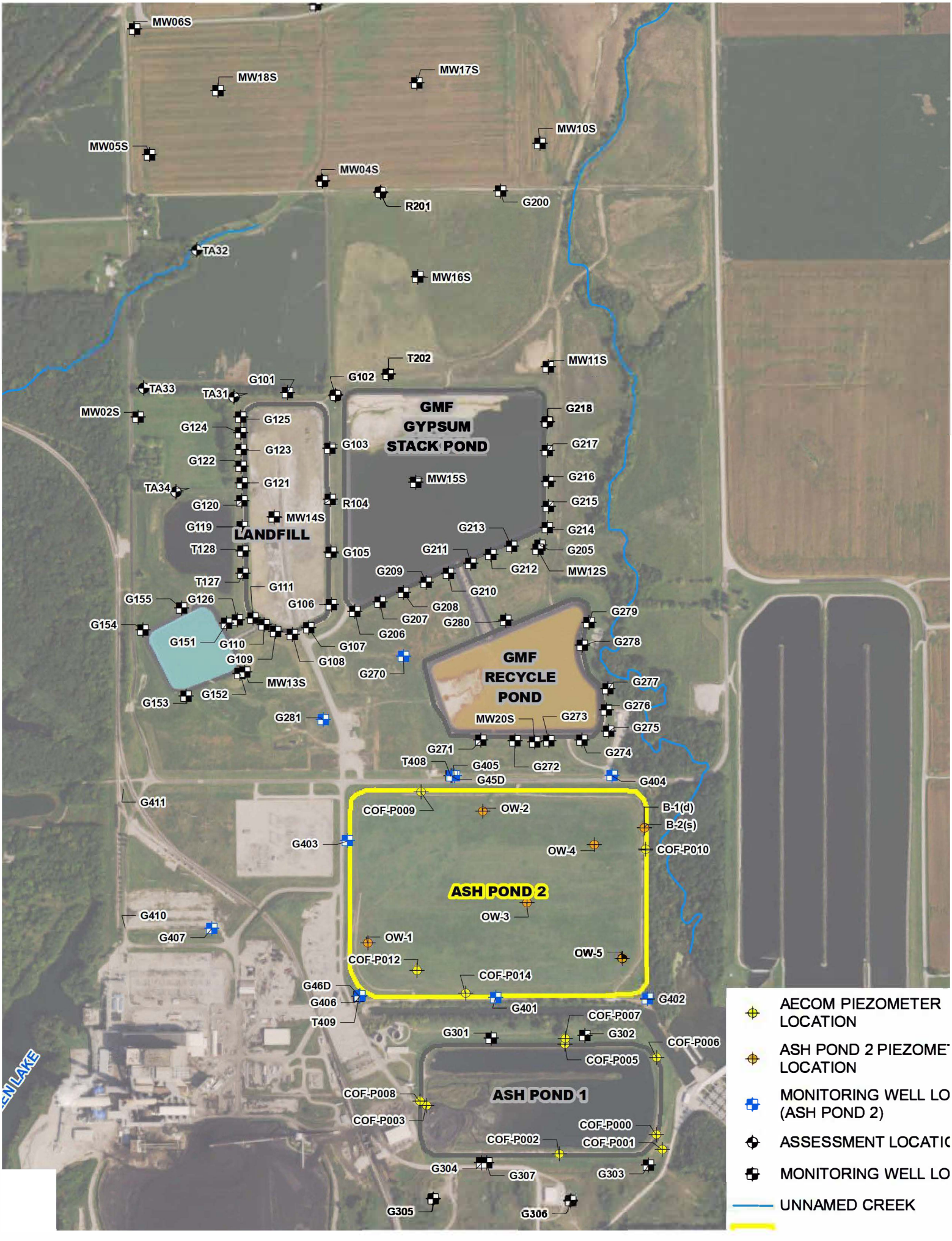
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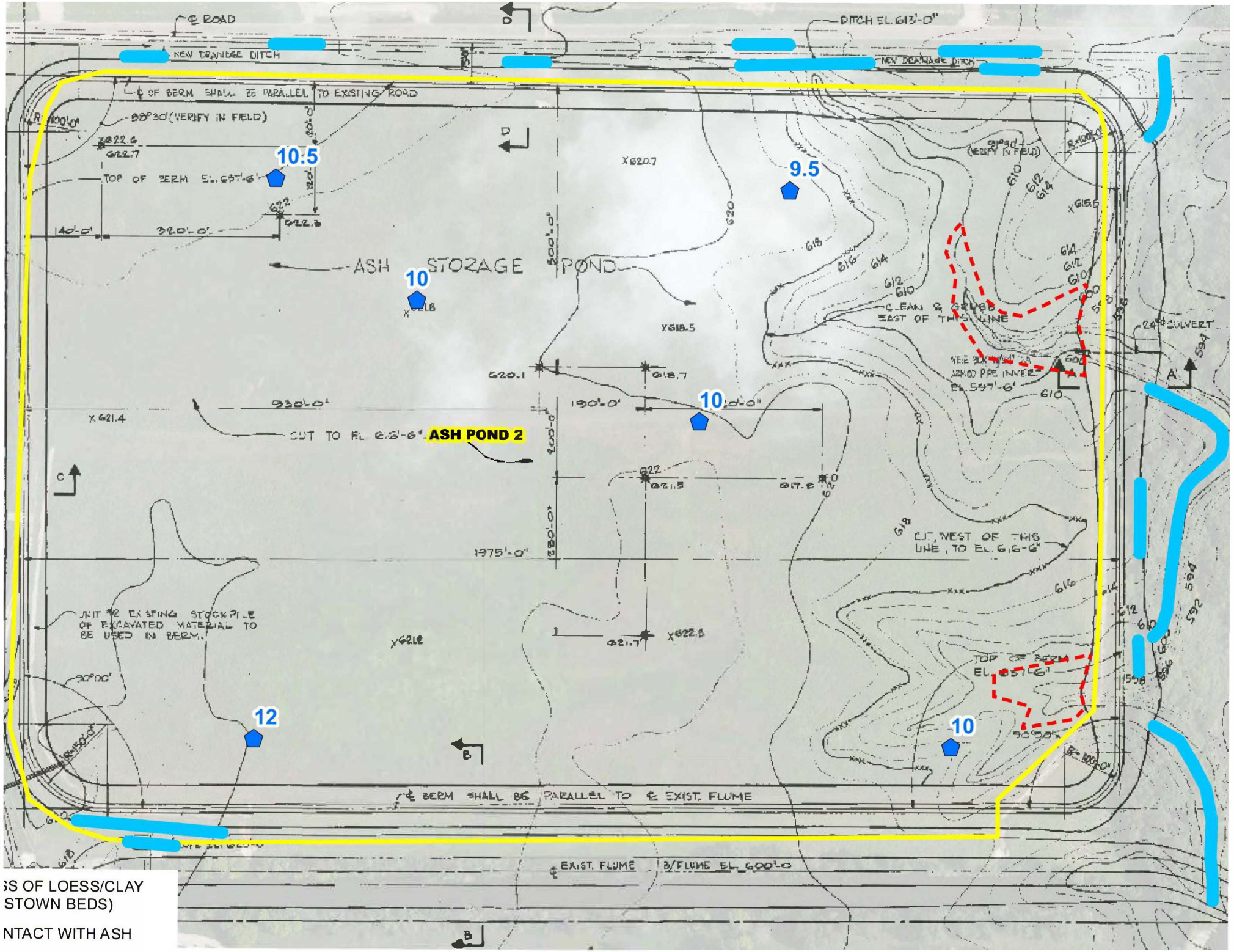
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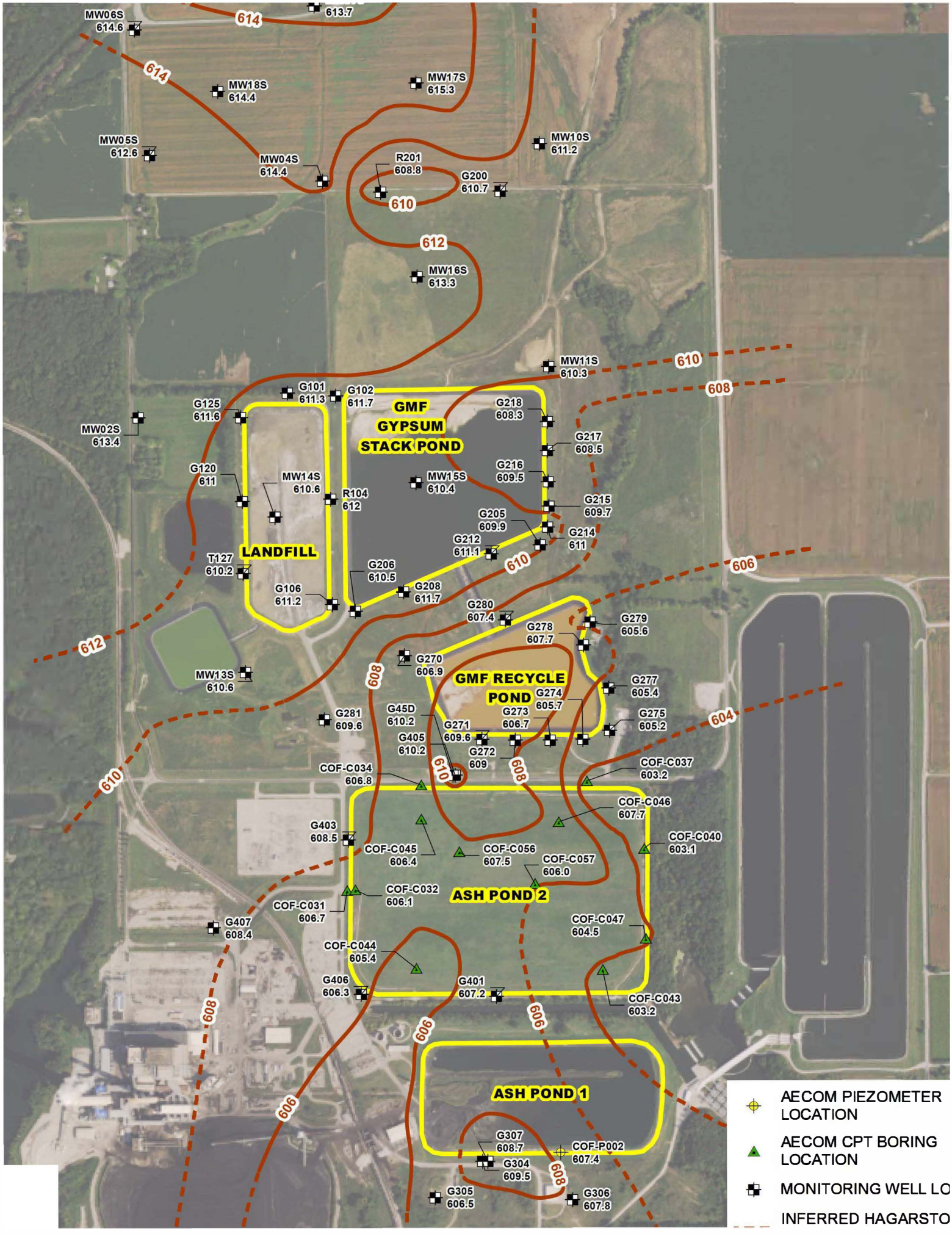
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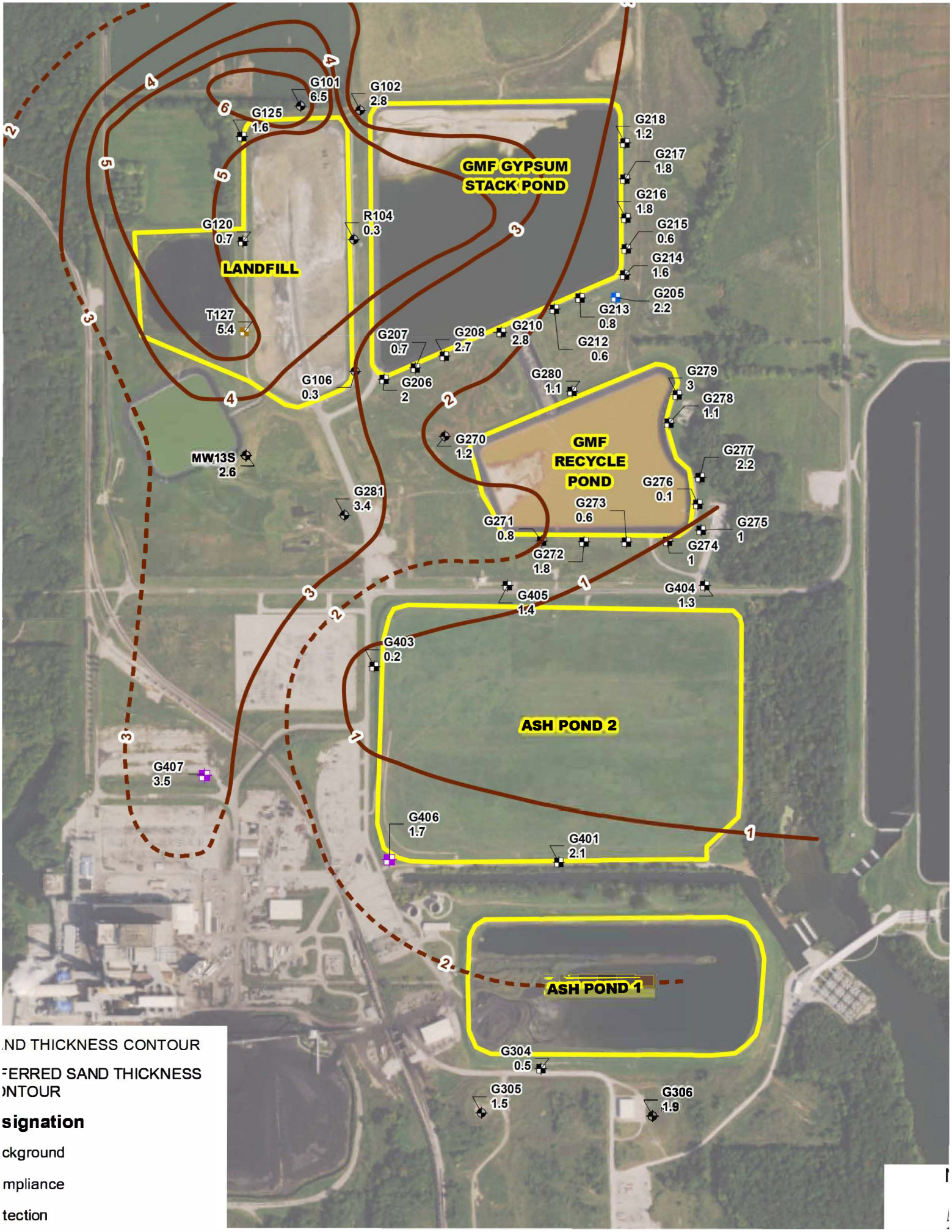

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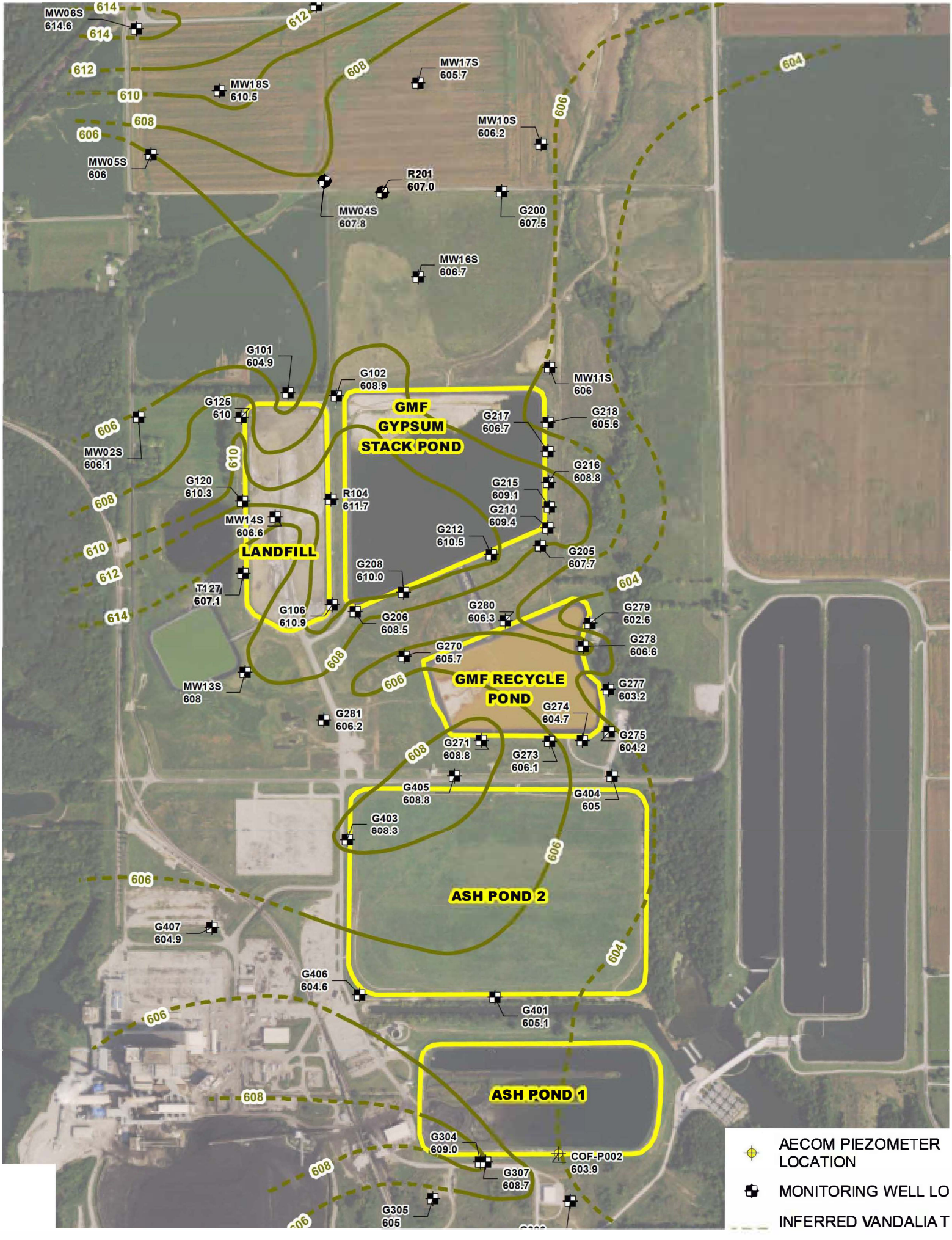
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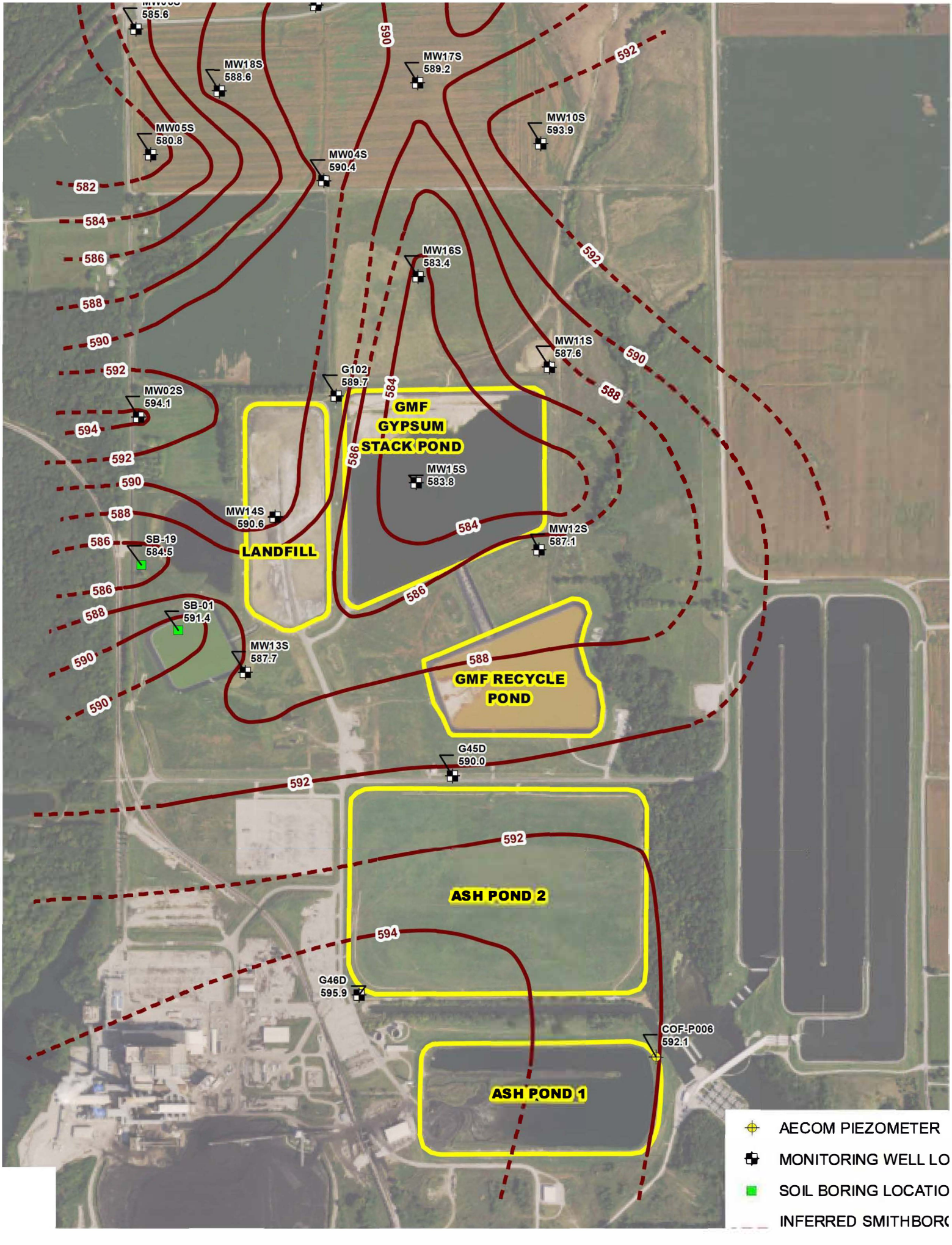
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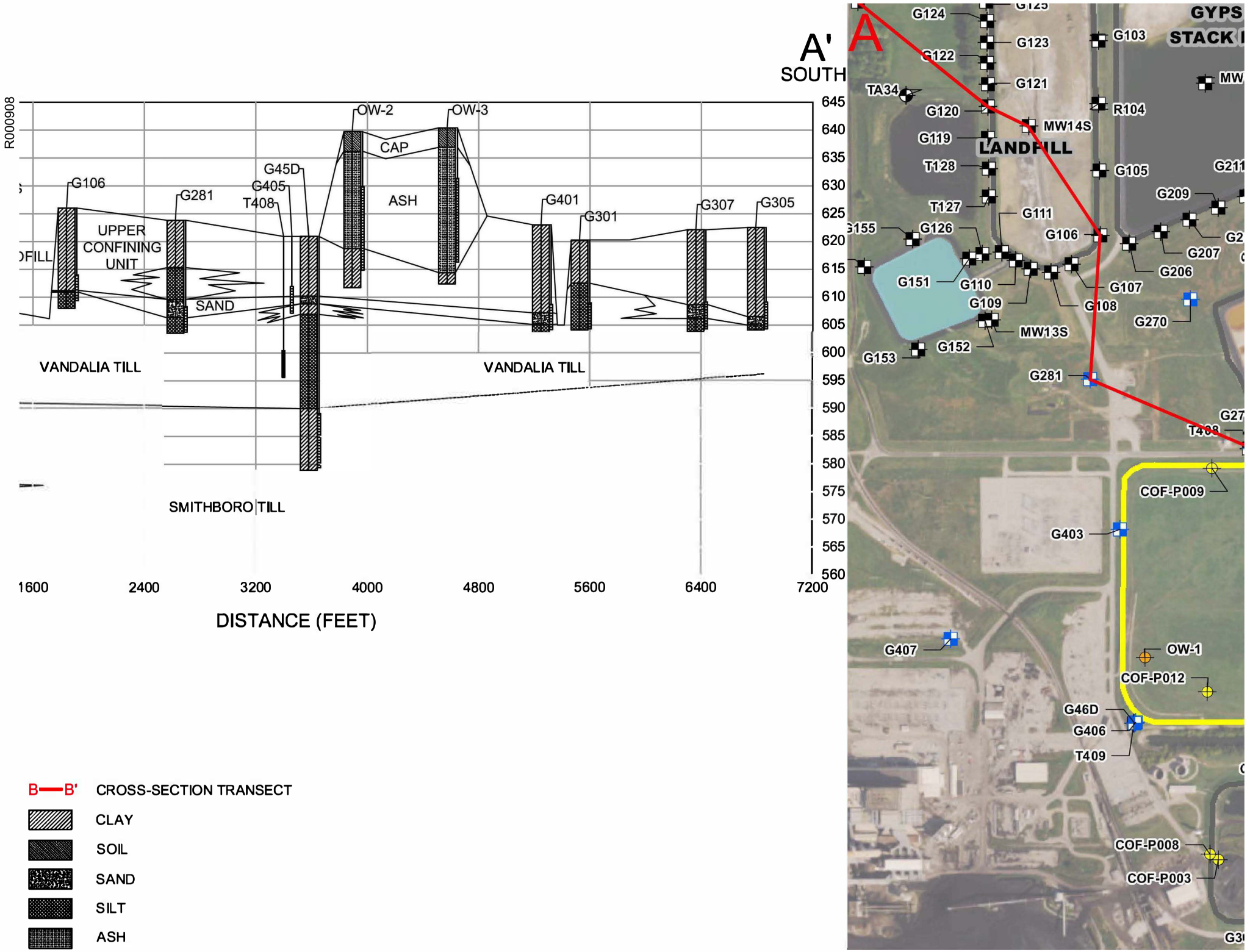
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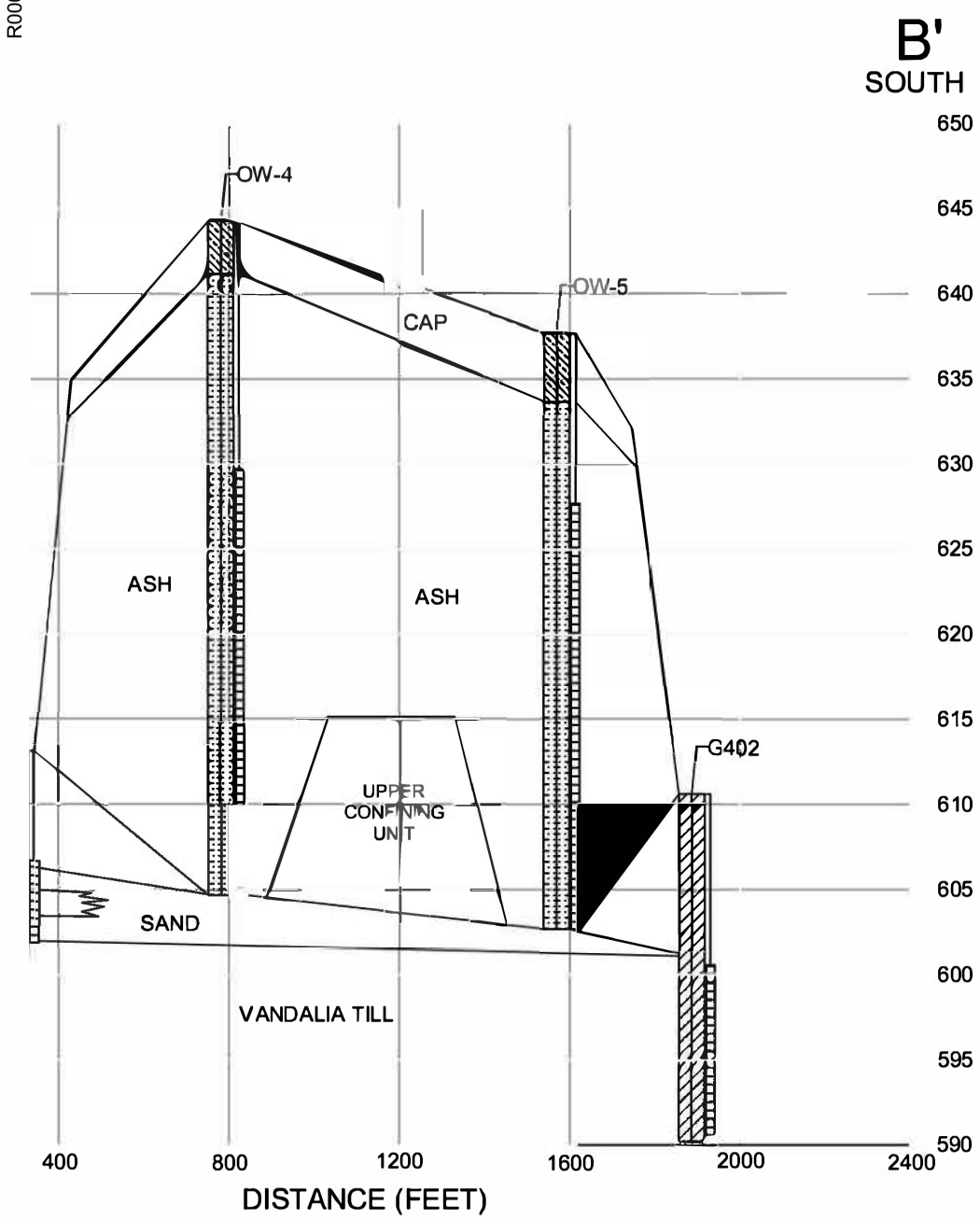
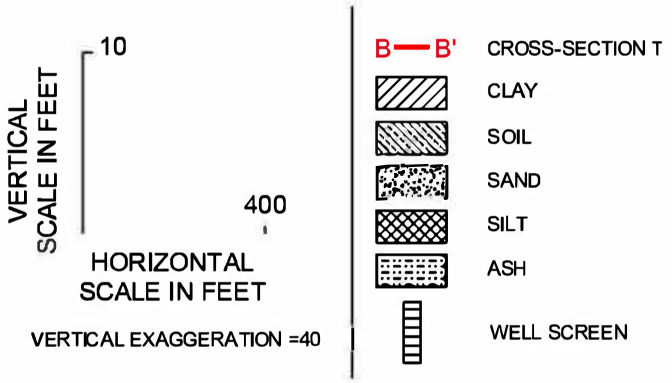
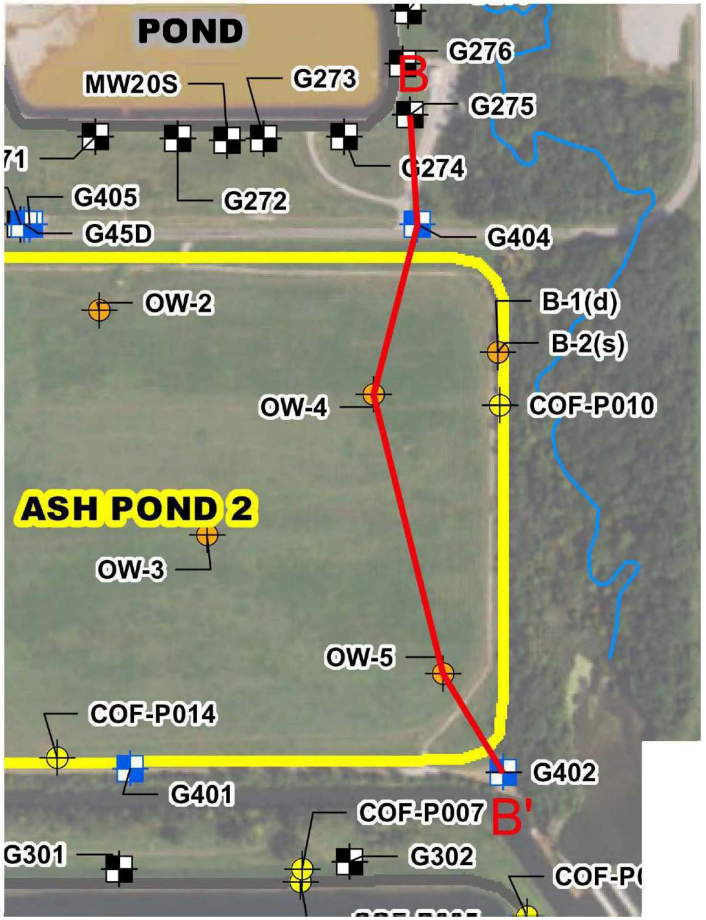
5600
6400
7200
DISTANCE (FEET)
G124
G123
G122
G121
G120
G119
G103
TA34
R104
MW14S
LANDFILL
T128
G105
T127
G111
G126
G106
G209
G207
G206
G151
G110
G107
G109
G108
G270
MW13S
G153
G152
G281
COF-P009
G403
G407
OW-1
COF-P012
G46D
G406
T409
COF-P008
COF-P003
GYPS
STACK
B—B' CROSS-SECTION TRANSECT
CLAY
SOIL
SAND
SILT
ASH

R000909


B'
SOUTH
650
645
640
635
630
625
620
615
610
605
600
595
590
OW-4
OW-5
CAP
ASH
ASH
G402
UPPER CONFINING UNIT
SAND
VANDALIA TILL
400
800
1200
1600
2000
2400
DISTANCE (FEET)


VERTICAL SCALE IN FEET
10
400
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION =40
B — B'
CROSS-SECTION T
CLAY
SOIL
SAND
SILT
ASH
WELL SCREEN


POND
MW20S
G273
G276
B
G275
G274
G405
G272
G45D
G404
OW-2
B-1(d)
B-2(s)
OW-4
COF-P010
ASH POND 2
OW-3
OW-5
COF-P014
G401
G402
COF-P007
B'
G301
G302

R000910

650
645
640
635
630
625
620
615
610
605
600
595
590

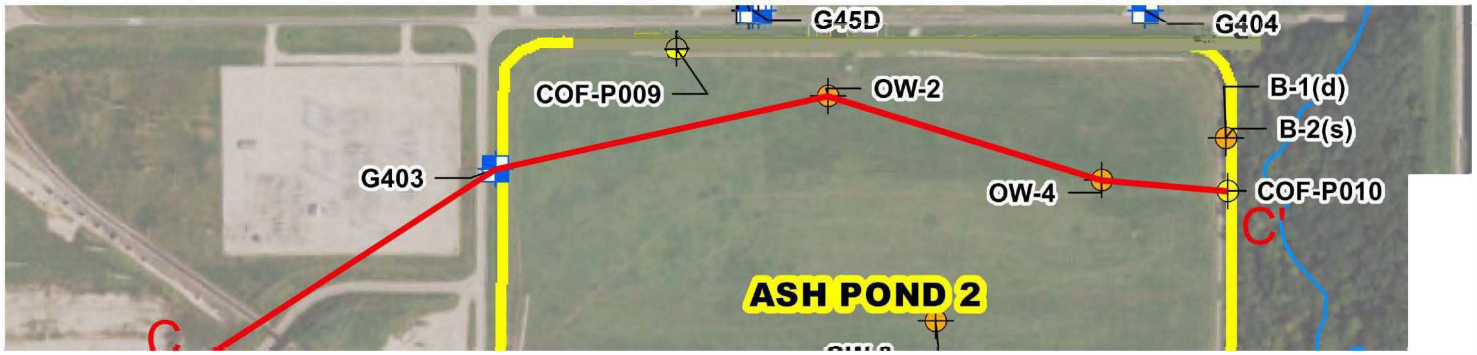
OW-4
OW-2
CAP
CAP
B010(P010)
G403
ASH
ASH
ASH
UPPER CONFINING UNIT
UPPER CONFINING UNIT
VANDALIA TILL

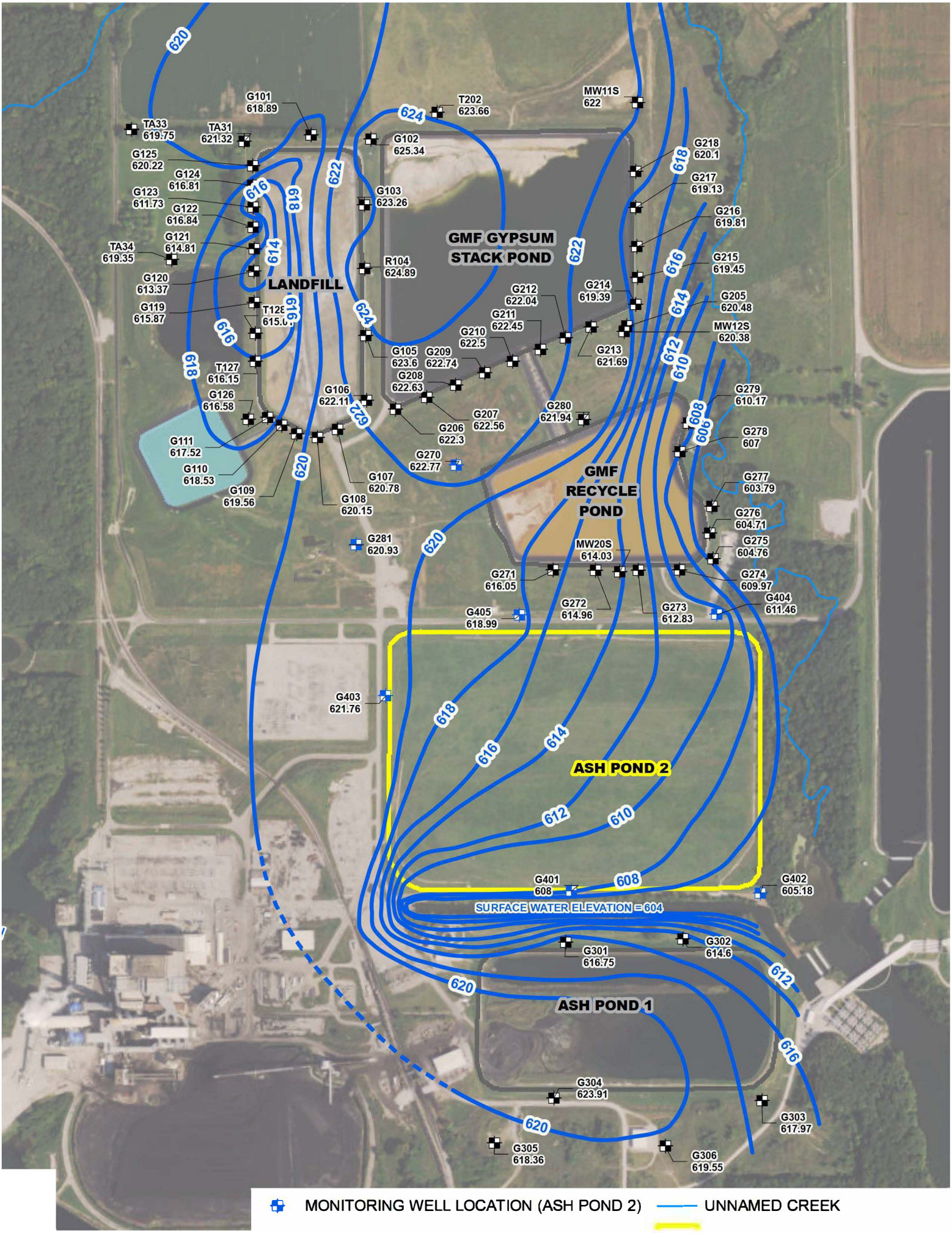
00 800 1200 1600 2000 2400 2800 3200

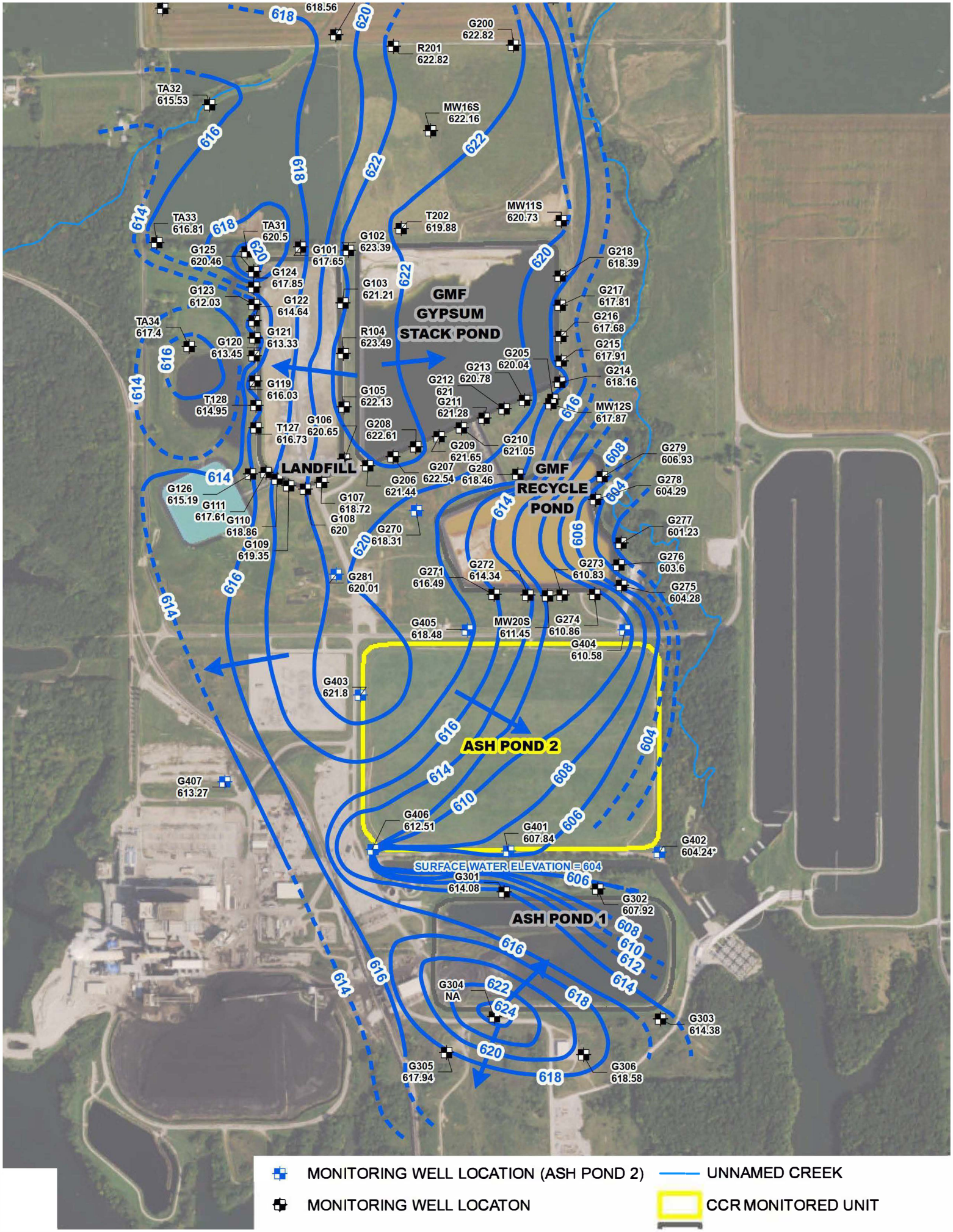
DISTANCE (FEET)

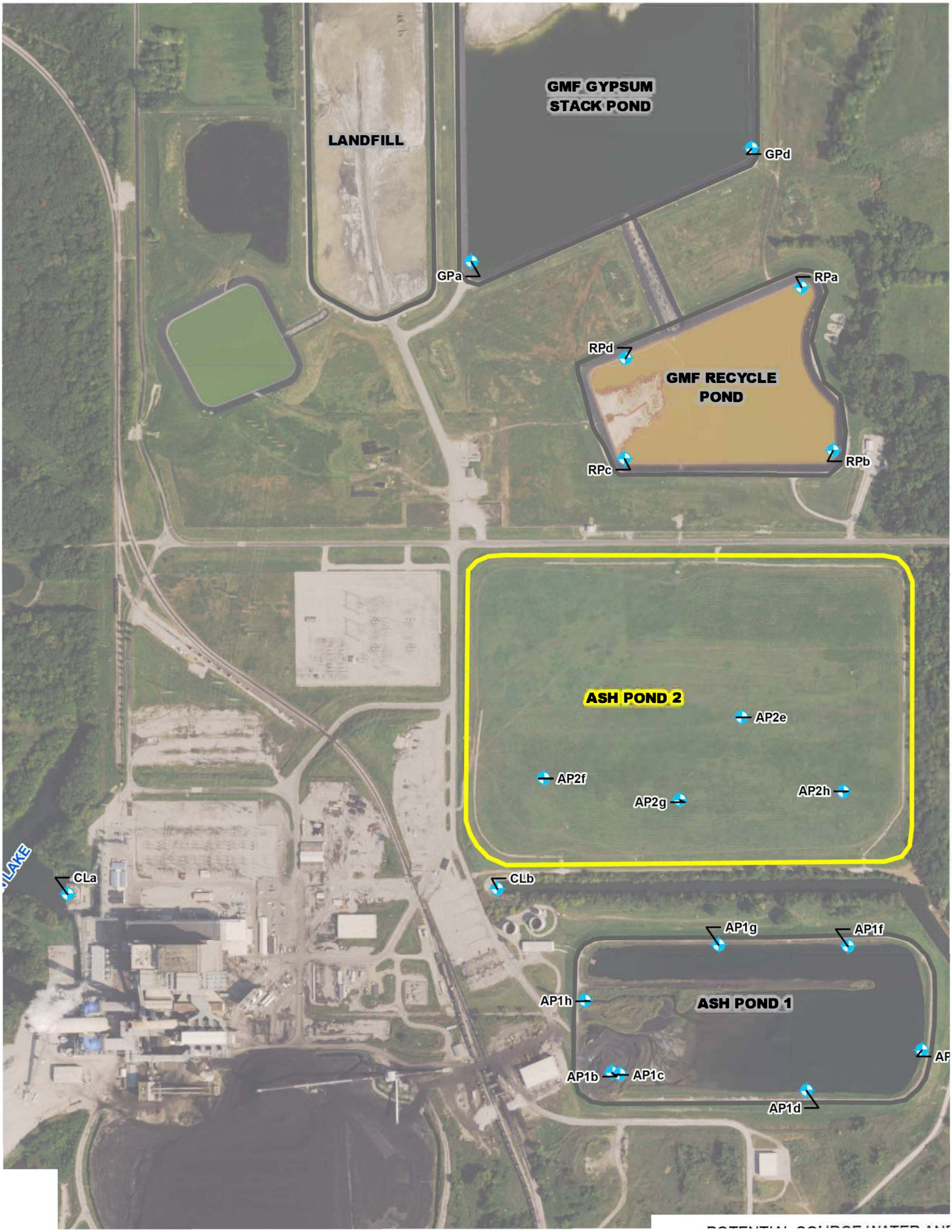
B — B' CROSS-SECTION TRANSEC
CLAY
SOIL
SAND
SILT
ASH
FILL
WELL SCREEN

VERTICAL SCALE IN FEET
10
400
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION =




GMF GYPSUM STACK POND
LANDFILL
GMF RECYCLE POND
ASH POND 2
ASH POND 1
SURFACE WATER ELEVATION = 604
G101 618.89
T202 623.66
MW11S 622
TA33 619.75
TA31 621.32
G102 625.34
G218 620.1
G125 620.22
G124 616.81
G217 619.13
G123 611.73
G103 623.26
G122 616.84
G216 619.81
G121 614.81
TA34 619.35
R104 624.89
G215 619.45
G120 613.37
G214 619.39
G212 622.04
G205 620.48
G119 615.87
G211 622.45
MW12S 620.38
G210 622.5
G213 621.69
G105 623.6
G209 622.74
T127 616.15
G208 622.63
G279 610.17
G126 616.58
G106 622.11
G280 621.94
G207 622.56
G278 607
G206 622.3
G111 617.52
G270 622.77
G277 603.79
G110 618.53
G107 620.78
G109 619.56
G108 620.15
G276 604.71
G281 620.93
MW20S 614.03
G275 604.76
G271 616.05
G274 609.97
G404 611.46
G272 614.96
G273 612.83
G405 618.99
G403 621.76
G401 608
G402 605.18
G301 616.75
G302 614.6
G304 623.91
G303 617.97
G305 618.36
G306 619.55
MONITORING WELL LOCATION (ASH POND 2)
UNNAMED CREEK


618.56
G200
622.82
R201
622.82
TA32
615.53
MW16S
622.16
TA33
616.81
TA31
620.5
G125
620.46
G101
617.65
G102
623.39
T202
619.88
MW11S
620.73
G218
618.39
G124
617.85
G103
621.21
GMF
GYPSUM
STACK POND
G217
617.81
G123
612.03
G122
614.64
G216
617.68
TA34
617.4
G121
613.33
R104
623.49
G215
617.91
G120
613.45
G205
620.04
G213
620.78
G214
618.16
G212
621
G119
616.03
G105
622.13
G211
621.28
MW12S
617.87
T128
614.95
G106
620.65
T127
616.73
G208
622.61
G210
621.05
G209
621.65
G279
606.93
LANDFILL
G207
622.54
G280
618.46
GMF
RECYCLE
POND
G278
604.29
G126
615.19
G206
621.44
G111
617.61
G107
618.72
G110
618.86
G108
620
G270
618.31
G277
601.23
G109
619.35
G281
620.01
G271
616.49
G272
614.34
G273
610.83
G276
603.6
G275
604.28
G405
618.48
MW20S
611.45
G274
610.86
G404
610.58
G403
621.8
ASH POND 2
G407
613.27
G406
612.51
G401
607.84
G402
604.24*
SURFACE WATER ELEVATION = 604
G301
614.08
G302
607.92
ASH POND 1
G304
NA
G303
614.38
G305
617.94
G306
618.58
MONITORING WELL LOCATION (ASH POND 2)
MONITORING WELL LOCATON
UNNAMED CREEK
CCR MONITORED UNIT


GMF GYPSUM STACK POND
LANDFILL
GPd
GPa
RPa
RPd
GMF RECYCLE POND
RPb
RPc
ASH POND 2
AP2e
AP2f
AP2g
AP2h
CLa
CLb
AP1g
AP1f
AP1h
ASH POND 1
AP1b
AP1c
AP1d

TABLES

619.10	622.02	AP-3		MW	609.1	599.1	Hagarstown/Vandalia Till Contact
623.46	626.72	AP-4	Ash Pond 1	MW	613.5	603.5	Hagarstown Beds
622.54	625.55			MW	609.1	604.3	Hagarstown Beds
622.84	625.72			MW	609.8	605.2	Hagarstown Beds
622.08	624.47			MW	609.1	604.3	Hagarstown Beds
623.82	626.36			MW	608.31	603.66	Hagarstown Beds
623.03	625.57			MW	608.67	604.24	Hagarstown Beds
610.56	613.37	AP-2		MW	600.6	590.6	Upper Vandalia Till
623.81	626.47			MW	610.7	606.03	Hagarstown Beds
613.10	615.67			MW	606.68	601.93	Hagarstown Beds
620.90	623.63			MW	611.89	607.14	Hagarstown Beds
621.86	621.86			MW	608.3	603.49	Hagarstown Beds
618.35	621.32			MW	604.57	599.74	Hagarstown Beds
621.09	624.08		Ash Pond 2	PZ (Hyd. conductivity only)	600.43	595.6	Vandalia Till
621.85	625.01			PZ (Hyd. conductivity only)	600.06	595.26	Vandalia Till (Sand Seam)
620.94	623.81	G405D		PZ	589.06	579.42	Smithboro Till
621.91	625.24	G406D		PZ	580.3	570.65	Smithboro Till
639.80	641.14			Ash Pond PZ	634.74	619.74	Ash
639.70	641.34			Ash Pond PZ	629.84	614.84	Ash
640.40	641.78			Ash Pond PZ	631.28	616.28	Ash
644.70	damaged			Ash Pond PZ	629.7	604.7	Ash
637.70	638.8			Ash Pond PZ	627.7	602.7	Ash
	639.44			PZ			Fill
	638.7			PZ			Fill
625.27	627.6			MW	609.59	604.95	Hagarstown Beds
625.70	630.96	MW03S		MW	613.68	608.92	Hagarstown Beds
630.99	633.8			MW	615.11	610.32	Hagarstown Beds
629.03	632.84	G104		MW	614.44	609.71	Hagarstown Beds
629.26	632.08			MW	613.15	608.36	Hagarstown Beds
628.39	631.15			MW	614.02	609.43	Hagarstown Beds
627.79	630.23			MW	613.92	609.29	Hagarstown Beds
627.50	630.22			MW	610.68	606	Hagarstown Beds (Silt)
627.20	629.76			MW	611.81	607.27	Hagarstown Beds
627.02	629.65			MW	611.97	607.43	Hagarstown Beds
627.24	629.9			MW	612.63	608.09	Hagarstown Beds
628.85	631.55			MW	611.56	607.02	Hagarstown Beds
629.30	631.87		Landfill	MW	614.2	609.68	Hagarstown Beds
629.57	632.83			MW	612.78	608.1	Hagarstown Beds
629.86	632.69			MW	613.35	608.81	Hagarstown Beds
630.13	632.96			MW	609.19	604.67	Hagarstown Beds
630.42	633.39			MW	614.44	609.91	Hagarstown (Silt)/Vandalia Till Contact
630.68	633.51			MW	613.65	609.12	Hagarstown Beds

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630.57	633.16			MW	613.04	608.51	Hagarstown Beds	
630.57	632.91			MW	612.83	608.29	Hagarstown Beds	
630.48	632.99		Gypsum Stack	MW	611.09	606.55	Hagarstown Beds	
630.31	632.64			MW	612.97	608.43	Hagarstown (Sandy Clay)/Vandalia Till Contact	
630.59	632.89			MW	613.85	609.3	Hagarstown Beds	
630.34	632.81			MW	613.59	609.05	Hagarstown Beds	
630.39	632.85			MW	612.64	608.25	Hagarstown Beds	
630.48	633.06			MW	611.07	606.68	Hagarstown Beds	
630.28	632.76			MW	610.24	605.86	Hagarstown Beds	
630.67	633.1			MW	610.18	605.79	Hagarstown Beds	
630.64	633.11			MW	610.31	605.87	Hagarstown Beds	
624.10	sealed			MW	613.76	608.98		
622.40	625.79			MW	612.57	608.14	Hagarstown Beds	
622.60	625.8			MW	609.94	605.19	Hagarstown Beds	
623.10	626.14			MW	612.06	607.48	Hagarstown Beds	
624.50	627.54			MW	614.59	610.71	Hagarstown Beds	
624.70	627.9			MW	613.19	608.7	Hagarstown Beds	
624.60	627.46			MW	613.39	608.98	Hagarstown Beds	
621.20	624.22		Hydrogeologic	MW	609.92	605.44	Hagarstown Beds	
622.00	625.08		Characterization	MW	613.11	608.37	Hagarstown Beds	
622.20	625.21		Report (historical)	MW	611.59	607.02	Hagarstown Beds	
622.70	625.89			MW	611.27	606.47	Hagarstown Beds	
624.60	sealed			MW	612.34	607.58	Hagarstown Beds	
623.80	sealed			MW	609.39	604.64	Hagarstown Beds	
626.10	629.37			MW	611.51	606.69	Hagarstown Beds	
627.10	630.47			MW	613.08	603.54	Hagarstown Beds	
625.60	628.66			MW	614.29	609.81	Hagarstown Beds	
	622.84			MW				
622.92	625.92			MW	609.79	605	Hagarstown Beds	
622.89	625.57			MW	612.93	608.58	Hagarstown Beds	
620.72	623.81			MW	611.61	606.74	Hagarstown Beds (Silt)	
620.17	623.02			MW	611.09	605.61	Hagarstown Beds	
621.67	624.04			MW	608.77	604	Hagarstown Beds	
616.14	618.26		Recycle Pond	MW	607.92	603.52	Hagarstown Beds	
629.14	632.			MW	606.73	601.92	Hagarstown Beds	
620.79	623.08			MW	606.5	602.02	Hagarstown Beds	
628.85	631.19			MW	609.92	605.15	Hagarstown Beds	
629.19	632.04			MW	606.79	602.4	Hagarstown Beds	
622.95	625.85			MW	610.16	605.32	Hagarstown Beds	

[O:RJH 9/2016, C: NRK 10/10/2016, O: NRK 11/8/2

:luded on boring logs when the well was installed, and top of PVC elevations based on survey completed in Fall 2015.

Table 2
Summary of Laboratory Hydraulic Conductivity in Confining Units
Hydrogeologic Characterization Report
Coffeen Energy Center - Ash Pond 2

Laboratory Tests			
Well/ Soil Boring ID	Approximate Sample Elevation (ft)	Hydraulic Conductivity (cm/sec)	Interpreted Unit
COF-B001	613.0	1.3E-08	Loess - Upper Confining Unit
COF-B003	606.5	2.2E-07	
COF-B004	610.5	5.0E-07	
COF-B007	615.0	7.0E-08	
Geometric Mean		**1.0E-07**	
G46D	599.2	4.5E-06	Vandalia Till
T408	597.6	1.5E-07	
SB-12	577.7-572.7	6.8E-09	
SB-13	598-593	7.0E-09	
SB-18	603.5-603	8.8E-09	
Geometric Mean		**4.9E-08**	
SB-09	598.5-598	1.9E-06	Mulberry Grove Silt
SB-16	589-588.5	1.6E-06	
Geometric Mean		**1.7E-06**	
G45D	586.4	1.0E-07	Smithboro Till
G46D	578.9	2.1E-08	
SB-07	572-571.5	1.1E-09	
Geometric Mean		**1.3E-08**	
SB-19	569-564	3.4E-09	Deep Confining Unit
SB-16	548-547.5	1.3E-08	
Geometric Mean		**6.6E-09**	

[O:NRK 10/26/2016]

Landfill	KGS	B-R	7.0E-05	2.8E-04	1.4E-04	614.4-609.7	
	KGS	KGS	1.5E-04	5.7E-05	9.2E-05	613.2-608.4	
	B-R	B-R	4.0E-05	7.4E-04	1.7E-04	614.0-609.4	
	KGS	KGS	6.3E-05	8.9E-05	7.5E-05	613.9-609.3	
	KGS	KGS	4.7E-05	2.0E-05	3.1E-05	612.0-607.4	Hagarstown Beds
	KGS	KGS	8.6E-05	8.2E-05	8.4E-05	611.6-607	
	low water elevation; no test conducted					614.2-609.7	
	KGS	KGS	4.8E-05	4.1E-05	4.4E-05	613.7-609.1	
	KGS	KGS	1.2E-03	1.7E-05	1.4E-04	610.5-606	
		Unit Geometric Mean			8.5E-05		
Gypsum Pond	KGS	KGS	4.5E-04	5.5E-04	5.0E-04	614.0-609.6	
	B-R	KGS	3.0E-04	1.6E-04	2.2E-04	613.0-608.6	
	KGS	KGS	6.0E-05	2.1E-05	3.5E-05	613.0-608.5	
	KGS	KGS	2.0E-04	1.6E-04	1.8E-04	612.8-608.3	Hagarstown Beds
	KGS	KGS	5.0E-04	4.8E-04	4.9E-04	611.1-606.6	
	KGS	KGS	1.3E-04	1.8E-04	1.5E-04	613.9-609.3	
	KGS	KGS	5.0E-04	3.5E-04	4.2E-04	611.1-606.7	
	KGS	KGS	4.1E-04	4.1E-04	4.1E-04	610.3-605.9	
		Unit Geometric Mean			2.3E-04		
Recycle Pond	KGS	KGS	5.5E-04	4.8E-04	5.1E-04	609.8-605.0	
	KGS	KGS	1.6E-04	1.1E-03	4.2E-04	612.9-608.6	Hagarstown Beds
	KGS	KGS	1.0E-03	8.3E-04	9.1E-04	611.1-605.6	
	low water					606.7-601.9	Hagarstown Beds, v. thin
	KGS	KGS	1.7E-03	1.5E-03	1.6E-03	606.8-602.4	
	KGS	KGS	1.3E-03	1.3E-03	1.3E-03	610.2-605.3	Hagarstown Beds
	KGS	KGS	2.1E-03	8.9E-04	1.4E-03	608.3-603.7	
		Unit Geometric Mean			9.0E-04		
Ash Pond 1	KGS	KGS	2.7E-04	5.0E-04	3.7E-04	609-604.3	Upper Vandalia Till
	KGS	KGS	4.9E-04	6.3E-04	5.6E-04	604.7-600.1	
	KGS	KGS	5.6E-05	3.1E-05	4.2E-05	609.1-599.1	Hagarstown/Vandalia Till Contact
	KGS	KGS	8.9E-04	1.0E-03	9.4E-04	613.5-603.5	Hagarstown Beds
		Unit Geometric Mean			3.0E-04		
Ash Pond 2	B-R	B-R	1.8E-04	2.8E-04	2.2E-04	608.7-603.7	Hagarstown Beds
	KGS	KGS	4.5E-04	1.9E-04	2.9E-04	600.6-590.6	Upper Vandalia Till
	KGS	KGS	4.3E-05	7.2E-05	5.6E-05	610.7-606.0	Hagarstown Beds, v. thin
	KGS	KGS	4.2E-04	3.8E-04	4.0E-04	606.7-601.9	Hagarstown Beds
	KGS	KGS	9.8E-04	9.7E-04	9.7E-04	611.9-607.1	
		Unit Geometric Mean			2.7E-04		
SW Pond	KGS	KGS	2.5E-04	5.4E-04	3.7E-04	607.5-603.0	Hagarstown Beds
		Unit Geometric Mean			3.7E-04		
2009 Hydrogeo. Invest.	B-R	B-R	6.0E-04	1.1E-03	8.1E-04	613.7-608.6	
	B-R	B-R	1.3E-03	8.0E-04	1.0E-03	612.6-607.6	
	B-R	B-R	8.0E-04	8.0E-04	8.0E-04	610.9-604.9	
	B-R	B-R	1.0E-03	2.0E-04	4.5E-04	611.3-606.1	Hagarstown Beds
	B-R	B-R	1.0E-03	5.0E-04	7.1E-04	612.4-607.2	
	B-R	B-R	1.5E-04	8.1E-05	1.1E-04	609.3-604.2	
	B-R	B-R	6.0E-04	4.5E-04	5.2E-04	611.5-606.3	
	B-R	B-R	5.8E-04	5.5E-04	5.6E-04	613.1-603	
		Unit Geometric Mean			5.4E-04		

Lower Confining Unit (Vandalia and Smithboro Till)							
sh Pond 2	KGS	KGS	2.15E-06	7.50E-08	9.02E-07	600.4-595.2	Vandalia Till
	KGS	KGS	3.6E-05	3.20E-05	3.41E-05	600.1-594.9	Vandalia Till (sand seam)
	KGS	KGS			4.90E-07	589.1-579	Smithboro Till

R000919

Table 4
Summary of AECOM Piezometer Construction
Hydrogeologic Characterization Report
Coffeen Energy Center - Ash Pond 2

Well ID	Unit	Coordinates		Ground Surface Elevation (ft)	Location	Well Type	Top of PVC Elevation (ft)	Total Depth (ft)	Top of Screened Inteval (ft bgs)	Bottom of Screeed Interval (ft bgs)	Screened Interval
		Northing	Easting								
COF-P000	Ash Pond 1	871590	2516694	634.9	Crest	PZ	639.3	27.9	619.9	609.9	Fill and Loess/Clay
COF-P001		871488	2516735	615.6	Toe	VWP	VWP	12.0	603.6	603.6	Clay/ Silt
COF-P002		871459	2516042	635.4	Crest	PZ	639.2	39.3	609.9	599.9	Hagarstown Beds
COF-P003		871786	2515150	635.7	Crest	PZ	640.3	48.0	607.2	592.2	Hagarstown Beds
COF-P005		872198	2516077	635.0	Crest	PZ	639.6	23.2	620.0	615.0	Fill/ Clay Contact
COF-P006		872106	2516696	635.1	Crest	PZ	639.7	47.4	605.1	590.1	Hagarstown Beds
COF-P007		872235	2516081	617.5	Toe	VWP	VWP	15.0	602.5	602.5	Hagerstown Beds
COF-P008		871814	2515103	625.1	Toe	VWP	VWP	19.0	606.1	606.1	Hagerstow Beds
COF-P009	Ash Pond 2	873894	2515111	638.0	Crest	PZ	642.6	33.0	618.0	608.0	Clay/ Hagarstown Beds
COF-P010		873505	2516621	635.2	Crest	PZ	639.1	41.5	611.7	596.7	Clay/ Hagarstown Beds
COF-P012		872691	2515086	642.2	Interior (ash)	PZ	646.4	43.3	609.7	599.7	Hagarstown Beds
COF-P014		872538	2515412	635.0	Crest	PZ	639.5	45.4	606.5	596.5	Hagarstown Beds

[O:AECOM, 2016]

Notes:

1. For standpipe piezometers, stickup and WL measurement referenced to top edge of yellow protector cover with hinged cap open.
2. Total Depth = Approx. bottom of screen for standpipe piezometers, or installed depth for VWPs.
3. VWP = vibrating wire peizometer installed at locations not accessible with drill rig.
4. Piezometers COF-P004, -P011, and -P013 were planned but not installed due to access issues.

NATURAL RESOURCE TECHNOLOGY

.95	620.45	619.23	618.42	617.78	616.76	615.93	615.64	612.75	613.63	610.79	610.84	615.27	617.83	615.22	NM
.73	622.19	620.85	620.31	619.71	618.60	617.48	615.86	613.43	614.63	615.94	612.41	617.85	620.45	616.45	NM
.72	621.43	620.15	621.22	620.41	619.55	618.03	616.55	613.47	614.09	615.26	612.76	618.25	620.71	616.34	615.43
.65	620.50	619.10	618.92	618.12	617.70	616.79	615.31	612.94	613.31	614.39	611.89	617.27	619.66	614.13	614.86
M	619.32	NM	NM	NM	616.55	NM	NM	612.37	NM	NM	NM	NM	614.60	NM	NM
M	621.55	NM	NM	NM	617.88	NM	NM	613.06	NM	NM	NM	NM	619.95	NM	614.88
.73	621.68	620.70	619.16	618.58	617.25	616.62	616.00	612.89	613.65	615.17	611.58	616.22	619.30	615.80	NM
M	622.11	NM	NM	NM	618.53	NM	NM	613.37	NM	NM	NM	NM	620.22	NM	615.58
.62	622.00	620.74	620.15	619.58	618.57	617.44	615.85	613.17	614.86	616.82	611.76	616.78	620.21	616.54	NM
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	620.62	NM	NM	NM	617.64	NM	NM	612.87	NM	NM	NM	NM	621.53	NM	NM

00	G205	G206	G207	G208	G209	G210	G211	G212	G213	G214	G215	G216	G217	G218	G270
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
.35	NM	621.87	622.31	622.76	622.37	621.88	621.79	621.77	621.55	618.83	618.43	NM	618.10	618.82	618.88
.05	NM	620.69	620.72	620.62	620.56	619.83	619.00	620.76	620.21	617.56	616.56	NM	616.71	616.93	616.07
.66	NM	619.27	NM	NM	620.06	NM	NM	618.54	NM	NM	616.38	NM	NM	617.11	621.06
.29	NM	621.92	622.18	622.06	622.26	621.68	622.03	621.99	621.21	617.95	618.31	618.61	618.20	619.05	622.94
.93	620.32	622.36	NM	NM	622.44	NM	NM	621.85	NM	NM	618.08	NM	NM	619.15	622.67
.52	620.48	622.30	622.55	622.63	622.74	622.41	622.39	622.04	621.59	619.25	619.45	619.62	619.03	620.10	622.77
.13	NM	NM	NM	NM	622.69	NM	NM	622.08	NM	NM	619.27	NM	NM	620.01	623.02
M	NM	620.51	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
.82	NM	621.71	NM	NM	621.52	NM	NM	620.89	NM	NM	617.10	NM	NM	618.01	617.73

75	G276	G277	G278	G279	G280	G281	G301	G302	G303	G304	G305	G306	G307	G401	G402
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
.26	604.00	NM	NM	607.48	618.68	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	NM	NM	NM	608.14	614.54	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	603.25	NM	NM	607.80	618.45	619.56	616.51	610.74	616.70	623.78	NM	NM	NM	607.82	604.02
.66	603.71	NM	606.40	609.16	621.37	621.21	NM	NM	NM	NM	NM	NM	NM	608.14	604.90
M	603.77	NM	NM	609.01	621.15	NM	617.21	613.14	617.87	624.07	618.35	619.55	NM	NM	NM
.12	604.71	603.84	607.02	610.17	621.94	620.93	616.75	614.60	617.97	623.91	NM	NM	NM	608.00	605.18
M	604.72	NM	NM	610.21	621.95	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
M	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	616.28	615.11	NM	NM	NM
M	604.92	NM	NM	606.94	618.21	620.30	614.65	608.16	614.92	626.72	618.12	619.07	624.42	608.47	604.33

01	T127	T128
M	615.65	614.73
M	616.04	614.89
.27	616.04	615.40
.94	615.66	614.67
.44	615.91	NM
.40	616.04	614.91
.14	615.96	NM
.81	616.15	NM
.39	616.12	614.99

R000920

R000921

Table 6
Groundwater Elevations in Piezometers: 2015 - 2016
Hydrogeologic Characterization Report
Coffeen Energy Center - Ash Pond 2

Water Elevation (feet)												
PZ ID	COF-P000	COF-P001	COF-P002	COF-P003	COF-P005	COF-P006	COF-P007	COF-P008	COF-P009	COF-P010	COF-P012	COF-P014
Date	Ash Pond 1								Ash Pond 2			
8/29/2015	616.97	614.30	624.90	620.38	620.62	612.94	611.40	622.55	621.50	605.62	625.43	613.57
10/5/2015	618.17	- -	624.69	619.93	621.42	612.90	- -	- -	621.40	607.22	624.91	613.29
10/30/2015	617.95	613.29	624.68	619.82	622.15	612.72	610.32	622.11	620.73	607.99	624.53	613.07
11/23/2015	619.15	614.66	625.80	621.06	622.60	612.81	612.14	623.32	623.02	608.98	624.95	613.31
12/23/2015	619.57	614.77	626.19	622.30	622.50	613.22	614.21	623.80	624.31	609.18	625.82	614.08
1/18/2016	619.64	615.03	625.89	620.74	621.89	612.56	614.60	623.27	622.76	610.59	626.04	613.86

Notes:

[O:AECOM, 2016]

- - No data available

NATURAL RESOURCE TECHNOLOGY

Table 7
Ash Pond 2 Leachate Elevations in 2009
Hydrogeologic Characterization Report
Coffeen Energy Center - Ash Pond 2

Well ID	Leachate Elevations (ft) Date					
	4/1/2009[1]	5/29/2009	6/6/2009	8/6/2009	9/21/2009	11/9/2009
OW-1	619.83	636.87	636.59	635.48	635.10	636.15
OW-2	615.14	636.62	636.69	635.24	634.92	635.98
OW-3	616.68	636.57	636.43	635.26	634.90	635.90
OW-4	- -	638.47	- -	- -	- -	- -
OW-5	609.05	636.48	635.81	635.18	634.85	635.77

Notes: [O:Hanson, 2016]
[1] Measurement collected after pumping of Ash Pond 2.
- - No leachate elevation data

NATURAL RESOURCE TECHNOLOGY

Table 8
Summary of Vertical Hydraulic Gradients
Hydrogeologic Characterization Report
Coffeen Energy Center - Ash Pond 2

Well ID	Date	Screen Elev. (ft)[1]	Formation	Groundwater Elevation (ft MSL)	Vertical Gradient [2]
G405	11/12/2016	609.515	Hagarstown Beds	618.48	-0.009
T408	11/12/2016	598.015	Vandalia Till	618.58	
T408	11/12/2016	598.015	Vandalia Till	618.58	2.44
G45D	11/12/2016	584.24	Smithboro Till	584.91	
G406	11/12/2016	605.895	Hagarstown Beds	612.51	-0.42
T409	11/12/2016	597.66	Vandalia Till	615.98	
T409	11/12/2016	597.66	Vandalia Till	615.98	1.46
G46D	11/12/2016	575.475	Smithboro Till	583.59	

Notes: [O:NRK, 12/2016, C:JJW 12/2016]

1. Center of screen
2. Based on dates when both wells were sampled, **negative** vaues indicate upward gradients while **positive** indicate downward gradients

'dissolved - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
(G402)	8	7.245	7.18	8.10	6.30	0.626	0.0%	0.27
51	16	0.016	0.012	0.052	0.003	0.013	50.0%	0
52	16	0.047	0.041	0.11	0.015	0.025	0.0%	0.01
53	16	0.028	0.027	0.058	0.012	0.012	0.0%	-0.01
54	16	0.036	0.037	0.045	0.021	0.008	0.0%	0
70	34	0.029	0.012	0.125	0.005	0.034	47.1%	0
71	29	0.281	0.260	0.610	0.130	0.128	0.0%	**0.05**
72	29	0.019	0.005	0.27	0.005	0.050	86.2%	0
73	29	0.224	0.18	0.62	0.019	0.176	6.9%	**0.06**
74	29	0.295	0.18	0.97	0.005	0.302	27.6%	**0.13**
75	25	3.176	3.50	4.60	0.91	1.04	0.0%	0.1

'total - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
51	3	0.0183	0.019	0.026	0.010	0.008	0%	-0.03
52	3	0.038	0.036	0.047	0.032	0.008	0%	-0.03
53	3	0.044	0.036	0.064	0.031	0.018	0%	-0.07
54	3	0.030	0.031	0.038	0.021	0.009	0%	0.01
70	38	0.021	0.005	0.125	0.005	0.026	68%	0.00
71	33	0.309	0.240	0.980	0.110	0.190	0%	**0.03**
72	29	0.014	0.005	0.060	0.005	0.017	69%	0.00
73	33	0.208	0.200	0.480	0.016	0.137	9%	**0.05**
74	29	0.264	0.160	0.740	0.005	0.253	24%	**0.11**
75	25	3.336	3.600	4.600	1.200	0.965	0%	0.04
01	4	3.575	3.450	4.100	3.300	0.359	0%	0.79
02	4	6.500	6.450	7.400	5.700	0.707	0%	1.83
03	4	0.036	0.033	0.064	0.014	0.021	0%	-0.03
04	4	2.075	1.850	3.200	1.400	0.806	0%	0.40
05	4	16.25	16.500	17.000	15.000	0.957	0%	-1.96

IESE (dissolved - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
(G402)	8	0.432	0.414	0.730	0.130	0.166	0%	0.01
51	16	0.131	0.092	0.560	0.011	0.131	0%	0.00
52	16	0.294	0.180	0.927	0.034	0.277	0%	0.07
53	16	0.235	0.175	1.020	0.024	0.249	0%	-0.12
54	16	0.062	0.035	0.462	0.003	0.112	0%	0.00
70	34	0.094	0.045	0.470	0.003	0.108	0%	**-0.02**
71	29	0.015	0.001	0.220	0.001	0.045	62%	0.00
72	29	0.011	0.001	0.230	0.001	0.043	76%	0.00
73	29	0.042	0.028	0.330	0.001	0.059	0%	**-0.01**
74	29	0.003	0.001	0.046	0.001	0.009	69%	0.00
75	25	0.051	0.019	0.340	0.001	0.086	8%	0.00

pe Trend is in milligrams per Liter per year; negative value (-) is downward trend; positive value is upward trend, **BOLD** icates statistical significance (Mann Kendall 95%).Mann Kendall tests not performed on wells with less than 8 data ponts. results below the method detection limit (MDL) for that parameter have been replaced by the detection limit.

Wells with groundwater exceeding Class 1 groundwater standard for the given parameter in 2015 or 2016.

IESE (total - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
51	3	0.225	0.23	0.36	0.086	0.137	0%	0.56
52	3	0.32	0.31	0.37	0.27	0.050	0%	0.12
53	3	0.67	0.51	1.30	0.21	0.563	0%	-2.21
54	3	0.16	0.16	0.16	0.15	0.006	0%	0.02
70	34	0.146	0.083	0.62	0.021	0.134	0%	**-0.03**
71	29	0.058	0.021	0.27	0.001	0.075	0%	-0.01
72	29	0.029	0.011	0.15	0.002	0.040	0%	0.00
73	29	0.06	0.043	0.19	0.019	0.043	0%	**-0.01**
74	29	0.05	0.02	0.37	0.003	0.087	0%	0.00
75	25	0.17	0.09	0.78	0.01	0.203	0%	0.01

E (dissolved - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
(G402)	8	805.375	840	1100	500	173.11	13%	5.17
51	16	112	110	140	100	11.21	0%	**4.8**
52	16	161	135	300	107.0	61.15	0%	**26.3**
53	16	1824	1800	2100	1500	206.55	0%	**184.5**
54	16	110	105	175	82	23.60	0%	**-12.0**
70	34	54	43	140	2	50.37	0%	**15.7**
71	29	354	360	520	220	87.45	0%	**35.8**
72	29	264	270	380	140	63.00	0%	**28.1**
73	29	524	520	700	46	131.06	0%	9.0
74	29	340	350	400	240	41.75	0%	0.0
75	25	678	720	920	280	183.63	0	30.3

E (total - mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
51	3	104.333	98	120	95	13.65	0%	6.09
52	3	120	120	130	110	10	0%	20.3
53	3	1633	1500	1900	1500.0	231	0%	0.0
54	3	99	93	110	93	10	0%	34.5
70	38	59	65	140	2	50	0%	**15.6**
71	33	357	350	540	230	87	0%	**28.3**
72	29	253	250	380	120	69	0%	**30.5**
73	33	530	520	750	340	106	0%	6.5
74	29	337	330	460	230	55	0%	6.7
75	25	684	720	990	310	213	0%	0.8
81	4	330	325	370	300	32	0%	68.7
01	4	2275	2250	2500	2100	171	0%	-390.6
02	4	1013	980	1200	890	133	0%	-392.5
03	4	18	14	35	10	12	0%	-30.9
04	4	165	165	190	140.0	23.8	0%	-12.3
05	4	1700	1700	1800	1600.0	81.7	0%	-71.6

pe Trend is in milligrams per Liter per year; negative value (-) is downward trend; positive value is upward trend, **BOLD** icates statistical significance (Mann Kendall 95%).Mann Kendall tests not performed on wells with less than 8 data ponts. results below the method detection limit (MDL) for that parameter have been replaced by the detection limit.

Wells with groundwater exceeding Class 1 groundwater standard for the given parameter in 2015 or 2016.

ISSOLVED SOLIDS (mg/L)

oring umber	Number of Data Points	Mean	Median	Maximum	Minimum	Standard Deviation	Percent Non-Detects	Sen Slope Trend
(G402)	8	1651.25	1600	1810	1600	78.456	0%	0
51	17	551	560	660	500	44	0%	0.0
52	17	677	620	1,100	494	156	0%	**73**
53	17	3,362	3,300	3,900	2,800	341	0%	**42.5**
54	17	476	460	624	410	52	0%	17
70	37	454	460	550	340	53	0%	11
71	31	862	860	1,000	710	96	0%	**29**
72	27	703	680	840	570	69	0%	**25.5**
73	31	1,085	1,100	1,300	840	140	0%	0
74	27	863	870	980	770	64	0%	**-16.1**
75	24	1,388	1,500	2,000	840	270	0%	0.0
81	4	770	760	820	740	38	0%	-28.7
01	4	2,925	2,950	3,000	2,800	96	0%	-185.3
02	4	1,600	1,600	1,700	1,500	115	0%	-346
03	4	325	320	340	320	10	0%	0.0
04	4	555	570	620	460	68	0%	-14
05	4	2,325	2,300	2,500	2,200	150	0%	-347

[O: NRK 12/2016, C: SJC 12/2016]

pe Trend is in milligrams per Liter per year; negative value (-) is downward trend; positive value is upward trend, **BOLD** icates statistical significance (Mann Kendall 95%).Mann Kendall tests not performed on wells with less than 8 data ponts. results below the method detection limit (MDL) for that parameter have been replaced by the detection limit.

Wells with groundwater exceeding Class 1 groundwater standard for the given parameter in 2015 or 2016.

R000927

alinity, bonate ng/L	Antimony, Total ug/L	Arsenic, Total ug/L	Barium, Total ug/L	Beryllium, Total ug/L	Boron, Total ug/L	Cadmium, Total ug/L	Calcium, Total mg/l	Chloride, Total mg/L	Chromium, Total ug/L	Cobalt, Total ug/L	Fluoride, Total mg/L	Lithium, Total ug/L	Magnesium, Total mg/L	Mercury, Total ug/L	Molybdenum , Total ug/L	pH	Potassium, Total mg/L	Selenium, Total ug/L	Sodium Total mg
< 2.0	3.1	7.2	130	< 1.0	3800	< 1.0	380	3.2	< 4.0	< 2.0	< 0.250	39	67	< 0.20	47	6.99	7.3	3.0	33
< 2.0	3.3	17	100	< 1.0	3100	< 1.0	320	13	< 4.0	< 2.0	0.977	47	52	< 0.20	100	7.01	18	6.9	53
< 2.0	< 3.0	18	130	< 1.0	2900	< 1.0	390	13	< 4.0	< 2.0	0.614	51	49	< 0.20	81	7.05	18	3.1	59
< 20	< 3.0	2.0	200	< 1.0	2000	< 1.0	210	18	< 4.0	< 2.0	1.08	55	35	< 0.20	31	7.21	26	1.5	83
< 2.0	< 3.0	1.4	160	< 1.0	2100	< 1.0	200	18	< 4.0	< 2.0	1.00	55	34	< 0.20	30	7.12	26	1.2	80
< 20	< 3.0	1.5	150	< 1.0	2100	< 1.0	200	17	< 4.0	< 2.0	1.00	57	35	< 0.20	31	7.20	26	1.2	82
< 2.0	< 3.0	1.3	140	< 1.0	2100	< 1.0	210	17	< 4.0	< 2.0	1.00	56	32	< 0.20	29	7.21	26	1.4	100
< 20	< 3.0	1.5	180	< 1.0	2200	< 1.0	230	17	< 4.0	< 2.0	0.980	55	30	< 0.20	31	7.41	27	1.2	110
< 20	< 3.0	23	26	< 1.0	5300	< 1.0	210	< 5.0	< 4.0	< 2.0	0.438	190	40	< 0.20	90	6.49	27	< 1.0	25
< 20	< 3.0	1.2	22	< 2.0	2000	< 1.0	170	< 5.0	< 4.0	< 2.0	0.398	130	33	< 0.20	3.2	6.42	21	< 1.0	14
< 2.0	< 3.0	5.5	20	< 2.0	4300	4.6	410	< 5.0	< 4.0	< 2.0	0.506	180	51	< 0.20	41	6.46	29	< 1.0	27
< 2.0	< 3.0	75	23	< 1.0	14000	< 1.0	310	1.7	< 4.0	< 2.0	0.406	120	29	< 0.20	570	7.17	40	< 1.0	39
< 2.0	< 3.0	1.8	54	< 1.0	270	< 1.0	23	23	< 4.0	< 2.0	0.443	< 10	12	< 0.20	5.0	7.22	7.4	< 1.0	19
< 2.0	< 3.0	1.8	52	< 1.0	280	< 1.0	23	22	< 4.0	< 2.0	0.425	< 10	11	< 0.20	4.9	7.52	7.8	< 1.0	19
< 2.0	< 3.0	1.8	56	< 1.0	280	< 1.0	23	22	< 4.0	< 2.0	0.426	< 10	12	< 0.20	4.7	7.62	7.4	< 1.0	19
< 2.0	< 3.0	1.8	54	< 1.0	270	< 1.0	23	23	< 4.0	< 2.0	0.421	< 10	12	< 0.20	4.8	7.30	7.5	< 1.0	20
< 2.0	< 3.0	4.7	120	2.6	59000	40	450	1900	< 4.0	52	42.7	300	1500	< 0.80	130	7.16	210	890	620
< 2.0	8.6	92	1100	< 20	97000	67	1400	2600	150	110	69.4	480	2500	27	140	6.65	360	1500	1000
< 2.0	< 6.0	4.4	110	2.6	72000	41	570	1800	< 4.0	54	49.2	300	1500	< 0.80	120	6.73	260	890	650
< 2.0	< 3.0	4.2	110	< 20	66000	38	560	1900	< 4.0	52	51.3	300	1500	< 0.80	120	6.73	230	800	660
< 2.0	< 3.0	3.3	89	2.3	60000	37	380	1600	< 4.0	44	47.0	310	1200	< 0.20	63	6.70	190	840	450
< 2.0	< 3.0	2.8	90	2.1	56000	33	380	1800	< 4.0	45	44.4	310	1200	< 0.40	64	6.49	210	780	470
< 2.0	< 3.0	3.1	88	2.2	59000	37	380	2000	< 4.0	43	45.0	310	1200	< 0.20	64	6.32	200	830	440
< 2.0	< 3.0	3.4	89	2.4	59000	36	400	1600	< 4.0	45	51.2	310	1300	< 0.20	66	6.32	200	860	460

APPENDIX A

BORING LOGS AND WELL CONSTRUCTION DETAILS

APPENDIX A1

ASH POND 2

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/14/2015
Finish: 9/14/2015
WEATHER: Sunny, hi 60's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: R. Hasenyager

BOREHOLE ID: G401
Well ID: G401
Surface Elev: 623.03 ft. MSL
Completion: 19.30 ft. BGS
Station: 2,515,614.84N
872,510.57E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss	2-2 3-7 N=5	17			0	Dark grayish brown (10YR4/2), moist, soft, CLAY with little silt and trace very fine- to fine-grained sand - FILL.		622	
							2	Yellowish brown (10YR5/6) moist, medium, CLAY with some silt and trace very fine- to coarse-grained sand - FILL.			
2A	21/24 88%	ss	8-11 8-9 N=19	17		1.80		Dark gray (10YR4/1), moist, stiff, SILT with little clay and trace very fine-grained sand.		620	
2B				25			4	Yellowish brown (10YR5/6), moist, stiff, CLAY with some silt and trace very fine- to fine-grained sand.			
3A	23/24 96%	ss	3-4 7-8 N=11	23		2.50		Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with some silt and trace very fine- to fine-grained sand.		618	
4A	24/24 100%	ss	8-9 12-14 N=21	21		3.30	6			616	
4B				19		2.80	8	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, stiff, SILT and very fine-grained SAND with trace clay.			
5A	24/24 100%	ss	2-3 4-5 N=7	21		1.30				614	
6A	24/24 100%	ss	2-4 5-6 N=9	17		2.50	10	Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with some silt and trace very fine- to fine-grained sand.		612	
7A	24/24 100%	ss	9-7 8-9 N=15	21		1.40	12			610	
8A	24/24 100%	ss	2-3 2-4 N=5	17		1.30	14	Gray (10YR6/1), moist soft, CLAY with very fine- to fine-grained sand and little silt.		608	
8B				19			16	Yellowish brown (10YR5/6), wet, loose, very fine- to fine-grained SAND with trace silt.			
9A	20/24 83%	ss	5-4 5-10 N=9	21				Yellowish brown (10YR5/6), wet medium, SILT with some very fine-grained sand and little clay.		606	
9B				16			18	Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND with trace silt.			
10A	12/16 75%	ss	23-41 50/4"	6		4.50		Gray (10YR5/1), moist, very hard, SILT with few clay and little very fine- to very coarse sand.		604	

End of boring = 19.3 feet

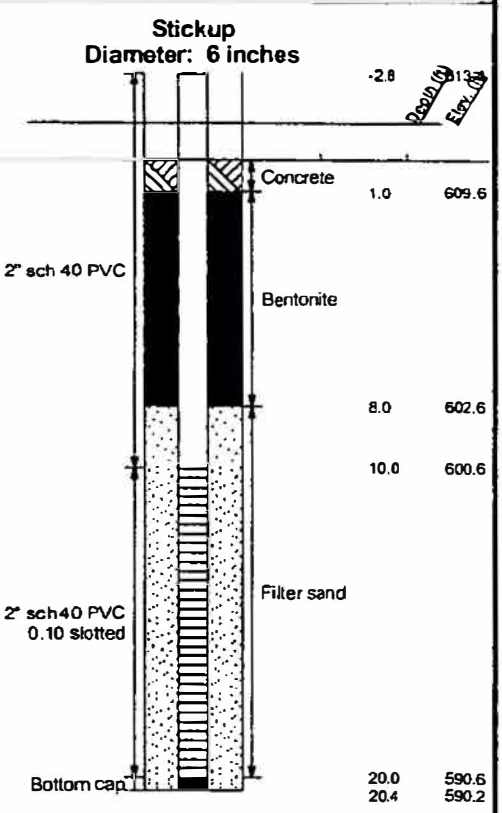
NOTE(S): G401 installed in borehole.

R000931

Surface Elevation: 610.56
Datum msl
Completion Date: 8/27/10
Northing: 872502.26
Easting: 2516632.59

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff, brown, silty CLAY - CL			
			6-3-3	SS1
			1-2-4	SS2
5	Medium stiff, gray, silty CLAY, trace sand - CL			
			1-2-5	SS3
	Hard to stiff, brown to gray, silty CLAY, trace sand seams - CL (TILL)			
10			9-22-28	SS4
			1-6-12	SS5
15				
20	Boring terminated at 20 feet.		3-4-9	SS6
25				
30				
35				

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01- COFFEEN.GPJ GTINC.0638301.GPJ 12/13/10

GROUNDWATER DATA

ENCOUNTERED AT 7 FEET ▽

DRILLING DATA

__ AUGER 4 1/4" HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER SWG LOGGER
CME 55TRK DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KSA | Checked by: DJK | App'vd. by: KRB
Date: 9/10/10 | Date: 1-4-11 | Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren-Coffeen Ash Pond Evaluation

LOG OF BORING: APW-2
G402

Project No. J017150.01

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/11/2015
Finish: 9/11/2015
WEATHER: Raining, hi 60's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G403
Well ID: G403
Surface Elev: 623.81 ft. MSL
Completion: 18.15 ft. BGS
Station: 2,514,616.63N
873,561.34E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	SS	2-2 2-2 N=4	25		0.80	0	Very dark brown (10YR2/2) grading to dark grayish brown (10YR4/2), moist, medium, SILT with some clay, trace roots and grass.		622	
2A	22/24 92%	SS	2-2 3-4 N=5	29			2	Very dark brown (10YR2/2) grading to dark grayish brown (10YR4/2), moist , stiff, SILT with some clay, trace wood.			
2B				26		1.50		Yellowish brown (10YR5/4) with 10% very dark brown (10YR2/2) mottles, moist, stiff, CLAY with little silt, trace very fine-grained sand seams (<1/16" thick).		620	
3A	8/24 33%	SS	2-3 4-4 N=7	25		1.50	4	Yellowish brown (10YR5/4), moist, stiff, CLAY with little silt and trace very fine-grained sand.			
4A	21/24 88%	SS	8-7 8-7 N=15	20		1.30	6	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/6) and 5% very dark grayish brown (10YR3/2) mottles, moist, stiff, CLAY with little silt and trace very fine-grained sand.		618	
5A	20/24 83%	SS	2-2 3-3 N=5	22		0.70	8	Grayish brown (10YR5/2) with 5% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with little silt and trace very fine-grained sand.		616	
6A	24/24 100%	SS	2-2 3-4 N=5	23		1.40	10	Grayish brown (10YR5/2) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, CLAY with little silt, few very fine- to medium-grained sand, and trace gravel.		614	
7A	21/24 88%	SS	5-5 6-5 N=11	20		0.90	12	Grayish brown (10YR5/3) with 45% yellowish brown (10YR5/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with some clay, few very fine- to coarse-grained sand, and trace gravel.		612	
8A	24/24 100%	SS	3-2 3-6 N=5	17			14	Grayish brown (10YR5/3) with 40% yellowish brown (10YR5/6) mottles, moist, medium, SILT with little clay, few very fine- to coarse-grained sand, and trace gravel.		610	
								Yellowish brown (10YR5/6) with 30% grayish brown (10YR5/2) mottles, moist, medium, SILT with little clay, few very fine- to coarse-grained sand, and trace gravel.			
							16	Yellowish brown (10YR5/6), wet, loose, SAND with some clay and few silt.		608	
9A	19/24 79%	SS	8-12 21-25 N=33	8		4.50		Yellowish brown (10YR5/6) with 30% grayish brown (10YR5/2) mottles, moist, stiff, SILT with few clay, very fine- to coarse-grained sand, and gravel.			
	0/2 0%	BD					18	Yellowish brown (10YR5/6), moist, very stiff, SILT with some clay and few sand and gravel.		606	
								Very dark grayish brown (10YR3/2), dry, hard, SILT with little clay and few very fine- to coarse-grained sand and gravel.			

End of boring = 18.15 feet

NOTE(S): G403 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/1/2007
Finish: 5/1/2007
WEATHER: Partly sunny, warm

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" Hollow stem auger with split spoon sampler
FIELD STAFF: **Driller:** A. Rachford
Helper: M. Brown
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB22
Well ID: G404
Surface Elev: 613.10 ft. MSL
Completion: 12.00 ft. BGS
Station: 873,999.77N
2,516,397.85E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 2.07 - 05/10/2007
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	ss		26		0.85 B	0	Black (10YR2/1), moist, firm, clayey SILT (TOPSOIL)		612	
1B				26			2				
2A	19/24 79%	ss		16		2.47 B	4	Gray (10YR5/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with sand and trace gravel		610	
3A	18/24 75%	ss		19		2.18 B	6	Gray (10YR6/1) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel		608	
3B				18		2.33 B		Yellowish brown (10YR5/8), moist, soft, sandy CLAY with slight trace gravel			
4A	24/24 100%	ss		23		0.58 B	8	Yellowish brown (10YR5/8), very moist to wet, very soft, clayey, very fine- to medium-grained SAND with trace gravel		606	
4B				18				Yellowish brown (10YR5/4) with 30% yellowish brown (10YR5/8) mottles, moist, hard, clayey SILT with sand and trace gravel		604	
5A	23/24 96%	ss		10			10	Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND with coarse-grained sand and slight trace gravel		602	
5B				19				Dark yellowish brown (10YR4/6) with 40% yellowish brown (10YR5/8) mottles, moist, very hard, very silty CLAY with sand and gravel			
6A	19/24 79%	ss		19			12	**End of Boring = 12.0 ft. BGS**			
6B				11							

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/1/2007
Finish: 5/1/2007
WEATHER: Partly sunny, warm

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" Hollow stem auger with split spoon sampler
FIELD STAFF: **Driller:** A. Rachford
Helper: M. Brown
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB21
Well ID: G405
Surface Elev: 620.90 ft. MSL
Completion: 14.21 ft. BGS
Station: 873,996.79N
2,515,335.70E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 1.28 - 05/10/2007
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Black (10YR2/1), moist, soft, clayey SILT (TOPSOIL)		620	
1A	19/24 79%	ss		43		0.78 B	2				
1B				26		1.94 B		Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY		618	
2A	12/12 100%	ss		27		2.52 BSh	4				
3A				24		3.92 BSh				616	
	24/24 100%	ss						Gray (10YR6/1), moist, firm, silty CLAY slight trace sand			
3B				24		2.33 BSh	6	Gray (10YR5/1), very moist, soft, clayey, very fine- to fine-grained SAND			
4A	24/24 100%	ss		20		2.33 BSh		Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel		614	
							8				
5A	24/24 100%	ss		24		1.55 BSh		Yellowish brown (10YR5/8) with 40% gray (10YR6/1) mottles, moist, firm, silty CLAY with sand and trace gravel		612	
							10				
	24/24 100%	ss						Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND		610	
6A				19				Dark brown (10YR3/3), very moist, soft, clayey, fine- to very coarse-grained SAND with slight trace gravel			
6B				18			12	Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
7A				9		7.42 BSh		Dark yellowish brown (10YR4/4), moist, soft, sandy SILT with trace gravel		608	
	24/24 100%	ss						Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
							14	Gray (10YR5/1), moist, very hard, very silty CLAY with sand and gravel			

End of Boring = 14.2 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/17/2016
WEATHER: Cloudy, rain, (hi-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G405D
Well ID: G45D
Surface Elev: 620.94 ft. MSL
Completion: 42.00 ft. BGS
Station: 873,998.03N
2,515,322.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Black (10YR2/1), moist, soft, clayey SILT (TOPSOIL)		620	
	0/60 0%	BD					2				
							4	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY		618	
							6	Gray (10YR6/1), moist, firm, silty CLAY slight trace sand		616	
								Gray (10YR5/1), very moist, soft, clayey, very fine- to fine-grained SAND			
	0/60 0%	BD					8	Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel		614	
							10	Yellowish brown (10YR5/8) with 40% gray (10YR6/1) mottles, moist, firm, silty CLAY with sand and trace gravel		612	
								Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
								Dark brown (10YR3/3), very moist, soft, clayey, fine- to very coarse-grained SAND with slight trace gravel		610	
	0/48 0%	BD					12	Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
								Dark yellowish brown (10YR4/4), moist, soft, sandy SILT with trace gravel		608	
								Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
							14	Gray (10YR5/1), moist, very hard, very silty CLAY with sand and gravel		606	
1A	24/24 100%	SS	6-23 37-44 N=60	11		1.50					
							16	Dark gray (10YR4/1), moist, hard, SILT with few fine- to coarse-grained sand, little clay and trace small gravel.		604	
2A	23/24 96%	SS	14-32 41-45 N=73	7		4.50					
							18			602	
3A	14/17 82%	SS	16-47 50/5"	7		4.50		Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and trace small gravel.			
							20				

NOTE(S): G45D installed in boring.
Boring was blind drilled to 14.0 feet bgs. Blind drill lithologies from boring G405.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/17/2016
WEATHER: Cloudy, rain, (hi-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G405D
Well ID: G45D
Surface Elev: 620.94 ft. MSL
Completion: 42.00 ft. BGS
Station: 873,998.03N
2,515,322.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.			
	19/24 79%	SS	15-36 32-36 N=68					Dark gray (10YR4/1), moist, dense, fine- to coarse-grained SAND.		600	
4A				8		4.50	22				
	19/24 79%	SS	10-18 30-33 N=48					Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.		598	
5A				8		4.50	24				
6A	11/24 46%	SS	22-42 34-36 N=76	8		4.50				596	
							26				
7A	11/24 46%	SS	28-26 23-26 N=49	11		4.50		Dark gray (10YR4/1) with 5% light brownish gray (10YR6/2) mottles, dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.		594	
							28				
	23/24 96%	SS	7-11 16-25 N=27					Dark gray (10YR4/1) with 5% light brownish gray (10YR6/2) and dark greenish gray (10YR4/2) mottles, dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.		592	
8A				10		4.50					
							30				
9A				16				Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.			
9B	17/24 71%	SS	7-14 12-12 N=26	14				Dark gray (10YR4/1), dry, very stiff, SILT with some very fine-grained SAND.		590	
9C				9				Very dark gray (10YR3/1), moist, very stiff, CLAY with few silt and little medium-grained sand.			
							32				
	24/24 100%	SS	2-5 8-13 N=13							588	
10A				15		3.25		Very dark gray (10YR3/1), moist, very stiff, CLAY with little silt and little medium-grained sand.			
11-1							34				
11-2	22/24 92%	SH		15						586	
11-3											
11-4							36				
	24/24 100%	SS	2-5 8-10 N=13					Very dark gray (10YR3/1), moist, very stiff, CLAY with little silt, little medium-grained sand, and trace small gravel.		584	
12A				16		2.00					
							38				
	22/24 92%	SS	2-5 7-8 N=12					Very dark gray (10YR3/1) with 5% black (10YR2/1) mottles, moist, very stiff, CLAY with little silt, little medium-grained sand, and trace small gravel.		582	
13A				16		2.00	40				

NOTE(S): G45D installed in boring.
Boring was blind drilled to 14.0 feet bgs. Blind drill lithologies from boring G405.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/17/2016
WEATHER: Cloudy, rain, (hi-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G405D
Well ID: G45D
Surface Elev: 620.94 ft. MSL
Completion: 42.00 ft. BGS
Station: 873,998.03N
2,515,322.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Qp (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
14A	23/24 96%	ss	1-3 7-7 N=10	16		3.50		Very dark gray (10YR3/1) with 5% black (10YR2/1) mottles, moist, very stiff, CLAY with little silt, little medium-grained sand, and trace small gravel. *[Continued from previous page]*		580	
							42	**End of Boring = 42.0 ft. BGS**			

NOTE(S): G45D installed in boring.
Boring was blind drilled to 14.0 feet bgs. Blind drill lithologies from boring G405.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Sunny, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G406
Well ID: G406
Surface Elev: 621.86 ft. MSL
Completion: 18.75 ft. BGS
Station: 872,521.34N
2,514,702.38E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark brown (10YR3/3), moist, stiff, SILT with few clay and trace organics.			
							2	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay and trace small gravel.		620	
							4	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay. Grayish brown (10YR5/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with few silt and little fine-grained sand. Very pale brown (10YR7/4) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with trace silt.		618	
							6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt and trace fine- to medium-grained sand.		616	
							8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt, little fine- to medium-grained sand and trace small gravel.		614	
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.		612	
							12	Gray (10YR6/1) with 25% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.		610	
							14	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with some fine- to medium-grained sand, little silt, and trace small gravel.		608	
							16	Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, wet, loose, fine-grained SAND with some clay. Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, moist, loose, fine-grained SAND with some clay.		606	
							18	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel.		604	
								End of Boring = 18.75 ft. BGS			

NOTE(S): G406 installed in boring.
Boring was blind drilled adjacent to G406D.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Sunny, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G406D
Well ID: G46D
Surface Elev: 621.91 ft. MSL
Completion: 52.00 ft. BGS
Station: 872,519.70N
2,514,697.78E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type
1A				11		1.50
	18/24 75%	ss	4-3 4-6 N=7			
1B				15		3.00
2A	12/24 50%	ss	4-6 3-3 N=9	12		2.50
2B				18		2.00
3A				24		
	3/24 13%	ss	3-3 4-7 N=7			
	20/24 83%	ss	2-3 4-5 N=7			
4A				21		1.25
	19/24 79%	ss	1-3 4-6 N=7			
5A				18		1.75
	23/24 96%	ss	2-2 4-5 N=6			
6A				18		2.50
	21/24 88%	ss	1-3 4-5 N=7			
7A				16		1.00
8A	23/24 96%	ss	1-2 2-2 N=4	18		0.75
8B				17		0.75
9A	22/24 92%	ss	4-13 27-23 N=40	8		
9B				8		
10A	17/24 71%	ss	13-31 33-42 N=64	7		4.50

Depth ft. BGS	Lithologic Description	Elevation ft. MSL
0	Dark brown (10YR3/3), moist, stiff, SILT with few clay and trace organics.	
2	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay and trace small gravel.	620
4	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay. Grayish brown (10YR5/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with few silt and little fine-grained sand. Very pale brown (10YR7/4) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with trace silt.	618
6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt and trace fine- to medium-grained sand.	616
8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt, little fine- to medium-grained sand and trace small gravel.	614
10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.	612
12	Gray (10YR6/1) with 25% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.	610
14	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with some fine- to medium-grained sand, little silt, and trace small gravel.	608
16	Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, wet, loose, fine-grained SAND with some clay. Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, moist, loose, fine-grained SAND with some clay.	606
18	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel.	604
20		602

Borehole Detail

NOTE(S): G46D installed in boring.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Sunny, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G406D
Well ID: G46D
Surface Elev: 621.91 ft. MSL
Completion: 52.00 ft. BGS
Station: 872,519.70N
2,514,697.78E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11-1	3/3 100%	SH									
	8/24 33%	DS					22	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel. *[Continued from previous page]*		600	
12-1											
13-1											
13-2	24/24 100%	DS									
13-3											
13-4							24			598	
14A				19				Pale brown (10YR6/3), wet, loose, fine-grained SAND.			
14B	21/21	SS	*7-30*	7				Pale brown (10YR6/3), wet, loose, fine-grained SAND and small GRAVEL.			
14C	100%		*32-20* N=62	8		*4.50*		Gray (10YR5/1), dry, hard, SILT with some clay, trace fine- to coarse-grained sand and trace small gravel.			
							26			596	
	12/24 50%	SS	*15-16* *10-11* N=26					Dark gray (10YR4/1), dry, hard, CLAY with some silt, trace fine- to coarse-grained sand and trace small gravel.			
15A				10		*4.50*					
							28			594	
	17/24 71%	SS	*2-5* *7-11* N=12					Dark gray (10YR4/1), moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel.			
16A				16		*3.00*					
							30			592	
	17/24 71%	SS	*2-5* *7-12* N=12								
17A				15		*2.50*					
							32	Dark gray (10YR4/1), moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small to large gravel.		590	
	12/24 50%	SS	*3-7* *12-20* N=19					Dark gray (10YR4/1), moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel.			
18A				17		*2.50*					
							34			588	
	23/24 96%	SS	*4-4* *6-9* N=10					Dark gray (10YR4/1) with 5% very dark gray (10YR3/1) and brown (10YR5/3) mottles, moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel.			
19A				25		*1.00*					
							36	Gray (10YR5/1) with 5% very dark gray (10YR3/1) and brown (10YR5/3) mottles, moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel.		586	
	22/24 92%	SS	*2-2* *5-7* N=7								
20A				17		*1.00*					
							38	Dark gray (10YR4/1), moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel.		584	
	24/24 100%	SS	*2-3* *4-6* N=7								
21A				17		*1.00*					
							40			582	

NOTE(S): G46D installed in boring.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Sunny, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G406D
Well ID: G46D
Surface Elev: 621.91 ft. MSL
Completion: 52.00 ft. BGS
Station: 872,519.70N
2,514,697.78E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
22A	24/24 100%	SS	1-3 5-6 N=8	17		1.50	42			580	
23-1											
23-2	24/24 100%	SH									
23-3				16							
23-4							44			578	
24A	24/24 100%	SS	3-4 6-7 N=10	17		1.50		Dark gray (10YR4/1), moist, very stiff, CLAY with few silt, trace fine- to coarse-grained sand and trace small gravel. *[Continued from previous page]*			
25A	24/24 100%	SS	2-2 5-7 N=7	18		1.25	46			576	
26A	24/24 100%	SS	2-5 6-8 N=11	17		1.75	48			574	
27A	23/24 96%	SS	2-3 9-12 N=12	15		3.50	50			572	
							52			570	

End of Boring = 52.0 ft. BGS

NOTE(S): G46D installed in boring.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/16/2016
WEATHER: Rain, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G407
Well ID: G407
Surface Elev: 618.35 ft. MSL
Completion: 20.00 ft. BGS
Station: 872,973.39N
2,513,705.87E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 10, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type
1A	12/24 50%	ss	4-3 3-3 N=6	14		3.50
2A	20/24 83%	ss	2-2 4-4 N=6	18		1.50
3A	23/24 96%	ss	1-2 3-4 N=5	19		1.75
4A	24/24 100%	ss	1-3 3-5 N=6	19		1.50
5A	21/24 88%	ss	1-2 4-4 N=6	19		0.50
6A	22/24 92%	ss	1-2 2-1 N=4	17		
7A	24/24 100%	ss	7-29 33-17 N=62	8		
8A	24/24 100%	ss	3-7 12-17 N=19	12		4.50
9A	24/24 100%	ss	4-9 14-20 N=23	13		4.00
10A	24/24 100%	ss	2-8 14-19 N=22	14		4.50

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	Very dark gray (10YR3/1), wet, medium, SILT with some organics. [Fill]		618	
2	Gray (10YR6/1), wet, loose, SAND with some gravel and little clay. [Fill]			
	Yellowish brown (10YR5/6) with 5% dark yellowish brown (10YR3/6) mottles, moist, very stiff, SILT with some clay and trace very fine- to fine-grained sand.		616	
4	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with some clay, little fine- to coarse-grained sand, and trace small gravel.		614	
6	Brown (10YR5/3) with 25% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, trace fine-grained sand and trace small gravel.		612	
8	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.		610	
10	Yellowish brown (10YR5/6) with 25% brown (10YR5/3) mottles, moist, medium, CLAY with few silt, few fine-grained sand, and trace small gravel.		608	
12	Yellowish brown (10YR5/8) with 5% gray (10YR5/1) mottles, moist, very loose, fine-grained SAND with some clay and trace small gravel.		606	
14	Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, very dense, fine-grained SAND		604	
	Brown (10YR5/3), moist, hard, SILT with some clay and little fine- to coarse-grained sand.			
16 ▼	Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6) and 5% black (10YR2/1) mottles, SILT with some clay and little fine- to coarse-grained sand.		602	
18	Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, moist, hard, SILT with little fine- to coarse-grained sand and trace small gravel.		600	
20	Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, wet, stiff, SILT with little fine- to coarse-grained sand and little small gravel. Dark grayish brown (10YR4/2) with 10% dark yellowish brown (10YR3/6) mottles, moist, hard, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.			

End of Boring = 20.0 ft. BGS

NOTE(S): G407 installed in boring.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/17/2016
Finish: 8/17/2016
WEATHER: Hazy, (low-80s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: T408
Well ID: T408
Surface Elev: 621.09 ft. MSL
Completion: 25.92 ft. BGS
Station: 873,999.36N
2,515,314.91E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Black (10YR2/1), moist, soft, clayey SILT (TOPSOIL)		620	
	0/60 0%	BD					2				
							4	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY		618	
							6	Gray (10YR6/1), moist, firm, silty CLAY slight trace sand		616	
								Gray (10YR5/1), very moist, soft, clayey, very fine- to fine-grained SAND			
	0/60 0%	BD					8	Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel		614	
							10	Yellowish brown (10YR5/8) with 40% gray (10YR6/1) mottles, moist, firm, silty CLAY with sand and trace gravel		612	
								Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
								Dark brown (10YR3/3), very moist, soft, clayey, fine- to very coarse-grained SAND with slight trace gravel		610	
	0/60 0%	BD					12	Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
								Dark yellowish brown (10YR4/4), moist, soft, sandy SILT with trace gravel		608	
								Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
							14	Gray (10YR5/1), moist, very hard, very silty CLAY with sand and gravel		606	
4A	22/24 92%	SS	8-16 33-35 N=49			4.50	16	Dark gray (10YR4/1), moist, hard, SILT with few fine- to coarse-grained sand, little clay and trace small gravel.		604	
	0/36 0%	BD					18	Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and trace small gravel.		602	
							20				

NOTE(S): T408 installed in boring.
Boring was blind drilled to 26.0 feet bgs. Blind drill lithologies from boring G405 and G405D.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/17/2016
Finish: 8/17/2016
WEATHER: Hazy, (low-80s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: T408
Well ID: T408
Surface Elev: 621.09 ft. MSL
Completion: 25.92 ft. BGS
Station: 873,999.36N
2,515,314.91E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/36 *0%*	BD						Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.			
								Dark gray (10YR4/1), moist, dense, fine- to coarse-grained SAND.		600	
							22				
7-1								Dark gray (10YR4/1), dry, hard, SILT with few fine- to coarse-grained sand, little clay and little small gravel.		598	
7-2	20/24 *83%*	DS					24				
7-3											
7-4										596	
	0/12 *0%*	BD									

End of Boring = 25.92 ft. BGS

NOTE(S): T408 installed in boring.
Boring was blind drilled to 26.0 feet bgs. Blind drill lithologies from boring G405 and G405D.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Cloudy, (70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: T409
Well ID: T409
Surface Elev: 621.85 ft. MSL
Completion: 26.99 ft. BGS
Station: 872,517.79N
2,514,693.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark brown (10YR3/3), moist, stiff, SILT with few clay and trace organics.			
							2	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay and trace small gravel.		620	
1	0/60 0%	BD					4	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay. Grayish brown (10YR5/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with few silt and little fine-grained sand. Very pale brown (10YR7/4) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with trace silt.		618	
							6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt and trace fine- to medium-grained sand.		616	
2	0/60 0%	BD					8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt, little fine- to medium-grained sand and trace small gravel.		614	
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.		612	
3	0/60 0%	BD					12	Gray (10YR6/1) with 25% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.		610	
							14	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with some fine- to medium-grained sand, little silt, and trace small gravel.		608	
							16	Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, wet, loose, fine-grained SAND with some clay. Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, moist, loose, fine-grained SAND with some clay.		606	
4	0/60 0%	BD					18	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel.		604	
							20			602	

NOTE(S): T409 installed in boring.
Boring was blind drilled to 27.0 feet bgs. Blind drill lithologies from boring G406D.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Cloudy, (70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: T409
Well ID: T409
Surface Elev: 621.85 ft. MSL
Completion: 26.99 ft. BGS
Station: 872,517.79N
2,514,693.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tst) Qp (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/36 0%	BD					22	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel. *[Continued from previous page]*		600	
6-1											
6-2	0/24 0%	DS					24	Pale brown (10YR6/3), wet, loose, fine-grained SAND.		598	
6-3								Pale brown (10YR6/3), wet, loose, fine-grained SAND and small GRAVEL.			
6-4								Gray (10YR5/1), dry, hard, SILT with some clay, trace fine- to coarse-grained sand and trace small gravel.			
	0/24 0%	BD					26	Dark gray (10YR4/1), dry, hard, CLAY with some silt, trace fine- to coarse-grained sand and trace small gravel.		596	
								End of Boring = 26.99 ft. BGS			

NOTE(S): T409 installed in boring.
Boring was blind drilled to 27.0 feet bgs. Blind drill lithologies from boring G406D.

Canonie Construction Co.

Canonie Canonie Test Boring Services

Hamilton Lakes, 500 Park Boulevard, Suite 1212, Itasca, Illinois 60143, 312-773-4877

Job No.	DD-0514
Date	Feb. 8, 1985
Total Footage	50'0"
Foreman	W. Holloman
Classification By	Foreman

Client Hanson Engineers, Inc.

Geographic Location Coffeen, Illinois

Boring No. OW-1

O.G. EL.

Coordinates

Ground Surface

0'0" — very hard brown silty sandy CLAY, with small to medium gravel

5'0" — COAL & CINDERS

20'0" — medium brown and gray silty CLAY — PUSHED

22'0"

Installed well with 15' of 2" PVC screen to a depth of 22'0".

Boring No. OW-2

O.G. EL.

Coordinates

Ground Surface

0'0" — very hard brown silty sandy CLAY with small to large gravel

3'6" — COAL & CINDERS

26'0" — medium brown silty CLAY — PUSHED

28'0"

Installed well with 15'0" of 2" PVC screen to a depth of 28'0".

A.... All borings are plotted to a scale of 1"= 8..... ft., using ..ground surface.. as a fixed datum.

B....Classifications are made from visual inspection of samples and are our opinion thereof.

C....Water Levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

D....Figures in right hand column indicate number of blows required to drive 2" O.D. sampling spoon (6" u.n.o.), using a 140 lb. weight falling 30 inches.

Canonie Construction Co.

Canonie Canonie Test Boring Services

Hamilton Lakes, 500 Park Boulevard, Suite 1212, Itasca, Illinois 60143, 312-773-4877

Job No.	DD-0514
Date	Feb. 8, 1985
Total Footage	68'0"
Foreman	W. Holloman
Classification By	Foreman

Client Hanson Engineers, Inc.

Geographic Location Coffeen, Illinois

Boring No. OW-3

O.G. EL.

Coordinates

Ground Surface — 0'0"

very hard brown silty sandy CLAY with small to large gravel and some concrete — 3'6"

COAL & CINDERS

26'0"

medium brown silty CLAY — PUSHED — 28'0"

Installed well with 15'0" of 2" PVC screen to a depth of 28'0".

Boring No. OW-4

O.G. EL.

Coordinates

Ground Surface — 0'0"

very hard brown silty sandy CLAY with small to medium gravel — 3'6"

COAL & CINDERS

PUSHED — 40'0"

Installed well with 25'0" of 2" PVC screen to a depth of 40'0".

A....All borings are plotted to a scale of 1"=....8.. ft., using ground..surface... as a fixed datum.

B....Classifications are made from visual inspection of samples and are our opinion thereof.

C....Water Levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

D....Figures in right hand column indicate number of blows required to drive 2" O.D. sampling spoon (6" u.n.o.), using a 140 lb. weight falling 30 inches.

Sheet ... of ...

Canonie Construction Co.

Canonie Canonie Test Boring Services

Hamilton Lakes, 500 Park Boulevard, Suite 1212, Itasca, Illinois 60143, 312-773-4877

Job No.	DD-0514
Date	Feb. 8, 1985
Total Footage	35'0"
Foreman	W. Holloman
Classification By	Foreman

Client	Hanson Engineers, Inc.	Geographic Location	Coffeen, Illinois
Boring No.	OW-5	Boring No.	
O.G. EL.		O.G. EL.	
Coordinates		Coordinates	

Ground Surface — 0'0"

very hard brown silty sandy CLAY with small to medium gravel — 4'0"

COAL & CINDERS mixed with lime

33'0"

soft brown and gray CLAY — PUSHED — 35'0"

Installed well with 25'0" of 2" PVC screen to a depth of 35'0".

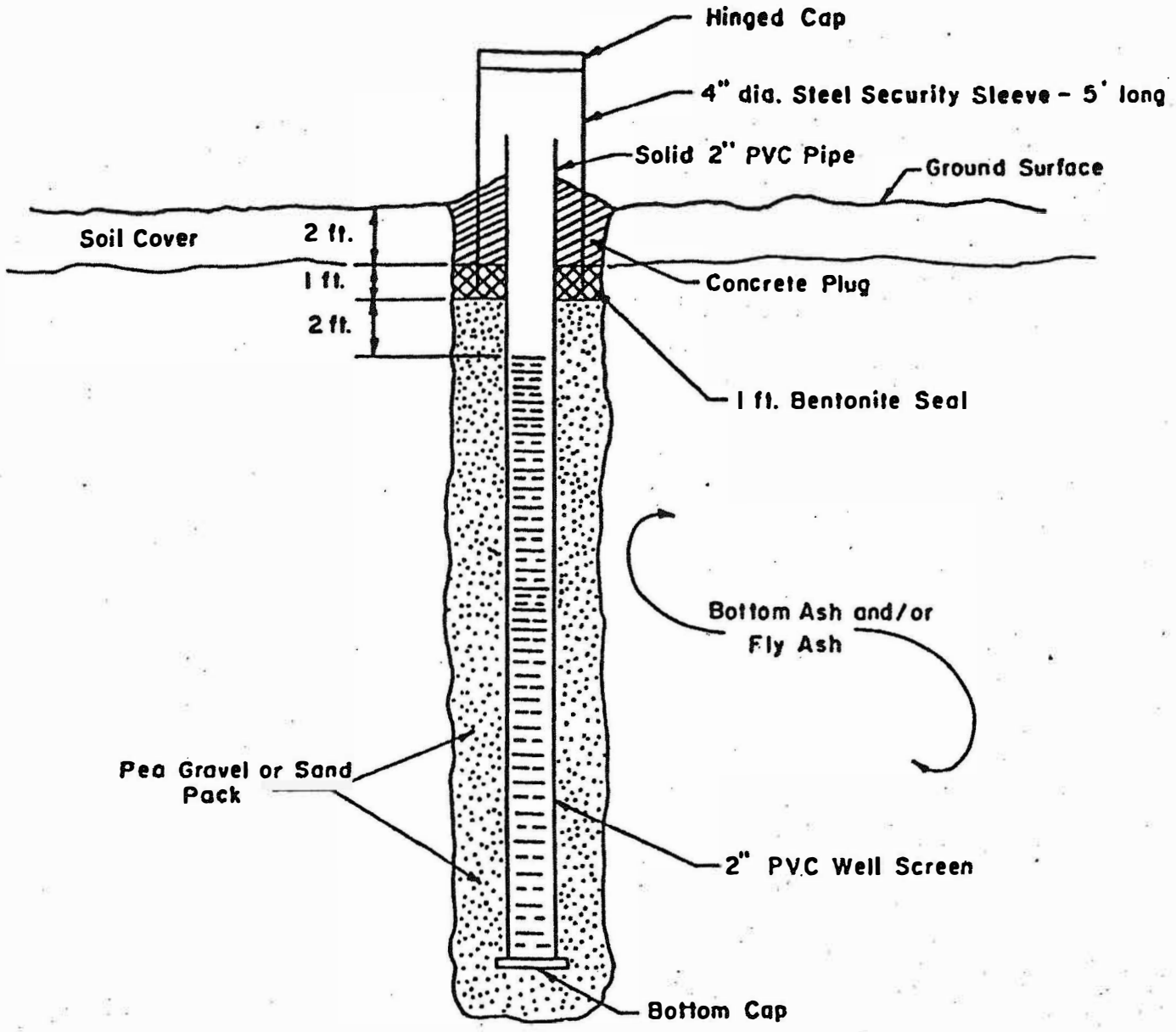
All wells installed in accordance with the attached "Exhibit 2", "Typical Observation Well Construction:.

A....All borings are plotted to a scale of 1"=...8... ft., using ...ground surface as a fixed datum.

B....Classifications are made from visual inspection of samples and are our opinion thereof.

C....Water Levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

D....Figures in right hand column indicate number of blows required to drive 2" O.D. sampling spoon (6" u.n.o.), using a 140 lb. weight falling 30 inches.



NOTE:
Install screen to the base of the pond or as determined in the field during well installations.

NO SCALE

Typical Observation Well Construction

HANSON ENGINEERS

SPRINGFIELD, IL • PEORIA, IL • ROCKFORD, IL

Coffeen Ash Pond No. 2
Coffeen Power Station
Central Illinois Public Service Company

Exhibit 2

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G401

Site Name: Coffeen Power Station Borehole #: G401

State Plane Coordinate: X 872,510.6 Y 2,515,614.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 9/14/2015 Date Finished: 9/14/2015

Report Form Completed By: Suzanna L. Keim Date: 10/7/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 25 minutes

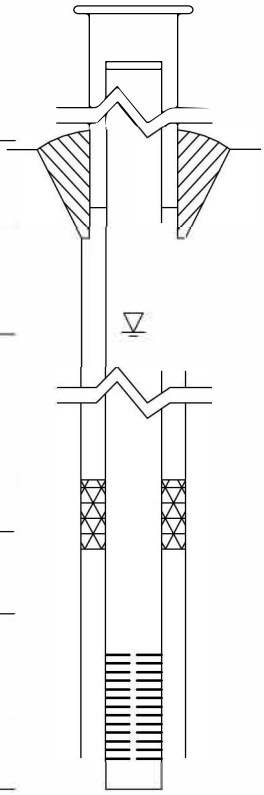
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.84	-2.81	Top of Protective Casing
625.57	-2.54	Top of Riser Pipe
623.03	0.00	Ground Surface
621.33	1.70	Top of Annular Sealant
		Static Water Level (After Completion)
n/a	n/a	Top of Seal
610.12	12.91	Top of Sand Pack
608.67	14.36	Top of Screen
604.24	18.79	Bottom of Screen
603.74	19.29	Bottom of Well
603.73	19.30	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.70
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.63
Total Length of Casing	(feet)	21.83
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G403

Site Name: Coffeen Power Station Borehole #: G403

State Plane Coordinate: X 873,561.3 Y 2,514,616.6 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/11/2015 Date Finished: 9/11/2015

Report Form Completed By: Suzanna L. Keim Date: 10/7/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >24 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: n/a

Setting Time: n/a

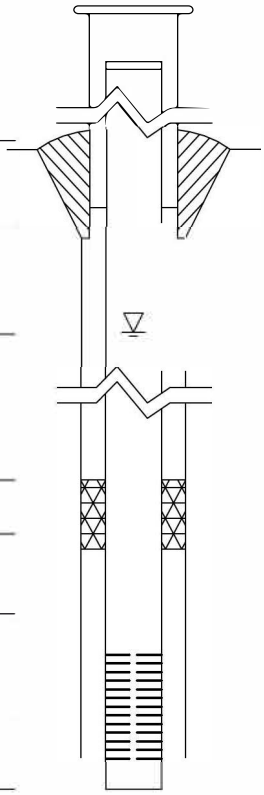
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.72	-2.91	Top of Protective Casing
626.47	-2.66	Top of Riser Pipe
623.81	0.00	Ground Surface
621.81	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
n/a	n/a	Top of Seal
612.64	11.17	Top of Sand Pack
610.70	13.11	Top of Screen
606.03	17.78	Bottom of Screen
605.66	18.15	Bottom of Well
605.66	18.15	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.77
Bottom of Screen to End Cap	(feet)	0.37
Screen Length (1st slot to last slot)	(feet)	4.67
Total Length of Casing	(feet)	20.81
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G404

Site Name: Coffeen Energy Center Borehole #: SB22

State Plane Coordinate: X 2,516,397.9 Y 873,999.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: A. Rachford

Consulting Firm: Hanson Professional Services Inc. Geologist: LPG #

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 5/1/2007 Date Finished: 5/1/2007

Report Form Completed By: Rhonald W. Hasenyager Date: 5/2/2007

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry
(choose one)

Installation Method:

Setting Time:

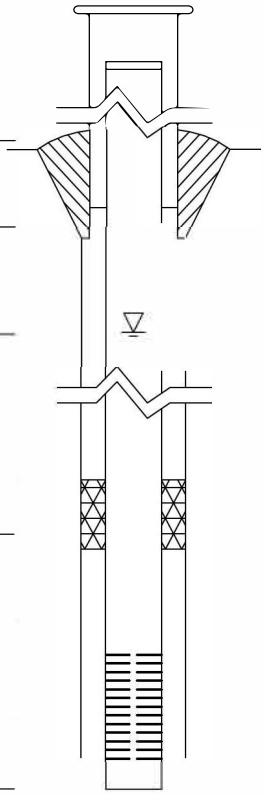
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: gravity

Type of Backfill Material: Formation sand
(if applicable)

Installation Method: slough



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
616.02	-2.92	Top of Protective Casing
615.77	-2.67	Top of Riser Pipe
613.10	0.00	Ground Surface
613.10	0.00	Top of Annular Sealant
611.03	2.07	Static Water Level (After Completion) 5/10/2007
n/a	n/a	Top of Seal
608.05	5.05	Top of Sand Pack
606.68	6.42	Top of Screen
601.93	11.17	Bottom of Screen
601.48	11.62	Bottom of Well
601.10	12.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	9.09
Bottom of Screen to End Cap	(feet)	0.45
Screen Length (1st slot to last slot)	(feet)	4.75
Total Length of Casing	(feet)	14.29
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G405

Site Name: Coffeen Energy Center Borehole #: SB21

State Plane Coordinate: X 2,515,335.7 Y 873,996.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: A. Rachford

Consulting Firm: Hanson Professional Services Inc. Geologist: LPG #

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 5/1/2007 Date Finished: 5/1/2007

Report Form Completed By: Rhonald W. Hasenyager Date: 5/2/2007

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method:

Setting Time:

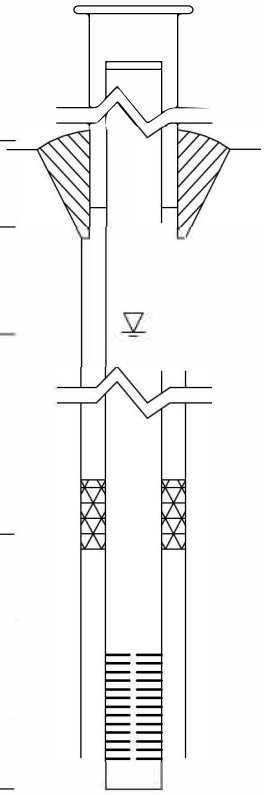
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: gravity

Type of Backfill Material: (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.04	-3.14	Top of Protective Casing
623.78	-2.88	Top of Riser Pipe
620.90	0.00	Ground Surface
620.90	0.00	Top of Annular Sealant
619.67	1.23	Static Water Level (After Completion) 5/10/2007
n/a	n/a	Top of Seal
613.19	7.71	Top of Sand Pack
611.89	9.01	Top of Screen
607.14	13.76	Bottom of Screen
606.69	14.21	Bottom of Well
606.69	14.21	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	11.89
Bottom of Screen to End Cap	(feet)	0.45
Screen Length (1st slot to last slot)	(feet)	4.75
Total Length of Casing	(feet)	17.09
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G45D

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G405D

State Plane Coordinate: X 2,515,322.2 Y 873,998.0 (or) Latitude: 39° 3' 51.657" Longitude: -89° 23' 46.612"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/16/2016 Date Finished: 8/17/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 38 minutes

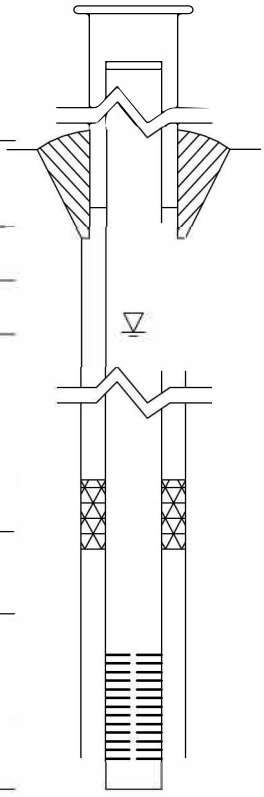
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.16	-3.22	Top of Protective Casing
623.81	-2.87	Top of Riser Pipe
620.94	0.00	Ground Surface
618.94	2.00	Top of Annular Sealant
584.66	36.28	Static Water Level (After Completion) 8/29/2016
590.59	30.35	Top of Seal
589.62	31.32	Top of Sand Pack
589.06	31.88	Top of Screen
579.42	41.52	Bottom of Screen
579.02	41.92	Bottom of Well
578.94	42.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	34.75
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	9.64
Total Length of Casing	(feet)	44.79
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G406

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G406

State Plane Coordinate: X 2,514,702.4 Y 872,521.3 (or) Latitude: 39° 3' 37.114" Longitude: -89° 23' 54.628"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/19/2016 Date Finished: 8/19/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 30 minutes

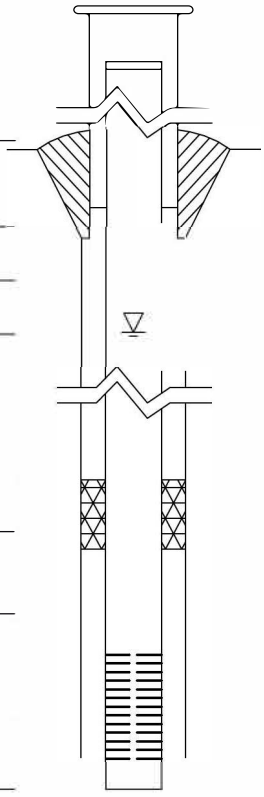
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
625.70	-3.84	Top of Protective Casing
625.36	-3.50	Top of Riser Pipe
621.86	0.00	Ground Surface
619.86	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
610.74	11.12	Top of Seal
609.65	12.21	Top of Sand Pack
608.30	13.56	Top of Screen
603.49	18.37	Bottom of Screen
603.11	18.75	Bottom of Well
603.11	18.75	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.06
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.81
Total Length of Casing	(feet)	22.25
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G46D

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G406D

State Plane Coordinate: X 2,514,697.8 Y 872,519.7 (or) Latitude: 39° 3' 37.098" Longitude: -89° 23' 54.687"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/19/2016 Date Finished: 8/19/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >12 hours

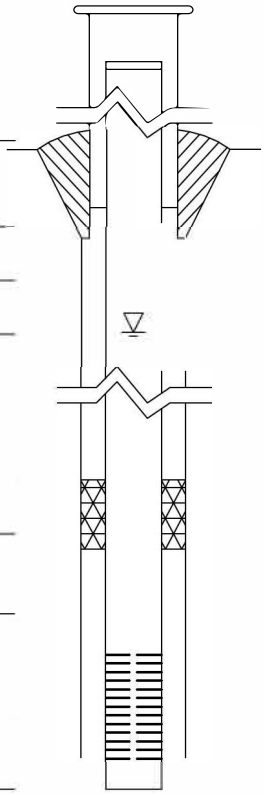
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.53	-3.62	Top of Protective Casing
625.24	-3.33	Top of Riser Pipe
621.91	0.00	Ground Surface
619.91	2.00	Top of Annular Sealant
589.60	32.31	Static Water Level (After Completion) 8/29/2016
582.34	39.57	Top of Seal
581.21	40.70	Top of Sand Pack
580.30	41.61	Top of Screen
570.65	51.26	Bottom of Screen
570.26	51.65	Bottom of Well
569.91	52.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	44.94
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	9.65
Total Length of Casing	(feet)	54.98
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G407

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G407

State Plane Coordinate: X 2,513,705.9 Y 872,973.4 (or) Latitude: 39° 3' 41.665" Longitude: -89° 24' 7.213"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/16/2016 Date Finished: 8/16/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 15 minutes

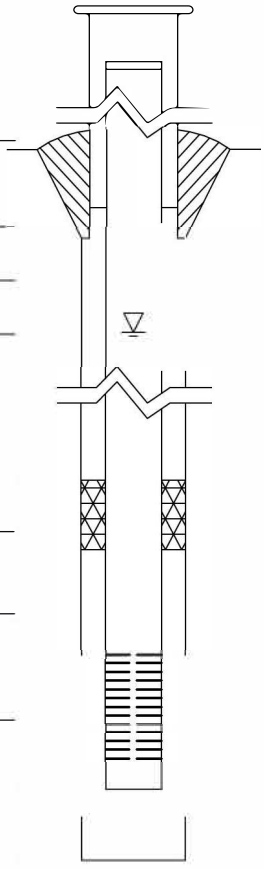
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand
(if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
621.70	-3.35	Top of Protective Casing
621.32	-2.97	Top of Riser Pipe
618.35	0.00	Ground Surface
616.35	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
607.50	10.85	Top of Seal
605.50	12.85	Top of Sand Pack
604.57	13.78	Top of Screen
599.74	18.61	Bottom of Screen
599.31	19.04	Bottom of Well
598.35	20.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.75
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.83
Total Length of Casing	(feet)	22.01
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: T408

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: T408

State Plane Coordinate: X 2,515,314.9 Y 873,999.4 (or) Latitude: 39° 3' 51.671" Longitude: -89° 23' 46.704"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/17/2016 Date Finished: 8/17/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 30 minutes

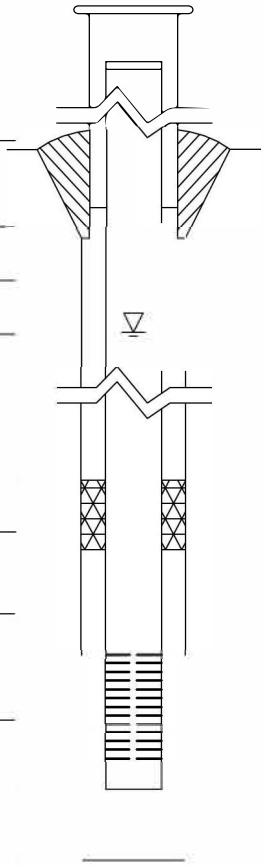
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material:
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.44	-3.35	Top of Protective Casing
624.08	-2.99	Top of Riser Pipe
621.09	0.00	Ground Surface
619.09	2.00	Top of Annular Sealant
618.21	2.88	Static Water Level (After Completion) 9/1/2016
602.99	18.10	Top of Seal
602.04	19.05	Top of Sand Pack
600.43	20.66	Top of Screen
595.60	25.49	Bottom of Screen
595.17	25.92	Bottom of Well
595.17	25.92	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	23.65
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.83
Total Length of Casing	(feet)	28.91
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: T409

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: T409

State Plane Coordinate: X 2,514,693.9 Y 872,517.8 (or) Latitude: 39° 3' 37.079" Longitude: -89° 23' 54.736"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/19/2016 Date Finished: 8/19/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 30 minutes

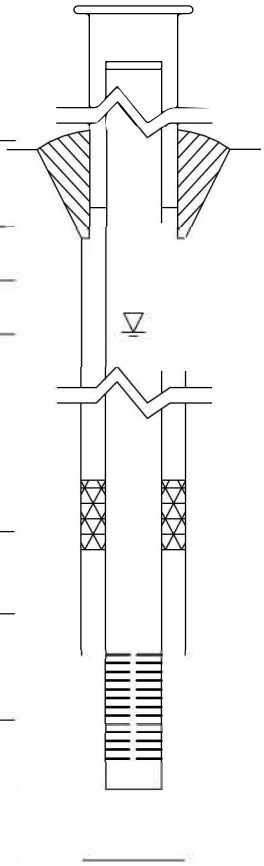
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material:
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.35	-3.50	Top of Protective Casing
625.01	-3.16	Top of Riser Pipe
621.85	0.00	Ground Surface
619.85	2.00	Top of Annular Sealant
615.80	6.05	Static Water Level (After Completion) 8/31/2016
602.65	19.20	Top of Seal
601.30	20.55	Top of Sand Pack
600.06	21.79	Top of Screen
595.26	26.59	Bottom of Screen
594.86	26.99	Bottom of Well
594.86	26.99	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	24.95
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	30.15
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A2

GMF RECYCLE POND

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/9/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G271
Well ID: G271
Surface Elev: 622.89 ft. MSL
Completion: 16.00 ft. BGS
Station: 874,239.38N
2,515,517.12E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.70 - While drilling
▼ = 12.50 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type
1A	20/24 83%	ss	2-5 5-6 N=10	27		
2A	24/24 100%	ss	2-6 5-5 N=11	23		
3A	23/24 96%	ss	4-5 4-5 N=9	18		
4A	24/24 100%	ss	2-4 4-5 N=8	17		
5A	24/24 100%	ss	2-4 4-6 N=8	20		
6A	24/24 100%	ss	2-4 4-5 N=8	22		
6B				20		
7A				20		
7B	20/24 83%	ss	2-2 3-7 N=5	19		
8A	24/24 100%	ss	10-19 30-33 N=49	7		

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	FILL - Yellowish brown (10YR5/4), moist, firm, silty CLAY with trace sand.			
	Grayish brown (10YR5/2), dry, friable, clayey SILT.		622	
2	Yellowish brown (10YR5/6) with 10% gray (10YR6/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		620	
4	Gray (10YR6/1), moist, firm, very silty CLAY with slight trace sand.		618	
6	Gray (10YR5/1) with 30% brownish yellow (10YR6/6) mottles, moist, firm, silty CLAY with sand and trace gravel.		616	
8	Very dark gray (10YR3/1), organic-rich (PEAT), silty CLAY and trace sand.		614	
10	Brownish yellow (10YR6/8) with 20% gray (10YR5/1) mottles, moist, firm, silty CLAY with sand and trace gravel.		612	
12	Gray (10YR6/1) with 20% brownish yellow (10YR6/8) mottles, very moist, soft, sandy CLAY with silt and slight trace gravel.			
	Brownish yellow (10YR6/6), very moist to wet, soft, sandy CLAY with silt and slight trace gravel.		610	
14	Gray (10YR6/1), wet, loose, very fine to medium SAND with silt.			
	Gray (10YR5/1), slightly moist, hard, very silty CLAY with sand and gravel.		608	
16	**End of Boring = 16.0 ft. BGS**			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G272
Well ID: G272
Surface Elev: 620.72 ft. MSL
Completion: 14.32 ft. BGS
Station: 874,234.83N
2,515,744.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.00 - While drilling
▼ = 9.49 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	3-2 3-4 N=5	18			0	FILL - Brownish yellow (10YR6/6) with 30% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		620	
2A	24/24 100%	ss	4-5 6-7 N=11	25			2	Brownish yellow (10YR6/6) with 20% brownish yellow (10YR6/8) and 20% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		618	
3A	23/24 96%	ss	2-4 4-6 N=8	18			4			616	
3B				17			6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with sand and trace gravel.		614	
4A	24/24 100%	ss	3-4 4-4 N=8	20			8			612	
5A	23/24 96%	ss	2-3 3-5 N=6	21			10	Yellowish brown (10YR5/8) with 15% gray (10YR6/1) mottles, moist, soft, silty CLAY with sand and slight trace gravel.		610	
6A	22/24 92%	ss	2-3 3-3 N=6	23			12	Gray (10YR6/1) with 30% brownish yellow (10YR6/6) mottles, very moist, soft, silty CLAY with sand and slight trace gravel.		608	
7A	18/24 75%	ss	2-9 15-21 N=24	14			14	Gray (10YR6/1), very moist, loose, SILT and very fine sand.			
7B				10				Gray (10YR6/1), wet, loose, SILT and very fine sand.			
								Yellowish brown (10YR5/6), moist, hard, very silty CLAY with sand and trace gravel.			
								End of Boring = 14.3 ft. BGS			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G273
Well ID: G273
Surface Elev: 620.17 ft. MSL
Completion: 16.00 ft. BGS
Station: 874,235.24N
2,515,975.49E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.50 - While drilling
▼ = 9.89 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss	3-3 3-3 N=6	24			0	FILL -Dark yellowish brown (10YR4/6), moist, firm, silty CLAY with slight trace sand.		620	
2A	24/24 100%	ss	3-4 5-7 N=9	28			2	FILL - Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		618	
3A				18			4			616	
3B	24/24 100%	ss	3-5 6-8 N=11	25				Brownish yellow (10YR6/8) with 40% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.			
4A				19			6	Gray (10YR6/1) with 10% brownish yellow(10YR6/6) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		614	
4B	24/24 100%	ss	3-5 5-6 N=10	16							
5A	23/24 96%	ss	2-4 5-4 N=9	19			8	Gray (10YR5/1), moist, firm, silty CLAY with sand and trace gravel.		612	
5B				21			▼ 10	Yellowish brown (10YR5/8) with 30% gray (10YR6/1) mottles, moist, soft, sandy CLAY with silty and slight trace gravel.		610	
6A	24/24 100%	ss	1-2 3-4 N=5	19				Brownish yellow (10YR6/8) with 10% gray (10YR6/1) mottles, very moist, soft, sandy CLAY with silt and slight trace gravel.			
7A	24/24 100%	ss	4-8 17-24 N=25	11			12	Gray (10YR6/1), moist, hard, very silty CLAY with sand and trace gravel.		608	
7B				11			▼ 14	Light yellowish brown (10YR6/4), wet, loose, very fine- to very coarse-grained SAND with trace silt.		606	
8A	22/24 92%	ss	9-22 22-23 N=44	8				Light yellowish brown (10YR6/4), wet, dense, sandy, silty CLAY. Gray (10YR6/1), moist, hard, very silty CLAY with sand and trace gravel.			
							16	**End of Boring = 16.0 ft. BGS**			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/16/2009
Finish: 9/16/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G274
Well ID: G274
Surface Elev: 621.67 ft. MSL
Completion: 18.06 ft. BGS
Station: 874,239.25N
2,516,195.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.00 - While drilling
▼ = 13.12 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 *83%*	ss	*2-3* *3-4* N=6	17			2	FILL - Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		620	
2A	24/24 *100%*	ss	*4-6* *7-9* N=13	25			4			618	
3A	24/24 *100%*	ss	*3-4* *6-9* N=10	26			6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		616	
3B				21							
4A	16/24 *67%*	ss	*3-6* *6-8* N=12	24			8			614	
5A	24/24 *100%*	ss	*2-4* *4-6* N=8	20			10	Dark gray (10YR4/1) with 15% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		612	
6A	22/24 *92%*	ss	*1-3* *4-6* N=7	19			12	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with sand and trace gravel.		610	
7A	23/24 *96%*	ss	*1-2* *4-4* N=6	21			▼ 14			608	
8A	22/24 *92%*	ss	*1-3* *3-6* N=6	17			▼ 16	Yellowish brown (10YR5/8), very moist, soft, silty CLAY with sand and trace gravel.		606	
9A	14/24 *58%*	ss	*wor-4* *9-11* N=13	13				Brownish yellow (10YR6/6), wet, loose, very fine- to very coarse-grained SAND.			
9B				13			18	Brownish yellow (10YR6/6), moist, firm, very silty CLAY with sand and gravel. Gray (10YR6/1), moist, hard, very silty CLAY with sand and gravel.		604	

End of Boring = 18.1 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/16/2009
Finish: 9/16/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G275
Well ID: G275
Surface Elev: 616.14 ft. MSL
Completion: 13.19 ft. BGS
Station: 874,298.94N
2,516,375.86E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.90 - While drilling
▼ = 10.25 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
1A	22/24 92%	ss	2-4 4-6 N=8	22			0	FILL - Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.	616	
2A	18/24 75%	ss	3-6 7-7 N=13	19			2	Dark gray (10YR4/1) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with slight trace sand and gravel.	614	
3A	24/24 100%	ss	2-4 4-5 N=8	22			4	Gray (10YR6/1), moist, soft, silty CLAY with sand and slight trace gravel.	612	
4A	24/24 100%	ss	2-3 4-6 N=7	17			6	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with sand and slight trace gravel.	610	
5A	24/24 100%	ss	1-2 3-3 N=5	18			8	Yellowish brown (10YR5/8) with 15% gray (10YR6/1) mottles, very moist, soft, silty CLAY with sand and trace gravel.	608	
5B				21			10 ▼	Gray (10YR6/1) with 20% yellowish brown (10YR5/8) mottles, very moist, very soft, silty CLAY with sand and trace gravel.	606	
6A				16						
6B	20/24 83%	ss	woh-4 5-2 N=9	13						
6C				15			12	Gray (10YR6/1), wet, loose, very fine- to very coarse-grained SAND with trace gravel. Yellowish brown (10YR5/6), moist, hard, very silty CLAY with sand and gravel.	604	
7A	12/12 100%	ss	10-35	8						

End of Boring = 13.2 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/16/2009
Finish: 9/16/2009
WEATHER: Sunny, mild (70'S)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G276
Well ID: G276
Surface Elev: 629.14 ft. MSL
Completion: 28.00 ft. BGS
Station: 874,438.60N
2,516,358.83E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 25.55 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	17/24 71%	ss	5-8 9-10 N=17	10			2	FILL - Yellowish brown (10YR5/4) with 20% gray (10YR5/1) mottles, moist, hard, silty CLAY with trace sand and slight trace gravel.		628	
2A	19/24 79%	ss	7-7 10-14 N=17	15			4			626	
3A	11/24 46%	ss	5-10 14-27 N=24	14			6			624	Rock fragment in split spoon shoe
4A	24/24 100%	ss	5-9 10-14 N=19	8				FILL - Yellowish brown (10YR5/4) with 20% gray (10YR5/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.			
4B				5			8	FILL - Yellowish brown (10YR5/4) with 10% gray (10YR5/1) mottles, slightly moist, hard, friable, clayey SILT with sand and trace gravel.		622	
5A	17/24 71%	ss	4-4 8-19 N=12	22						620	
6A	17/24 71%	ss	4-5 8-14 N=13	14			10	FILL - Yellowish brown (10YR5/4) with 25% gray (10YR5/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		618	
7A	16/24 67%	ss	6-7 2-4 N=9	20			12			616	
8A	20/24 83%	ss	2-4 6-6 N=10	21			14	Gray (10YR6/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		614	
9A				17			16				
9B	22/24 92%	ss	1-4 5-7 N=9	13				Gray (10YR6/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, sandy CLAY with silt and slight trace gravel.		612	
10A	23/24 96%	ss	2-3 8-12 N=11	20			18	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and slight trace gravel.		610	
							20				

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/16/2009
Finish: 9/16/2009
WEATHER: Sunny, mild (70'S)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G276
Well ID: G276
Surface Elev: 629.14 ft. MSL
Completion: 28.00 ft. BGS
Station: 874,438.60N
2,516,358.83E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 25.55 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 100%	ss	1-3 5-7 N=8	21			22	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and slight trace gravel. *[Continued from previous page]*		608	
12A	24/24 100%	ss	1-4 6-7 N=10	16			24	Yellowish brown (10YR5/8), moist, firm, silty CLAY with sand and slight trace gravel.		606	
13A	24/24 100%	ss	2-3 4-6 N=7	16			▼	Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, very moist, soft, silty CLAY with sand and trace gravel. Gray (10YR6/1), very moist, loose, very fine- to fine-grained, SAND		604	
14A	24/24 100%	ss	1-5 15-29 N=20	16			26	Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, very moist, soft, silty CLAY with sand and trace gravel. Gray (10YR6/1), very moist, firm, clayey SILT with trace very fine-grained sand.		602	
							28	Gray (10YR6/1) with 40% yellowish brown (10YR5/4) mottles, moist, hard, very silty CLAY with sand and trace gravel. Yellowish brown (10YR5/4), moist, hard, very silty CLAY with sand and trace gravel. **End of Boring = 28.0 ft. BGS**			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/14/2009
Finish: 9/14/2009
WEATHER: Sunny, mild (70'S)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G277
Well ID: G277
Surface Elev: 620.79 ft. MSL
Completion: 20.00 ft. BGS
Station: 874,581.80N
2,516,370.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.40 - While drilling
▼ = 18.23 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	2-2 4-6 N=6	21			0	FILL - Yellowish brown (10YR5/4) with 10% yellowish brown (10YR5/8) mottles, very moist, soft, silty CLAY with slight trace sand and gravel.		620	
2A	24/24 100%	ss	2-4 6-7 N=10	22			2	FILL - Yellowish brown (10YR5/4) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		618	
2B				16			3.5	Yellowish brown (10YR5/4) with 20% gray (10YR5/1) and 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with slight trace sand.			
3A				11			4	Light brownish gray (10YR6/2), dry, friable, clayey SILT.		616	
3B	17/24 71%	ss	4-7 9-11 N=16	22			6	Light brownish gray (10YR6/2) with 25% yellowish brown (10YR5/8) mottles, moist, firm, clayey SILT with slight trace sand.		614	
4A	18/24 75%	ss	4-8 8-6 N=16	13			8	Gray (10YR6/1) with 50% very dark grayish brown (10YR3/2) mottles, moist, hard, clayey SILT with slight trace sand and gravel.		612	
5A	19/24 79%	ss	3-7 8-9 N=15	12			10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, hard, very silty CLAY with sand and slight trace gravel.		610	
6A	22/24 92%	ss	3-9 9-10 N=18	14			12	Yellowish brown (10YR5/8) with 30% gray (10YR6/1) mottles, moist, hard, silty CLAY with sand and trace gravel.		608	
6B				16							
7A	18/24 75%	ss	3-5 7-9 N=12	17			14	Gray (10YR6/1), moist, slightly dense, silty, very fine- to very coarse-grained SAND.		606	
8A	22/24 92%	ss	2-5 5-8 N=10	12			16	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel.		604	
9A	22/24 92%	ss	1-2 3-3 N=5	14				Gray (10YR6/1) with 20% brownish yellow (10YR6/6) mottles, wet, very soft, silty, very fine- to fine-grained SAND with trace gravel.			
10A				11			18	Gray (10YR6/1) with 30% grayish brown (10YR5/2) mottles, moist, soft, sandy CLAY with slight trace gravel.		602	
10B	23/24 96%	ss	1-3 19-47 N=22	9				Brownish yellow (10YR6/6) with 25% gray (10YR6/1) mottles, moist, hard, very silty CLAY with sand and trace gravel.			
10							20	**End of Boring = 20.0 ft. BGS**			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/11/2009
Finish: 9/11/2009
WEATHER: Sunny, warm (70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G278
Well ID: G278
Surface Elev: 628.85 ft. MSL
Completion: 24.06 ft. BGS
Station: 874,875.37N
2,516,200.66E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 23.98 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss	3-4 6-7 N=10	19			0			628	
2A	24/24 100%	ss	4-7 8-11 N=15	21			2			626	
3A	22/24 92%	ss	9-10 9-35 N=19	10			4			624	Rock fragment in split spoon shoe
4A	4/24 17%	ss	20-7 10-8 N=17				6	FILL - Yellowish brown (10YR5/4) with 15% yellowish brown(10YR5/8) mottles, moist, hard, silty CLAY with trace sand and slight trace gravel.		622	Rock fragment in split spoon shoe
5A	14/24 58%	ss	11-6 8-8 N=14	15			8			620	Rock fragment in split spoon shoe
6A	20/24 83%	ss	6-4 8-9 N=12	26			10			618	
7A	24/24 100%	ss	2-4 8-11 N=12	18			12			616	
8A	20/24 83%	ss	4-7 10-11 N=17	12			14	Gray (10YR6/1) with 30% brownish yellow (10YR6/6) mottles, moist, firm, clayey SILT with slight trace sand. Very dark gray (10YR3/1), moist, firm, clayey SILT with slight trace sand and trace roots.		614	
8B				22			16	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel.		612	
9A	22/24 92%	ss	4-6 6-9 N=12	17			18	Gray (10YR6/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel.		610	
10A	20/24 83%	ss	2-4 5-8 N=9	21			20	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, firm, silty CLAY with sand and trace gravel.			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/11/2009
Finish: 9/11/2009
WEATHER: Sunny, warm (70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G278
Well ID: G278
Surface Elev: 628.85 ft. MSL
Completion: 24.06 ft. BGS
Station: 874,875.37N
2,516,200.66E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 23.98 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Qp (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	18/24 *75%*	ss	*2-4* *7-7* N=11	19				Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, firm, silty CLAY with sand and trace gravel. *[Continued from previous page]*			
11B							22	Yellowish brown (10YR5/6), very moist, soft, silty, very fine- to medium-grained SAND.		608	
12A				16							
12B	20/24 *83%*	ss	*1-5* *10-18* N=15	10			▼ 24	Yellowish brown (10YR5/4), moist, hard, very silty CLAY with sand and trace gravel.		606	

End of Boring = 24.1 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G279
Well ID: G279
Surface Elev: 629.19 ft. MSL
Completion: 28.00 ft. BGS
Station: 875,028.06N
2,516,245.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.60 - While drilling
▼ = 24.68 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	3-3 5-6 N=8	18			0	FILL - Brown (10YR4/3) with 30% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with sand and trace gravel.		628	
2A	24/24 100%	ss	5-9 10-11 N=19	14			4			626	
3A	24/24 100%	ss	5-9 9-10 N=18	17			6			624	
4A	24/24 100%	ss	4-5 7-6 N=12	21			8	FILL - dark gray (10YR4/1) with 10% brownish yellow (10YR6/6) mottles, moist, hard, silty CLAY with sand and trace gravel.		622	
5A	24/24 100%	ss	3-3 5-7 N=8	19			10			620	
6A	24/24 100%	ss	3-4 6-9 N=10	17			12			618	
7A	23/24 96%	ss	2-5 5-6 N=10	23			14	Brownish yellow (10YR6/8) with 30% gray (10YR5/1) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		616	
8A	24/24 100%	ss	2-3 7-6 N=10	23			16	Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		614	
9A	18/24 75%	ss	4-7 8-9 N=15	25			18			612	
10A	24/24 100%	ss	3-6 7-10 N=13	17			20	Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel.		610	

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G279
Well ID: G279
Surface Elev: 629.19 ft. MSL
Completion: 28.00 ft. BGS
Station: 875,028.06N
2,516,245.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.60 - While drilling
▼ = 24.68 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	23/24 96%	ss	2-4 5-7 N=9	18				Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel. *[Continued from previous page]*		608	
							22				
12A	19/24 79%	ss	4-9 8-9 N=17	13				Yellowish brown (10YR5/8), moist, firm, clayey SILT and very fine-grained SAND with slight trace gravel.		606	
12B				12			24				
13A	17/24 71%	ss	1-5 5-7 N=10	18				Light brownish gray (10YR6/2), wet, loose, very fine- to coarse-grained SAND.		604	
14A				16			26				
14B	24/24 100%	ss	10-10 18-18 N=28	14				Brownish yellow (10YR6/6), moist, hard, very silty CLAY with sand and trace gravel. Gray (10YR6/1), moist, hard, very silty CLAY with sand and trace gravel.		602	
							28	**End of Boring = 28.0 ft. BGS**			

NOTE(S):

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G271

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G271

~~State~~ Plane Coordinate: X 2,515,517.1 Y 874,239.4 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/9/2009 Date Finished: 9/10/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 10 min

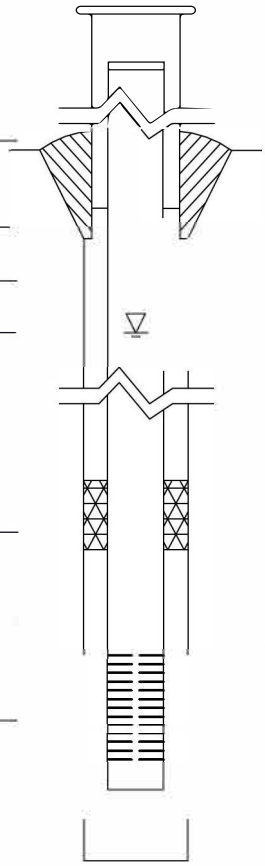
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.88	-2.99	Top of Protective Casing
625.57	-2.68	Top of Riser Pipe
622.89	0.00	Ground Surface
619.89	3.00	Top of Annular Sealant
610.39	12.50	Static Water Level (After Completion) 9/21/2009
616.16	6.73	Top of Seal
613.87	9.02	Top of Sand Pack
612.93	9.96	Top of Screen
608.58	14.31	Bottom of Screen
608.10	14.79	Bottom of Well
606.89	16.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	12.64
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	4.35
Total Length of Casing	(feet)	17.47
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G272

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G272

~~State~~ Plant ~~Plane~~ Coordinate: X 2,515,745.0 Y 874,234.8 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/10/2009 Date Finished: 9/10/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 10 min

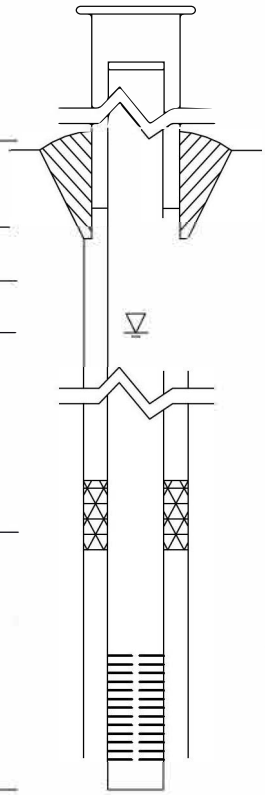
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.11	-3.39	Top of Protective Casing
623.81	-3.09	Top of Riser Pipe
620.72	0.00	Ground Surface
617.72	3.00	Top of Annular Sealant
611.23	9.49	Static Water Level (After Completion) 9/21/2009
614.55	6.17	Top of Seal
612.74	7.98	Top of Sand Pack
611.61	9.11	Top of Screen
606.74	13.98	Bottom of Screen
606.40	14.32	Bottom of Well
606.40	14.32	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	12.20
Bottom of Screen to End Cap	(feet)	0.34
Screen Length (1st slot to last slot)	(feet)	4.87
Total Length of Casing	(feet)	17.41
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G273

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G273

~~State~~ Plant ~~Plane~~ Coordinate: X 2,515,975.5 Y 874 235.2 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/10/2009 Date Finished: 9/10/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 10 min

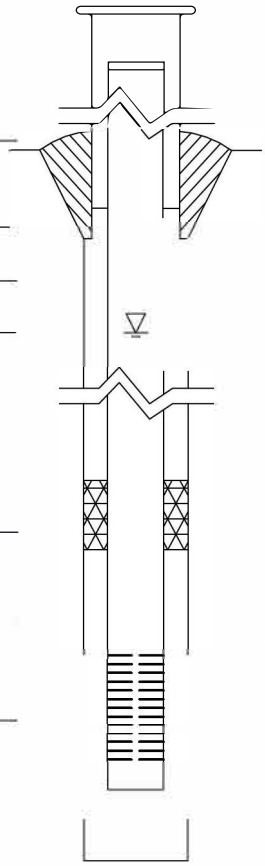
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
623.33	-3.16	Top of Protective Casing
623.02	-2.85	Top of Riser Pipe
620.17	0.00	Ground Surface
617.17	3.00	Top of Annular Sealant
610.28	9.89	Static Water Level (After Completion) 9/21/2009
614.07	6.10	Top of Seal
612.45	7.72	Top of Sand Pack
611.09	9.08	Top of Screen
605.61	14.56	Bottom of Screen
605.07	15.10	Bottom of Well
604.17	16.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	11.93
Bottom of Screen to End Cap	(feet)	0.54
Screen Length (1st slot to last slot)	(feet)	5.48
Total Length of Casing	(feet)	17.95
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G274

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G274

~~State~~ Plane Coordinate: X 2,516,195.6 Y 874 239.2 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/16/2009 Date Finished: 9/16/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

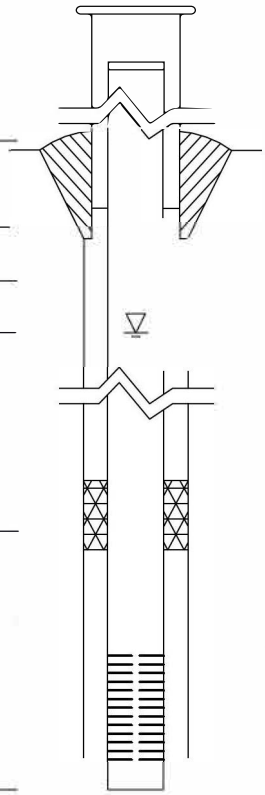
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.32	-2.65	Top of Protective Casing
624.04	-2.37	Top of Riser Pipe
621.67	0.00	Ground Surface
618.67	3.00	Top of Annular Sealant
608.55	13.12	Static Water Level (After Completion) 9/21/2009
611.93	9.74	Top of Seal
610.15	11.52	Top of Sand Pack
608.77	12.90	Top of Screen
604.00	17.67	Bottom of Screen
603.61	18.06	Bottom of Well
603.61	18.06	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.27
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.77
Total Length of Casing	(feet)	20.43
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G275

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G275

~~State~~ Plant ~~Plane~~ Coordinate: X 2,516,375.9 Y 874,298.9 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/16/2009 Date Finished: 9/16/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

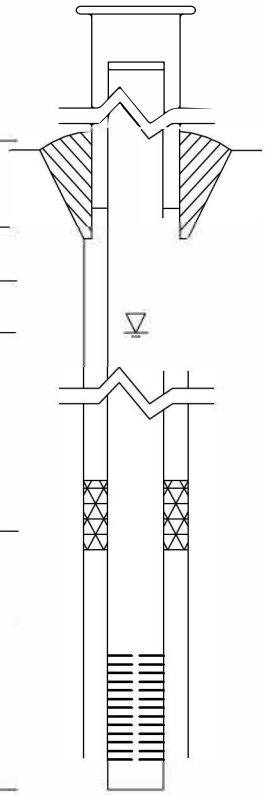
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
618.53	-2.39	Top of Protective Casing
618.26	-2.12	Top of Riser Pipe
616.14	0.00	Ground Surface
613.14	3.00	Top of Annular Sealant
605.89	10.25	Static Water Level (After Completion) 9/21/2009
610.42	5.72	Top of Seal
609.16	6.98	Top of Sand Pack
607.92	8.22	Top of Screen
603.52	12.62	Bottom of Screen
602.95	13.19	Bottom of Well
602.95	13.19	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	10.34
Bottom of Screen to End Cap	(feet)	0.52
Screen Length (1st slot to last slot)	(feet)	4.45
Total Length of Casing	(feet)	15.31
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G276

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G276

~~State~~ Plane Coordinate: X 2,516,358.8 Y 874,438.6 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/16/2009 Date Finished: 9/16/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

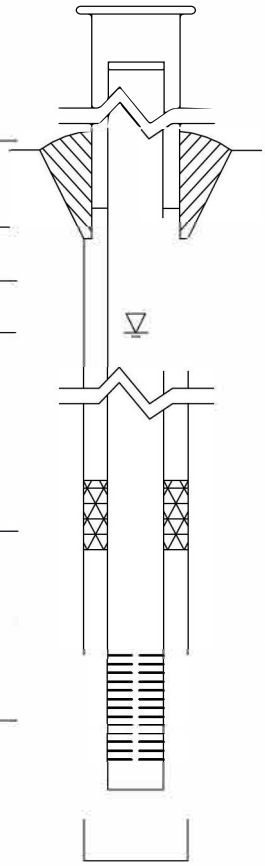
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	632.40	-3.26	Top of Protective Casing
	632.00	-2.86	Top of Riser Pipe
	629.14	0.00	Ground Surface
	626.14	3.00	Top of Annular Sealant
	603.59	25.55	Static Water Level (After Completion) 9/21/2009
	610.06	19.08	Top of Seal
	608.11	21.03	Top of Sand Pack
	606.73	22.41	Top of Screen
	601.92	27.22	Bottom of Screen
	601.49	27.65	Bottom of Well
	601.14	28.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	25.27
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.81
Total Length of Casing	(feet)	30.51
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G277

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G277

~~State~~ Plant ~~Plane~~ Coordinate: X 2,516,370.5 Y 874,581.8 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/14/2009 Date Finished: 9/14/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 18 min

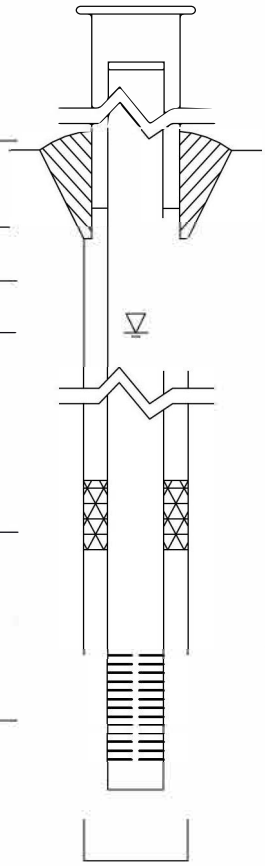
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	623.35	-2.56	Top of Protective Casing
	623.08	-2.29	Top of Riser Pipe
	620.79	0.00	Ground Surface
	617.79	3.00	Top of Annular Sealant
	602.56	18.23	Static Water Level (After Completion) 9/21/2009
	608.00	12.79	Top of Seal
	607.00	13.79	Top of Sand Pack
	606.50	14.29	Top of Screen
	602.02	18.77	Bottom of Screen
	601.55	19.24	Bottom of Well
	600.79	20.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.58
Bottom of Screen to End Cap	(feet)	0.47
Screen Length (1st slot to last slot)	(feet)	4.48
Total Length of Casing	(feet)	21.53
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G278

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G278

~~State~~ Plane Coordinate: X 2,516,200.7 Y 874,875.4 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/11/2009 Date Finished: 9/11/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 22 min

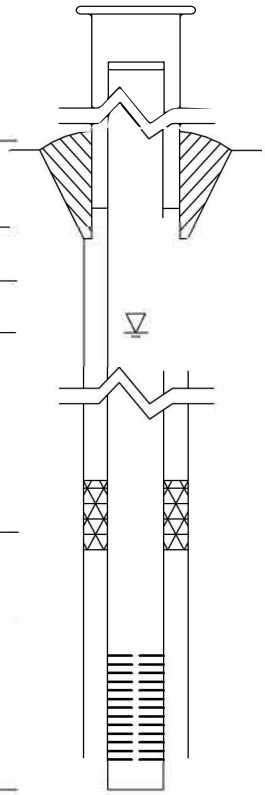
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
631.49	-2.64	Top of Protective Casing
631.17	-2.32	Top of Riser Pipe
628.85	0.00	Ground Surface
625.85	3.00	Top of Annular Sealant
604.87	23.98	Static Water Level (After Completion) 9/21/2009
613.74	15.11	Top of Seal
611.90	16.95	Top of Sand Pack
609.92	18.93	Top of Screen
605.15	23.70	Bottom of Screen
604.79	24.06	Bottom of Well
604.79	24.06	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	21.25
Bottom of Screen to End Cap	(feet)	0.36
Screen Length (1st slot to last slot)	(feet)	4.77
Total Length of Casing	(feet)	26.38
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G279

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G279

~~State~~ Plane Coordinate: X 2,516,245.6 Y 875,028.1 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/10/2009 Date Finished: 9/10/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 18 min

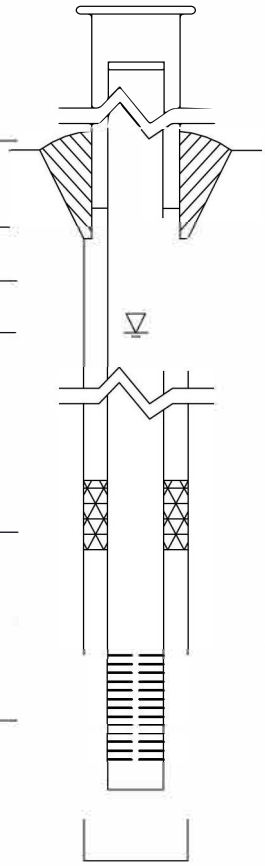
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
632.33	-3.14	Top of Protective Casing
632.04	-2.85	Top of Riser Pipe
629.19	0.00	Ground Surface
626.19	3.00	Top of Annular Sealant
601.66	27.53	Static Water Level (After Completion) 9/21/2009
610.45	18.74	Top of Seal
608.77	20.42	Top of Sand Pack
606.79	22.40	Top of Screen
602.40	26.79	Bottom of Screen
604.51	24.68	Bottom of Well
601.19	28.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	25.25
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	30.17
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A3

GMF GYPSUM STACK POND

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 2/25/2008
Finish: 2/25/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G200
Well ID: G200
Surface Elev: 624.2 ft. MSL
Completion: 18.0 ft. BGS
Station: 877,930.59N
2,515,649.96E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.50 - While drilling
▼ = 2.75 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) / % Recovery	Type	Blows / 6 in / N - Value / RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Very dark grayish brown (10YR3/2), moist, firm, friable, clayey SILT		624	
	24/24 100%	ss	3-2 3-3 N=5								
1A				31		1.36 B	2	Dark gray (10YR4/1) with 5% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY		622	
2A				26		1.94 BSh					
	19/24 79%	ss	3-3 6-6 N=9					Dark gray (10YR4/1) with 70% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY			
2B				26		2.33 Sh	4	Dark gray (10YR4/1) with 70% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand		620	
3A	19/24 79%	ss	3-3 4-5 N=7	26		1.59 B		Very dark gray (10YR3/1), moist, firm, silty CLAY, slight trace sand			
3B				23		1.55 B	6			618	
4A	22/24 92%	ss	5-5 5-5 N=10	29		0.31 B		Dark gray (10YR4/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace coarse sand			
							8			616	
5A	20/24 83%	ss	2-2 3-5 N=5	25		1.09 B					
							10	Dark gray (10YR4/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, sand and slight trace gravel		614	
	22/24 92%	ss	1-3 2-3 N=5								
6A				22		1.01					
							12			612	
	24/24 100%	ss	3-3 5-6 N=8					Yellowish brown (10YR5/8), moist, soft, sandy CLAY			
7A				15		0.50 B					
7B				18				Gray (10YR5/1), wet, soft, fine- to coarse-grained SAND			
8A				24		0.27 B	14	Gray (10YR5/1), wet, soft, silty CLAY, trace sand and gravel		610	
	19/24 79%	ss	0-3 5-8 N=8					Yellowish brown (10YR5/4), wet, soft, fine- to coarse-grained SAND, trace gravel			
8B				17							
9A				13			16			608	
	24/24 100%	ss	8-15 30-50 N=45					Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel			
9B				8			18				

End of Boring = 18.0 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/15/2010
Finish: 10/15/2010
WEATHER: Sunny (mid-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: R. Hasenyager

BOREHOLE ID: R201
Well ID: R201
Surface Elev: 624.02 ft. MSL
Completion: 17.22 ft. BGS
Station: 877,925.26N
2,514,841.96E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description
							0	Very dark grayish brown (10YR3/2), moist, soft, friable, clayey SILT, slight trace sand and gravel
							1	Dark brown (10YR3/3), moist, soft, silty CLAY
							2	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel
							4	Gray (10YR5/1) with 5% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY, sand and trace gravel
							6	Gray (10YR5/1), moist, firm, sandy CLAY, trace silt and slight trace gravel
							8	Yellowish brown (10YR5/8) with 10% gray (10YR5/1) mottles, moist, firm, sandy CLAY, trace gravel
							10	Yellowish brown (10YR5/8), wet, soft, silty SAND, trace gravel
							12	Yellowish brown (10YR5/8), moist, firm, clayey SILT
							14	Greenish gray (5GY6/1), moist, firm, interbedded clayey SILT and SILT
							16	Yellowish brown (10YR5/8), wet, soft, fine- to coarse-grained SAND, slight trace gravel
								Yellowish brown (10YR5/8), wet, firm, very fine- to fine-grained silty SAND
								Gray (10YR5/1), wet, soft, SILT
								Gray (10YR5/1), wet, soft, fine- to coarse-grained SAND, slight trace gravel
								Gray (10YR5/1), moist, hard, very silty CLAY, trace sand and gravel

End of Boring = 17.22 ft. BGS

Borehole Detail	Elevation ft. MSL	Remarks
	622	
	620	
	618	
	616	
	614	
	612	
	610	
	608	

NOTE(S): R201 blind drilled in borehole approximately 8 ft. west of G201. Lithology taken from G201.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 2/25/2008
Finish: 2/25/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G201
Well ID: G201
Surface Elev: 623.9 ft. MSL
Completion: 18.2 ft. BGS
Station: 877,924.94N
2,514,849.47E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.20 - While drilling
▼ = 2.17 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	22/24 92%	ss	3-3 2-3 N=5	23			0	Very dark grayish brown (10YR3/2), moist, soft, friable, clayey SILT, slight trace sand and gravel			
1B				33		1.16	▼ 2	Dark brown (10YR3/3), moist, soft, silty CLAY		622	
2A	22/24 92%	ss	2-3 5-6 N=8	26		2.33 BSh	4	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel		620	
3A	20/24 83%	ss	2-4 5-5 N=9	15		1.94 B	6	Gray (10YR5/1) with 5% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY, sand and trace gravel		618	
4A	24/24 100%	ss	7-7 7-6 N=14	19		1.24 B	8	Gray (10YR5/1), moist, firm, sandy CLAY, trace silt and slight trace gravel		616	
5A	24/24 100%	ss	1-2 3-3 N=5	23		1.16 B	▼ 10	Yellowish brown (10YR5/8) with 10% gray (10YR5/1) mottles, moist, firm, sandy CLAY, trace gravel		614	
6A	23/24 96%	ss	0-1 1-2 N=2	20			12	Yellowish brown (10YR5/8), wet, soft, silty SAND, trace gravel		612	
7A	20/24 83%	ss	3-6 6-12 N=12	22		2.72 BSh	14	Yellowish brown (10YR5/8), moist, firm, clayey SILT Greenish gray (5GY6/1), moist, firm, interbedded clayey SILT and SILT		610	
8A	24/24 100%	ss	4-7 7-10 N=14	23		1.59 Sh	16	Yellowish brown (10YR5/8), wet, soft, fine- to coarse-grained SAND, slight trace gravel		608	
8B				19							
9A				15				Yellowish brown (10YR5/8), wet, firm, very fine- to fine-grained silty SAND			
9B	24/24 100%	ss	7-12 25-30 N=37	20				Gray (10YR5/1), wet, soft, SILT			
9C				11				Gray (10YR5/1), wet, soft, fine- to coarse-grained SAND, slight trace gravel			
							18	Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel		606	

End of Boring = 18.15 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 2/21/2008
Finish: 2/21/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G205
Well ID: G205
Surface Elev: 622.2 ft. MSL
Completion: 16.0 ft. BGS
Station: 875,550.19N
2,515,914.87E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.10 - While drilling
▼ = 5.06 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Very dark grayish brown (10YR3/2), moist, firm, clayey SILT		622	
1A	24/24 100%	ss	4-3 4-4 N=7	22							
1B				30		1.67 Sh	2	Yellowish brown (10YR5/4) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand		620	
2A	19/24 79%	ss	3-5 6-5 N=11	24		1.86 B					
							4	Yellowish brown (10YR5/4) with 30% yellowish brown (10YR5/8) mottles, moist, hard, silty CLAY, slight trace sand		618	
3A	20/24 83%	ss	2-2 5-5 N=7	19		1.55 B	▼				
							6	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand, slight trace gravel		616	
4A	19/24 79%	ss	5-6 7-8 N=13	20		1.12 B					
							8			614	
5A	16/24 67%	ss	2-2 3-5 N=5	20		0.62 BSh		Yellowish brown (10YR5/6), moist, firm, silty CLAY with sand, trace gravel			
							10			612	
6A	22/24 92%	ss	1-2 3-3 N=5	17		0.62 BSh	▼				
6B				17				Yellowish brown (10YR5/6), moist, soft, sandy SILT, slight trace gravel			
7A				25			12			610	
7B	23/24 96%	ss	3-3 5-6 N=8	17		1.36 BSh		Yellowish brown (10YR 5/4), moist, soft, silty SAND, trace gravel			
							14			608	
8A	17/24 71%	ss	5-19 26-35 N=45	15							
8B				10				Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel			
							16				

End of Boring = 16.0 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/14/2010
Finish: 10/14/2010
WEATHER: Sunny, warm, breezy (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G206
Well ID: G206
Surface Elev: 630.54 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,103.91N
2,514,669.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 22.00 - While drilling
▼ = 21.54 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	12/24 50%	ss	2-2 3-2 N=5	18			0	FILL - Grayish brown (10YR5/2), moist, firm, silty CLAY with trace sand and gravel.		630	
2A	20/24 83%	ss	2-2 3-5 N=5	16			2			628	
3A	20/24 83%	ss	4-9 6-8 N=15	19			4	FILL - Dark gray (10YR4/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		626	
4A	19/24 79%	ss	2-4 5-6 N=9	20			6			624	
5A	17/24 71%	ss	2-3 4-5 N=7	30			8	Very dark gray (10YR3/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, trace roots. Dark grayish brown (10YR4/2) with 35% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		622	
6A	22/24 92%	ss	2-3 4-6 N=7	19			10	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand and gravel.		620	
7A	23/24 96%	ss	1-2 3-4 N=5	23			12	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		618	
8A	22/24 92%	ss	1-1 3-3 N=4	22			14	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		616	
9A	24/24 100%	ss	1-1 2-2 N=3	21			16	Dark yellowish brown (10YR4/6) with 30% gray (10YR5/1) mottles, moist, soft, silty CLAY with trace sand and gravel. Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		614	
10A	24/24 100%	ss	woh-woh 1-5	25			18	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, very soft, silty CLAY with trace sand and gravel. Gray (10YR5/1), moist, very soft, very fine- to fine-grained sandy CLAY with trace gravel.		612	
							20	Gray (10YR5/1), moist, firm, very fine- to fine-grained			

NOTE(S): G206 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/14/2010
Finish: 10/14/2010
WEATHER: Sunny, warm, breezy (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G206
Well ID: G206
Surface Elev: 630.54 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,103.91N
2,514,669.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 22.00 - While drilling
▼ = 21.54 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								sandy CLAY with trace gravel.			
11A	22/24 92%	ss	19-6 13-19 N=19	13				Dark yellowish brown (10YR4/6), wet dense, silty, fine- to coarse-grained SAND with trace gravel.		610	
11B				16				Dark yellowish brown (10YR4/6), moist, hard, clayey SILT with sand and gravel.			
							▼ 22	Grayish brown (10YR5/2), moist, dense, silty, very fine- to fine-grained SAND.			
								Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.		608	
12A	20/24 83%	ss	11-20 19-13 N=39	10							
12B				10				Dark gray (10YR4/1), wet, dense, silty, fine- to coarse-grained SAND with gravel.			
							24	Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.			
								End of Boring = 24.0 ft. BGS			

NOTE(S): G206 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/8/2010
Finish: 10/8/2010
WEATHER: Sunny, mild

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: R. Hasenyager

BOREHOLE ID: G207
Well ID: G207
Surface Elev: 630.61 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,166.36N
2,514,837.94E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	6-5 5-8 N=10	15			0	FILL - Yellowish brown (10YR5/6) with 10% gray (10YR6/1) and 5% black (10YR2/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.		630	
2A	24/24 100%	ss	4-4 7-8 N=11	15			2	FILL - Gray (10YR5/1) with 20% yellowish brown (10YR5/8) mottles, moist, hard, silty CLAY with sand and trace gravel.		628	
3A	23/24 96%	ss	3-6 7-9 N=13	17			4	FILL - Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, moist, hard, silty CLAY with sand and trace gravel.		626	
4A	24/24 100%	ss	3-4 6-7 N=10	16			6	FILL - Dark yellowish brown (10YR4/4), moist, hard, silty CLAY with slight trace sand and gravel.		624	
							7	FILL - Gray (10YR5/1) with 20% yellowish brown (10YR5/8) mottles, moist, hard, silty CLAY with slight trace sand and gravel.			
5A	24/24 100%	ss	2-2 3-4 N=5	22			8	Yellowish brown (10YR5/6) with 25% gray (10YR5/1) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		622	
5B				24			10	Gray (10YR5/1) with 15% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		620	
6A	22/24 92%	ss	2-2 2-5 N=4	27			12	Gray (10YR5/1) with 40% yellowish brown (10YR5/8) mottles, very moist, firm, silty CLAY with slight trace sand and gravel.		618	
7A	24/24 100%	ss	2-2 2-3 N=4	27			14	Yellowish brown (10YR5/8) with 30% gray (10YR6/1) mottles, very moist, soft, silty CLAY with trace sand and gravel.		616	
8A	24/24 100%	ss	woh-1 2-3 N=3	25			16	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, very moist, soft, silty CLAY with sand and slight trace gravel.		614	
9A	23/24 96%	ss	woh-2 2-3 N=4	22			18	Yellowish brown (10YR5/6) with 25% gray (10YR6/1) mottles, very moist, very soft, sandy, silty CLAY with trace gravel.		612	
10A	24/24 100%	ss	woh-woh 2-3	19			20	Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, very moist, very soft, sandy CLAY with silt and trace gravel.			

NOTE(S): G207 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/8/2010
Finish: 10/8/2010
WEATHER: Sunny, mild

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: R. Hasenyager

BOREHOLE ID: G207
Well ID: G207
Surface Elev: 630.61 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,166.36N
2,514,837.94E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	22/24 92%	ss	*woh-1* *2-2* N=3	18				Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, very moist, very soft, sandy CLAY with silt and trace gravel. *[Continued from previous page]*		610	
							22	Gray (10YR6/1) with 40% yellowish brown (10YR5/6) mottles, very moist to wet, loose, silty, very fine- to fine-grained SAND with slight trace gravel.		608	
12A	24/24 100%	ss	*10-24* *26-30* N=50					Gray (10YR5/1), slightly moist, hard, very silty CLAY with trace sand and slight trace gravel.			
							24	**End of Boring = 24.0 ft. BGS**			

NOTE(S): G207 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/7/2010
Finish: 10/7/2010
WEATHER: Sunny, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G208
Well ID: G208
Surface Elev: 630.57 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,231.46N
2,514,993.57E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 23.92 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	ss	4-3 3-5 N=6	23			0	FILL - Brown (10YR4/3) with 5% dark gray (10YR4/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		630	
2A	24/24 100%	ss	2-3 4-6 N=7	14			2			628	
3A	24/24 100%	ss	2-4 4-7 N=8	21			4	FILL - Brown (10YR4/3) with 15% dark gray (10YR4/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		626	
4A	24/24 100%	ss	2-4 6-8 N=10	17			6			624	
5A	20/24 83%	ss	2-2 4-5 N=6	24			8	Very dark gray (10YR3/1), moist, firm, silty CLAY with trace sand and gravel, trace roots.		622	
6A	23/24 96%	ss	1-2 4-4 N=6	26			10	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, trace roots.		620	
7A	19/24 79%	ss	1-2 2-3 N=4	23			12	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, trace roots.		618	
8A	22/24 92%	ss	1-1 2-3 N=3	24			14	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand, trace roots.		616	
9A	24/24 100%	ss	1-1 2-3 N=3	24			16	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel, trace roots.		614	
9B				20			18	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, very moist, soft, silty, very fine- to fine-grained sandy CLAY with trace gravel.		612	
10A	22/24 92%	ss	woh-woh 1-2	20							
10B				17			20	Dark yellowish brown (10YR4/6) with 15% gray (10YR5/1) mottles, very moist to wet, soft, clayey, very fine- to medium-grained SAND with trace gravel.			

NOTE(S): G208 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/7/2010
Finish: 10/7/2010
WEATHER: Sunny, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G208
Well ID: G208
Surface Elev: 630.57 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,231.46N
2,514,993.57E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 23.92 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	20/24 *83%*	ss	*woh-2* *5-12* N=7	13			22	Yellowish brown (10YR5/4), moist, firm, very silty CLAY with sand and gravel.		610	
12A	24/24 *100%*	ss	*6-11* *18-24* N=29	9			▼ 24	Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.		608	

End of Boring = 24.0 ft. BGS

NOTE(S): G208 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/7/2010
Finish: 10/7/2010
WEATHER: Sunny, cool (lo-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G209
Well ID: G209
Surface Elev: 630.57 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,298.23N
2,515,149.56E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 22.40 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	4-4 4-6 N=8	21			0			630	
2A	24/24 100%	ss	3-4 6-6 N=10	13			2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		628	
3A	24/24 100%	ss	2-3 6-8 N=9	19			4			626	
4A	22/24 92%	ss	2-3 6-8 N=9	17			6			624	
5A	18/24 75%	ss	2-3 3-5 N=6	20			8	Grayish brown (10YR5/2), moist, firm, clayey SILT with trace sand and gravel.		622	
6A	24/24 100%	ss	1-2 2-5 N=4	26			10	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		620	
7A	22/24 92%	ss	1-3 4-4 N=7	22			12	Dark gray (10YR4/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		618	
8A	24/24 100%	ss	woh-1 2-3 N=3	25			14			616	
9A	19/24 79%	ss	woh-1 2-3 N=3	24			16	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		614	
10A	14/24 58%	ss	woh-2 3-3 N=5	20			18			612	
							20				

NOTE(S): G209 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/7/2010
Finish: 10/7/2010
WEATHER: Sunny, cool (lo-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G209
Well ID: G209
Surface Elev: 630.57 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,298.23N
2,515,149.56E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 22.40 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	1/24 4%	ss	woh-1 1-1 N=2	21			22	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel. *[Continued from previous page]*		610	
12A	20/24 83%	ss	9-16 17-26 N=33	7			24	Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.		608	

End of Boring = 24.0 ft. BGS

NOTE(S): G209 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/6/2010
Finish: 10/6/2010
WEATHER: Sunny, warm (mid-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G210
Well ID: G210
Surface Elev: 630.48 ft. MSL
Completion: 25.00 ft. BGS
Station: 875,359.71N
2,515,298.97E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 19.90 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	4-3 5-6 N=8	16			0			630	
							2	FILL - Brown (10YR4/3) with 20% dark gray (N5/1) mottles, moist, firm, silty CLAY with trace sand and gravel.		628	
2A	24/24 100%	ss	3-4 7-7 N=11	15			4			626	
3A	24/24 100%	ss	3-5 10-9 N=15	19			6			624	
								FILL - Dark grayish brown (10YR4/2), slightly moist, firm, clayey SILT with trace sand and gravel.			
4A	24/24 100%	ss	3-6 9-11 N=15	17			8	Gray (10YR5/1) with 10% dark grayish brown (10YR4/2) mottles, moist, firm, silty CLAY with trace sand.		622	
								Dark gray (10YR4/1), moist, firm, silty CLAY with trace sand, trace roots.			
5A	24/24 100%	ss	3-4 5-7 N=9	15				Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with trace sand.			
							10			620	
6A	22/24 92%	ss	2-2 4-6 N=6	26				Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with trace sand and gravel.			
							12			618	
7A	19/24 79%	ss	1-3 3-5 N=6	23				Gray (10YR5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist to very moist, firm, silty CLAY with sand.			
							14			616	
8A	24/24 100%	ss	2-2 2-4 N=4	26				Gray (10YR5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with sand and trace gravel.			
							16			614	
9A	24/24 100%	ss	1-1 2-3 N=3	24				Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with sand and trace gravel.			
							18			612	
10A	20/24 83%	ss	1-1 2-2 N=3	24							
10B				31			▼ 20	Gray (N6/1), very moist, very soft, silty, very fine- to fine-grained sandy CLAY with trace gravel.			

NOTE(S): G210 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/6/2010
Finish: 10/6/2010
WEATHER: Sunny, warm (mid-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G210
Well ID: G210
Surface Elev: 630.48 ft. MSL
Completion: 25.00 ft. BGS
Station: 875,359.71N
2,515,298.97E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 19.90 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	14/24 *58%*	ss	*woh-5* *6-18* N=11	12				Yellowish brown (10YR5/4), moist, medium dense, silty, fine- to coarse-grained SAND with trace gravel.			
								Gray (N6/1), moist, medium dense, silty, very fine - to fine-grained SAND.		610	
							22	Yellowish brown (10YR5/4), slightly moist, hard, clayey SILT with sand and gravel.			
12A	19/24 *79%*	ss	*7-18* *26-36* N=44	14				Brown (10YR5/3), very moist, dense, very fine- to fine-grained sandy SILT with trace gravel.		608	
							24	Gray (N5/1), slightly moist, hard, very silty CLAY with sand and gravel.			
13A	10/12 *83%*	ss	*27-50/6"*	9						606	

End of Boring = 25.0 ft. BGS

NOTE(S): G210 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/11/2010
Finish: 10/11/2010
WEATHER: Sunny, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G211
Well ID: G211
Surface Elev: 630.31 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,424.49N
2,515,449.06E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 20.60 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	5-3 4-5 N=7	23			0			630	
							2	FILL - Brown (10YR4/3) with 20% dark gray (10YR4/1) mottles, moist, firm, silty CLAY with trace sand and gravel.		628	
2A	20/24 83%	ss	3-5 5-8 N=10	17							
							4			626	
3A	24/24 100%	ss	2-3 5-7 N=8	24			6	FILL - Dark gray (10YR4/1) with 20% brown (10YR4/3) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		624	
4A	24/24 100%	ss	3-5 7-9 N=12	29							
							8	Dark gray (10YR4/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY, slight trace roots.		622	
5A	24/24 100%	ss	2-2 3-5 N=5	31							
							10	Dark gray (10YR4/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		620	
6A	17/24 71%	ss	1-2 4-4 N=6	19							
							12			618	
7A	24/24 100%	ss	1-2 2-4 N=4	22			14	Dark gray (10YR4/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		616	
8A	24/24 100%	ss	1-1 3-2 N=4	28							
							16			614	
9A	22/24 92%	ss	1-1 1-2 N=2	19			18	Dark yellowish brown (10YR4/6) with 30% gray (10YR5/1) mottles, very moist, soft, very fine- to fine-grained sandy CLAY with trace gravel.		612	
10A	19/24 79%	ss	1-4 5-11 N=9	13			▼ 20	Dark yellowish brown (10YR4/4) with 15% grayish brown (10YR5/2) mottles, moist, firm, clayey SILT with sand and gravel.			

NOTE(S): G211 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/11/2010
Finish: 10/11/2010
WEATHER: Sunny, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G211
Well ID: G211
Surface Elev: 630.31 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,424.49N
2,515,449.06E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 20.60 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	18/24 75%	ss	7-17 23-21 N=40	10			0	Grayish brown (10YR5/2), slightly moist, hard, very silty CLAY with sand and gravel.		610	
							22			608	
12A	24/24 100%	ss	4-14 15-17 N=29	13				Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.			
							24	**End of Boring = 24.0 ft. BGS**			

NOTE(S): G211 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/11/2010
Finish: 10/11/2010
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G212
Well ID: G212
Surface Elev: 630.59 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,486.50N
2,515,583.03E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 19.00 - While drilling
▼ = 20.72 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	4-3 3-6 N=6	17			0	FILL - Brown (10YR4/3), slightly moist, firm, silty CLAY with trace sand and gravel.		630	
2A	24/24 100%	ss	2-3 4-5 N=7	21			2	FILL - Dark gray (10YR4/1) with 20% brown (10YR4/3) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		628	
3A	24/24 100%	ss	2-5 6-7 N=11	13			4			626	
4A	24/24 100%	ss	2-5 7-10 N=12	15			6	FILL - Brown (10YR4/3) with 15% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		624	
5A	24/24 100%	ss	2-2 4-7 N=6	29			8	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY, slight trace roots.		622	
6A	18/24 75%	ss	2-3 4-6 N=7	23			10	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		620	
7A	17/24 71%	ss	1-2 2-2 N=4	25			12			618	
8A	24/24 100%	ss	woh-1 2-3 N=3	27			14	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		616	
9A	22/24 92%	ss	1-1 2-2 N=3	25			16			614	
10A	24/24 100%	ss	woh-woh 1-2	19			18	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, very moist, very soft, silty, very fine- to fine-grained sandy CLAY with trace gravel.		612	
10B				22			20	Gray (10YR5/1), loose, wet, silty, very fine- to			

NOTE(S): G212 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/11/2010
Finish: 10/11/2010
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G212
Well ID: G212
Surface Elev: 630.59 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,486.50N
2,515,583.03E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 19.00 - While drilling
▼ = 20.72 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	7/24 29%	ss	1-6 10-22 N=16	19				medium-grained SAND. Brown (10YR5/3), moist, medium dense, SILT with trace sand and gravel.		610	
							22	Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.		608	
12A	20/24 83%	ss	5-21 18-27 N=39	12			24	**End of Boring = 24.0 ft. BGS**			

NOTE(S): G212 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Partly cloudy, mild (mid-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G213
Well ID: G213
Surface Elev: 630.34 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,544.37N
2,515,723.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 19.92 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	4-3 4-5 N=7	15			0			630	
2A	22/24 92%	ss	2-4 6-8 N=10	21			2			628	
3A	22/24 92%	ss	2-4 7-8 N=11	17			4	FILL - Brown (10YR4/3) with 10% dark gray (10YR4/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, silty CLAY with trace sand and gravel.		626	
4A	22/24 92%	ss	2-4 4-8 N=8	16			6			624	
5A	20/24 83%	ss	1-3 6-6 N=9	12			8			622	
6A	20/24 83%	ss	2-2 5-7 N=7	24			10	Dark gray (10YR4/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, trace roots.		620	
7A	20/24 83%	ss	2-3 3-5 N=6	19			12	Gray (10YR5/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT, trace roots.		618	
8A	22/24 92%	ss	1-2 2-3 N=4	24			14	Dark gray (10YR4/1) with 3% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		616	
9A	24/24 100%	ss	woh-1 2-2 N=3	24			16	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		614	
10A	18/24 75%	ss	woh-woh 1-2	24			18	Gray (10YR5/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		612	
								Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, very fine- to fine-grained sandy CLAY with trace gravel.			
							20 ▼	Dark yellowish brown (10YR4/6), very moist, soft, sandy CLAY with trace gravel.			

NOTE(S): G213 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Partly cloudy, mild (mid-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G213
Well ID: G213
Surface Elev: 630.34 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,544.37N
2,515,723.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 20.00 - While drilling
▼ = 19.92 - Upon completion
▽ =

SAMPLE			TESTING				Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type					
11A	18/24 75%	ss	1-1 1-2 N=2	18				Dark yellowish brown (10YR4/6), moist, soft, clayey, very fine- to coarse-grained SAND with trace gravel.		610	
								Dark yellowish brown (10YR4/6), moist, firm, very silty CLAY with sand and gravel.			
							22			608	
12A	22/24 92%	ss	10-13 18-22 N=31	11				Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.			
							24				

End of Boring = 24.0 ft. BGS

NOTE(S): G213 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/14/2010
Finish: 10/14/2010
WEATHER: Sunny, cool (lo-40's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G214
Well ID: G214
Surface Elev: 630.39 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,668.02N
2,515,960.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	6-7 7-9 N=14	15			0	FILL - Brown (10YR4/3) with 10% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		630	
2A	24/24 100%	ss	3-3 6-5 N=9	22			4	FILL - Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		628	
3A	24/24 100%	ss	3-4 6-8 N=10	18						626	
4A	24/24 100%	ss	3-4 7-10 N=11	17			6	FILL - Brown (10YR4/3) with 10% dark yellowish brown (10YR4/6) and 5% dark gray (10YR4/1) mottles, moist, firm, silty CLAY with trace sand and gravel.		624	
5A	24/24 100%	ss	3-2 4-5 N=6	19			8	Grayish brown (10YR5/2) with 15% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand and gravel.		622	
6A	24/24 100%	ss	2-3 4-7 N=7	24			10	Brown (10YR4/3) with 15% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		620	
7A	24/24 100%	ss	2-3 4-6 N=7	22			12	Gray (10YR6/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY.		618	
7B				16							
8A	24/24 100%	ss	woh-2 3-4 N=5	22			14	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		616	
9A	22/24 92%	ss	1-2 2-3 N=4	21			16	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		614	
10A	22/24 92%	ss	woh-2 2-2 N=4	15			18	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		612	
10B				21			20				

NOTE(S): G214 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/14/2010
Finish: 10/14/2010
WEATHER: Sunny, cool (lo-40's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G214
Well ID: G214
Surface Elev: 630.39 ft. MSL
Completion: 24.00 ft. BGS
Station: 875,668.02N
2,515,960.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	20/24 83%	ss	woh-woh 3-12	24				Gray (10YR5/1), wet, loose, silty, very fine- to medium-grained SAND with trace gravel and clayey seams. *[Continued from previous page]*		610	
11B				14							
							22	Dark yellowish brown (10YR4/6), moist, firm, very silty CLAY with trace sand and gravel.		608	
12A	24/24 100%	ss	12-28 32-28 N=60	7				Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with trace sand and gravel.			
							24	**End of Boring = 24.0 ft. BGS**			

NOTE(S): G214 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/13/2010
Finish: 10/13/2010
WEATHER: Sunny, warm, windy (hi-60's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G215
Well ID: G215
Surface Elev: 630.48 ft. MSL
Completion: 24.31 ft. BGS
Station: 875,810.19N
2,515,971.55E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ = 22.52 - 10/14/10

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	5-3 3-5 N=6	18			0			630	
2A	19/24 79%	ss	3-3 5-6 N=8	17			2	FILL - Brown (10YR4/3) with 30% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		628	
3A	20/24 83%	ss	2-3 7-7 N=10	13			4			626	
4A	23/24 96%	ss	3-6 6-7 N=12	16			6	FILL - Dark grayish brown (10YR4/2), moist, firm, silty CLAY with trace sand and gravel.		624	
4B				27			8	FILL - Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand.		622	
5A	20/24 83%	ss	3-3 3-5 N=6	20				Very dark gray (10YR3/1), moist, firm, silty CLAY with trace sand, trace roots.			
6A	13/24 54%	ss	2-2 3-5 N=5	24			10	Dark gray (10YR4/1) with 30% dark yellowish brown (10YR4/6) moist, firm, silty CLAY with trace sand.		620	
7A	19/24 79%	ss	2-3 4-6 N=7	17			12	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand.		618	
8A	20/24 83%	ss	2-3 4-5 N=7	19			14	Dark gray (10YR4/1), moist, firm, clayey SILT with trace sand.		616	
9A	22/24 92%	ss	1-3 3-4 N=6	19			16	Dark gray (10YR4/1) with 30% Dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		614	
10A	24/24 100%	ss	woh-1 2-2 N=3	17			18	Dark gray (10YR4/1) with 30% Dark yellowish brown (10YR4/6) mottles, moist, soft, sandy CLAY with trace gravel.		612	
							20				

NOTE(S): G215 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/13/2010
Finish: 10/13/2010
WEATHER: Sunny, warm, windy (hi-60's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G215
Well ID: G215
Surface Elev: 630.48 ft. MSL
Completion: 24.31 ft. BGS
Station: 875,810.19N
2,515,971.55E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = Dry - Upon completion
▽ = 22.52 - 10/14/10

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	20/24 *83%*	SS	*2-4* *4-4* N=8	17				Dark yellowish brown (10YR4/6), moist, medium dense, clayey SILT with sand and trace gravel.		610	
								Yellowish brown (10YR5/6), moist, medium dense, silty, very fine- to fine-grained SAND.			
							22 ▽	Dark yellowish brown (10YR4/6) with 30% dark gray (10YR4/1) mottles, moist, firm, sandy CLAY with trace gravel.		608	
12A	24/24 *100%*	SS	*7-11* *17-19* N=28	11				Grayish brown (10YR5/2), slightly moist, very firm, very silty CLAY with sand and gravel.			
12B	0/4 *0%*	BD		9			24	Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.			

End of Boring = 24.3 ft. BGS

NOTE(S): G215 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/13/2010
Finish: 10/13/2010
WEATHER: Partly cloudy, mild, windy (lo-60's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G216
Well ID: G216
Surface Elev: 630.28 ft. MSL
Completion: 26.00 ft. BGS
Station: 875,976.05N
2,515,968.53E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 21.00 - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	3-2 2-4 N=4	22			0			630	
							2	FILL - Brown (10YR4/3) with 20% dark gray (10YR4/6) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.			
2A	19/24 79%	ss	2-2 5-4 N=7	28			4			628	
3A	24/24 100%	ss	2-2 4-5 N=6	19			6	FILL - Dark gray (10YR4/1) with 15% brown (10YR4/3) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand and gravel.		626	
4A	22/24 92%	ss	3-4 6-6 N=10	19			8	FILL - Dark grayish brown (10YR4/2) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		624	
5A	20/24 83%	ss	2-3 3-6 N=6	18			10	Dark gray (10YR4/1) with 40% gray (10YR6/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand.		622	
6A	18/24 75%	ss	2-3 3-4 N=6	17			12			620	
7A	16/24 67%	ss	1-2 3-4 N=5	20			14	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		618	
8A	22/24 92%	ss	2-2 5-5 N=7	20			16	Very dark gray (10YR3/1), moist, firm, silty CLAY with trace sand.		616	
9A	23/24 96%	ss	woh-2 3-3 N=5	18			18	Gray (10YR5/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		614	
10A	24/24 100%	ss	woh-woh 1-2	17			20	Gray (10YR5/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, sandy CLAY with trace gravel.		612	

NOTE(S): G216 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/13/2010
Finish: 10/13/2010
WEATHER: Partly cloudy, mild, windy (lo-60's)

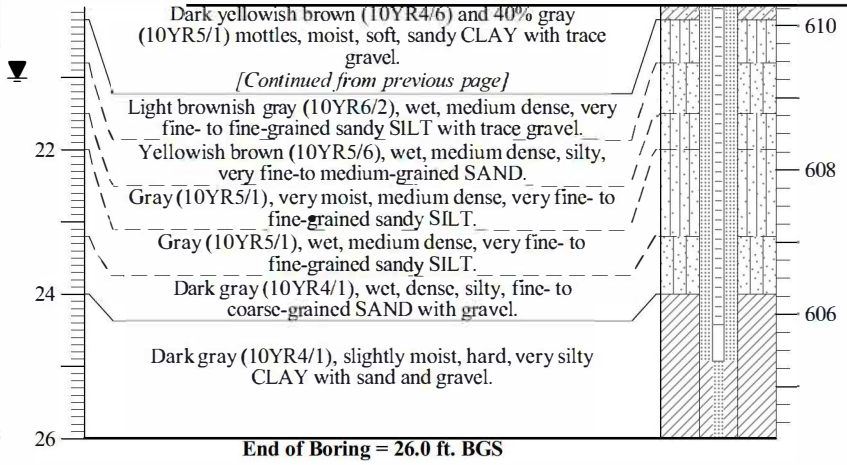
CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G216
Well ID: G216
Surface Elev: 630.28 ft. MSL
Completion: 26.00 ft. BGS
Station: 875,976.05N
2,515,968.53E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 21.00 - While drilling
▼ = Dry - Upon completion
▽ =

SAMPLE			TESTING			
Number	Recov / Total (in) / % Recovery	Type	Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) / Failure Type
11A	20/24 83%	ss	2-9 9-7 N=18	14		
12A	22/24 92%	ss	5-10 21-25 N=31	19		
12B				16		
13A	20/24 83%	ss	14-25 27-27 N=52	9		



End of Boring = 26.0 ft. BGS

NOTE(S): G216 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G217
Well ID: G217
Surface Elev: 630.67 ft. MSL
Completion: 26.00 ft. BGS
Station: 876,185.57N
2,515,963.02E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.00 - While drilling
▼ = 24.82 - Upon completion
▽ = 23.98 - 10/13/10

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	5-2 3-4 N=5	21			0			630	
							2	FILL - Brown (10YR4/3) with 10% dark gray (10YR4/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.			
2A	19/24 79%	ss	2-3 5-6 N=8	28						628	
							4				
3A	19/24 79%	ss	2-3 6-7 N=9	14				FILL - Dark gray (10YR4/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		626
							6	FILL - Brown (10YR4/3) with 10% dark gray (10YR4/1) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.			
4A	23/24 96%	ss	5-6 7-8 N=13	15						624	
							8	FILL - Dark grayish brown (10YR4/2) with 5% dark yellowish brown (10YR4/6) slightly moist, firm, clayey SILT with trace sand and gravel.			
5A	20/24 83%	ss	3-5 7-6 N=12	13						622	
							10	FILL - Very dark gray (10YR3/1), moist, firm, silty CLAY with trace sand and gravel.			
								Dark gray (10YR4/1), moist, firm, silty CLAY with trace sand and gravel.		620	
6A	19/24 79%	ss	3-3 4-5 N=7	27				Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, trace roots.			
							12				
7A	18/24 75%	ss	3-4 6-8 N=10	28				Dark grayish brown (10YR4/2) with 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY trace sand, trace roots.		618
							14				
8A	20/24 83%	ss	2-4 6-8 N=10	16				Dark gray (10YR4/1), moist, firm, silty CLAY with trace sand and gravel.		616	
							16				
9A	19/24 79%	ss	2-3 4-5 N=7	26				Dark gray (10YR4/1) with 10% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		614	
							18				
10A	19/24 79%	ss	1-2 2-3 N=4	18				Gray (10YR5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with sand and trace gravel.		612	
							20				

NOTE(S): G217 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G217
Well ID: G217
Surface Elev: 630.67 ft. MSL
Completion: 26.00 ft. BGS
Station: 876,185.57N
2,515,963.02E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.00 - While drilling
▼ = 24.82 - Upon completion
▽ = 23.98 - 10/13/10

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Gray (10YR5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with sand and trace gravel.		610	
11A	22/24 92%	ss	woh-woh 1-2	18				*[Continued from previous page]* Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with sand and trace gravel.			
							22				
12A	10/24 42%	ss	4-6 7-10 N=13	13				Yellowish brown (10 YR5/4), wet, medium dense, silty, very fine- to coarse-grained SAND with trace gravel.		608	
							24				
13A	22/24 92%	ss	8-18 17-17 N=35	12				Dark gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.		606	
							26	**End of Boring = 26.0 ft. BGS**			

NOTE(S): G217 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Partly cloudy, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G218
Well ID: G218
Surface Elev: 630.64 ft. MSL
Completion: 26.00 ft. BGS
Station: 876,380.92N
2,515,962.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 24.00 - While drilling
▼ = 24.76 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	18/24 75%	ss	4-1 2-1 N=3	20			0	FILL - Brown (10YR4/3) with 15% dark gray (10YR4/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		630	
2A	22/24 92%	ss	2-2 3-5 N=5	20			2			628	
3A	19/24 79%	ss	2-3 4-8 N=7	17			4	FILL - Dark gray (10YR4/1) with 30% brown (10YR4/3) and 10% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand and gravel.		626	
4A	22/24 92%	ss	2-5 6-8 N=11	14			6			624	
5A	20/24 83%	ss	3-4 8-7 N=12	17			8	FILL - Brown (10YR5/3) with 10% dark gray (10YR4/1) mottles, slightly moist, firm, clayey SILT with trace sand and gravel.		622	
6A				19			10	Dark grayish brown (10YR4/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand.		620	
6B	19/24 79%	ss	2-2 3-5 N=5	25			12	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, firm, silty CLAY with trace sand, slight trace roots.		618	
7A	22/24 92%	ss	2-3 5-7 N=8	22			14	Dark gray (10YR4/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with trace sand.		616	
8A	18/24 75%	ss	2-3 4-5 N=7	19			16			614	
9A	24/24 100%	ss	2-2 2-4 N=4	19			18	Gray (10YR5/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		612	
10A	24/24 100%	ss	1-2 2-3 N=4	18			20				

NOTE(S): G218 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/12/2010
Finish: 10/12/2010
WEATHER: Partly cloudy, warm (lo-70's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: S. Simpson

BOREHOLE ID: G218
Well ID: G218
Surface Elev: 630.64 ft. MSL
Completion: 26.00 ft. BGS
Station: 876,380.92N
2,515,962.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 24.00 - While drilling
▼ = 24.76 - Upon completion
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	22/24 92%	ss	woh-woh woh-woh	16			22	Gray (10YR5/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, very soft, clayey, very fine- to coarse-grained SAND with trace gravel.		610	
12A	24/24 100%	ss	1-1 1-3 N=2	10				Yellowish brown, wet, loose, silty, very fine- to coarse-grained SAND with trace gravel.		608	
12B				16			24 ▼	Dark gray (10YR4/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and gravel.			
13A	24/24 100%	ss	1-5 9-13 N=14	20			▼	Gray (10YR5/1), wet, loose, silty, very fine- to coarse-grained SAND with trace gravel.		606	
13B				17			26	Dark gray (10YR4/1), slightly moist, very firm, very silty CLAY with sand and gravel.			

End of Boring = 26.0 ft. BGS

NOTE(S): G218 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/15/2010
Finish: 10/15/2010
WEATHER: Sunny (mid-50's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: R. Hasenyager

BOREHOLE ID: T202
Well ID: T202
Surface Elev: 626.22 ft. MSL
Completion: 18.00 ft. BGS
Station: 876,699.42N
2,514,895.01E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, 1L
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ = 15.42 - Upon completion
▽ =

SAMPLE			TESTING							
Number	Recov / Total (in) / % Recovery	Type	Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	6-4 5-7 N=9	27			0	FILL - Yellowish brown (10YR5/6), slightly moist, hard, silty CLAY with trace sand and gravel.		626	
2A	24/24 100%	ss	3-4 6-6 N=10	25			2	Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist, hard, silty CLAY with slight trace sand and gravel.		624	
2B				26			4	Yellowish brown (10YR5/8) with 35% gray (10YR5/1) and 15% very dark brown (10YR2/2) mottles, moist, hard, silty CLAY with trace sand and slight trace gravel.		622	
3A	22/24 92%	ss	2-4 5-6 N=9	22			6			620	
4A	23/24 96%	ss	1-2 3-3 N=5	21			8	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		618	
5A	23/24 96%	ss	1-1 3-2 N=4	22			10	Gray (10YR6/1) with 15% yellowish brown (10YR5/8) mottles, very moist, soft, silty CLAY with sand and slight trace gravel.		616	
6A	24/24 100%	ss	woh-1 3-3 N=4	23			12	Yellowish brown (10YR5/8) with 10% gray (10YR6/1) mottles, very moist, firm, silty CLAY with sand and trace gravel.		614	
6B				21							
7A	24/24 100%	ss	1-2 1-2 N=3	21			14	Gray (10YR6/1) with 10% brownish yellow (10YR6/6) mottles, very moist, soft, sandy CLAY with silt and slight trace gravel.		612	
7B				25							
8A	24/24 100%	ss	woh-2 1-8 N=3	17			▼	Gray (10YR5/1), wet, loose, very fine- to medium-grained SAND with trace gravel.			
9A	24/24 100%	ss	6-15 20-24 N=35	9			16	Gray (10YR6/1), moist, hard, very silty CLAY with sand and trace gravel.		610	
							18	**End of Boring = 18.0 ft. BGS**			

NOTE(S): T202 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 2/26/2008
Finish: 2/26/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G270
Well ID: G270
Surface Elev: 622.9 ft. MSL
Completion: 18.3 ft. BGS
Station: 874,801.92N
2,514,996.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.00 - While drilling
▼ = 5.62 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark grayish brown (10YR4/2), moist, firm, clayey SILT		622	
	20/24 83%	ss	2-2 2-4 N=4								
1A				24			2	Dark grayish brown (10YR4/2), moist, firm, silty CLAY			
2A	19/24 79%	ss	3-4 5-9 N=9	22		2.33 B		Dark grayish brown (10YR4/2) with 5% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand		620	
2B				20		5.04 Sh	4	Gray (10YR5/1) with 70% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand and gravel			
	20/24 83%	ss	14-5 7-8 N=12							618	
3A				17		2.52 Sh	▼ 6	Dark gray (10YR4/1) with 5% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
4A	24/24 100%	ss	8-6 7-5 N=13	21		1.24 BSh				616	
4B				21		1.20 B	8	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
	22/24 92%	ss	2-3 4-4 N=7							614	
5A				21		1.36 B	10	Gray (10YR5/1) with 60% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
6A	24/24 100%	ss	1-2 2-3 N=4	21		0.74 BSh				612	
								Gray (10YR5/1), moist, soft, sandy CLAY			
6B				24		0.78 B	12				
	17/24 71%	ss	2-2 2-3 N=4					Gray (10YR5/1), moist, soft, sandy CLAY, trace gravel		610	
7A				21							
8A				20			14	Gray (10YR5/1), moist, soft, fine- to coarse-grained SAND, trace gravel			
	19/24 79%	ss	1-3 5-6 N=8					Dark yellowish brown (10YR4/4), moist, soft, sandy CLAY		608	
8B				17		4.46 Sh	▼ 16	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand and gravel			
9A	24/24 100%	ss	6-8 30-35 N=38	20				Yellowish brown (10YR5/4), wet, soft, fine to coarse SAND		606	
9B				8			18	Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel			

End of Boring = 18.27 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 2/26/2008
Finish: 2/26/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G280
Well ID: G280
Surface Elev: 623.0 ft. MSL
Completion: 18.0 ft. BGS
Station: 875,045.11N
2,515,679.48E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.60 - While drilling
▼ = 4.34 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark grayish brown (10YR4/2), moist, firm, clayey SILT		622	
1A	24/24 100%	ss	5-3 4-4 N=7	23							
1B				26		2.33 B	2	Brown (10YR4/3) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY			
2A				30		1.28 BSh		Dark yellowish brown (10YR4/4), moist, firm, silty CLAY		620	
	24/24 100%	ss	3-4 4-6 N=8					Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY			
2B				25			4 ▼				
	19/24 79%	ss	3-4 6-6 N=10							618	
3A				14		3.10 Sh		Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand			
	22/24 92%	ss	9-11 10-8 N=21				6			616	
4A				18		1.67 BSh		Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
							8				
5A	19/24 79%	ss	2-2 4-4 N=6	20		1.47 B		Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, sand, trace gravel		614	
5B				21		1.28 B	10				
	22/24 92%	ss	2-3 3-3 N=6							612	
6A				20				Yellowish brown (10YR5/8) with 20% light gray (10YR6/1) mottles, moist, soft, sandy CLAY			
							12				
	23/24 96%	ss	3-14 23-21 N=37					Yellowish brown (10YR5/8), moist, soft, fine to coarse SAND, trace gravel Yellowish brown (10YR5/8), moist, firm, sandy CLAY, trace gravel		610	
7A				13							
							14	Yellowish brown (10YR5/4), moist, firm, clayey SILT, trace sand and gravel			
	23/24 96%	ss	12-17 24-26 N=41							608	
8A				9			16 ▼				
8B				15				Yellowish brown (10YR5/4), wet, soft, fine- to coarse-grained SAND, trace gravel			
9A	24/24 100%	ss	11-27 54-43 N=81	26						606	
								Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel			
9B				7							

End of Boring = 17.98 ft. BGS

NOTE(S):

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G200

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G200

~~State~~ Plant ~~Plane~~ Coordinate: X 877,930.6 Y 2,515,650.0 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/25/2008 Date Finished: 2/25/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

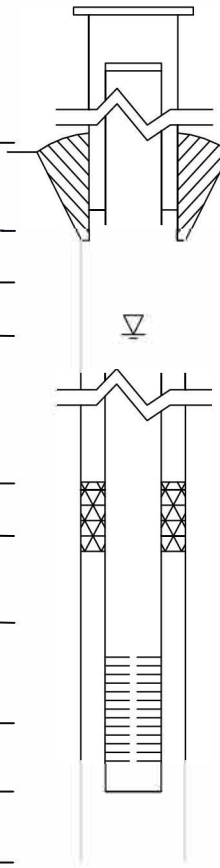
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Formation Sand
(if applicable)

Installation Method: Slough



	Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
	626.54	-2.34	Top of Protective Casing
	625.94	-1.74	Top of Riser Pipe
	624.20	0.00	Ground Surface
	620.70	3.50	Top of Annular Sealant
▽	621.45	2.75	Static Water Level (After Completion) 3/12/2008
	620.70	3.50	Top of Seal
	614.20	10.00	Top of Sand Pack
	612.01	12.19	Top of Screen
	607.22	16.98	Bottom of Screen
	606.84	17.36	Bottom of Well
	606.20	18.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.93
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	19.10
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: R201

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: R201

State Plane Coordinate: X 2,514,842.0 Y 877,925.3 (or) Latitude: 39 ° 4 ' 30.5 " Longitude: -89 ° 23 ' 52.3 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

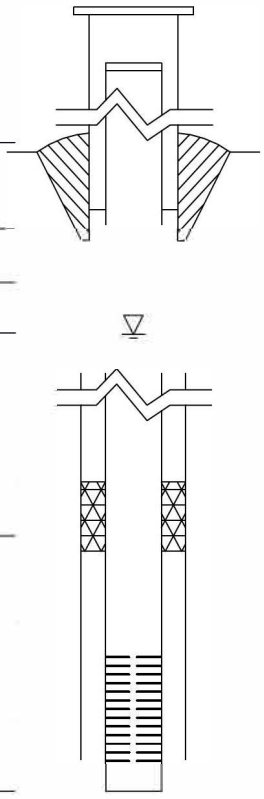
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Rhonald W. Hasenyager Date Started: 10/15/2010 Date Finished: 10/15/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 48 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	626.51	-2.49	Top of Protective Casing
	626.34	-2.32	Top of Riser Pipe
	624.02	0.00	Ground Surface
	621.52	2.50	Top of Annular Sealant
▽	618.70	5.32	Static Water Level (After Completion) 11/15/2010
	614.47	9.55	Top of Seal
	612.90	11.12	Top of Sand Pack
	611.75	12.27	Top of Screen
	607.36	16.66	Bottom of Screen
	606.80	17.22	Bottom of Well
	606.80	17.22	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:	(Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:	
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:	
Screen	SS304	SS316	PTFE	(PVC)	OTHER:	

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.59
Bottom of Screen to End Cap	(feet)	0.56
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	19.54
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G201

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G201

~~State~~ Plant ~~Plane~~ Coordinate: X 877,924.9 Y 2,514,849.5 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/25/2008 Date Finished: 2/25/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

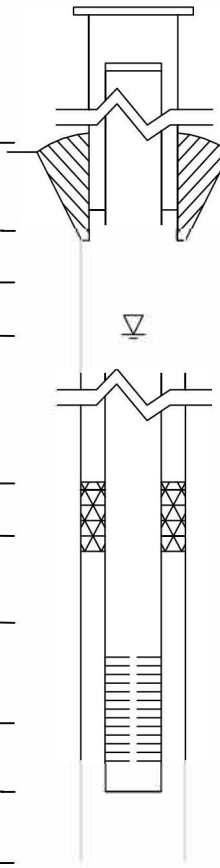
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.66	-3.76	Top of Protective Casing
627.12	-3.22	Top of Riser Pipe
623.90	0.00	Ground Surface
620.60	3.30	Top of Annular Sealant
621.73	2.17	Static Water Level (After Completion) 3/12/2008
620.60	3.30	Top of Seal
611.80	12.10	Top of Sand Pack
610.89	13.01	Top of Screen
606.10	17.80	Bottom of Screen
605.75	18.15	Bottom of Well
605.75	18.15	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.23
Bottom of Screen to End Cap	(feet)	0.35
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	21.37
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G205

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G205

~~State~~ Plant ~~Plane~~ Coordinate: X 875,550.2 Y 2,515,914.9 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/21/2008 Date Finished: 2/21/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

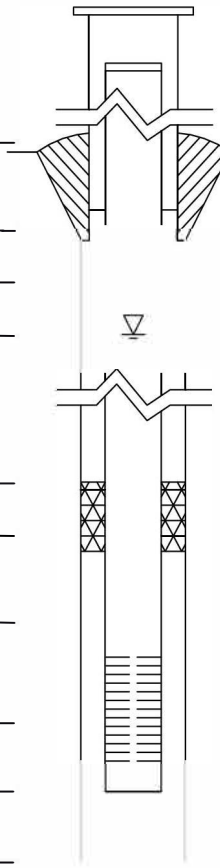
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Formation Sand
(if applicable)

Installation Method: Slough



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.87	-2.72	Top of Protective Casing
624.45	-2.30	Top of Riser Pipe
622.15	0.00	Ground Surface
619.95	2.20	Top of Annular Sealant
617.09	5.06	Static Water Level (After Completion) 3/12/2008
619.95	2.20	Top of Seal
613.35	8.80	Top of Sand Pack
612.11	10.04	Top of Screen
607.62	14.53	Bottom of Screen
607.08	15.07	Bottom of Well
606.15	16.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	12.34
Bottom of Screen to End Cap	(feet)	0.54
Screen Length (1st slot to last slot)	(feet)	4.49
Total Length of Casing	(feet)	17.37
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G206

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G206

State Plane Coordinate: X 2,514,669.2 Y 875,103.9 (or) Latitude: 39 ° 4 ' 2.6 " Longitude: -89 ° 23 ' 54.8 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

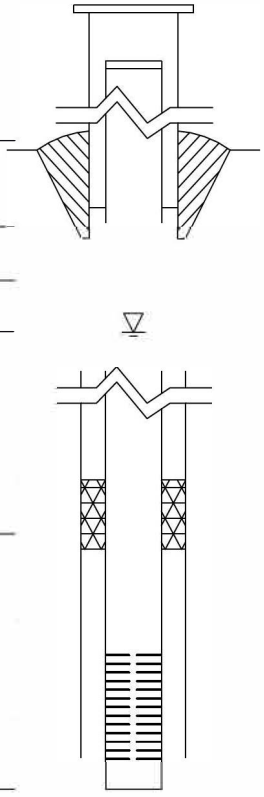
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/14/20 0 Date Finished: 10/14/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/15/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.07	-2.53	Top of Protective Casing
632.82	-2.28	Top of Riser Pipe
630.54	0.00	Ground Surface
627.84	2.70	Top of Annular Sealant
611.96	18.58	Static Water Level (After Completion) 11/15/2010
616.24	14.30	Top of Seal
615.04	15.50	Top of Sand Pack
613.03	17.51	Top of Screen
608.62	21.92	Bottom of Screen
608.12	22.42	Bottom of Well
606.54	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.79
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.41
Total Length of Casing	(feet)	24.70
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G207

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G207

State Plane Coordinate: X 2,514,837.9 Y 875,166.4 (or) Latitude: 39 ° 4 ' 3.2 " Longitude: -89 ° 23 ' 52.6 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/8/2010 Date Finished: 10/8/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/8/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

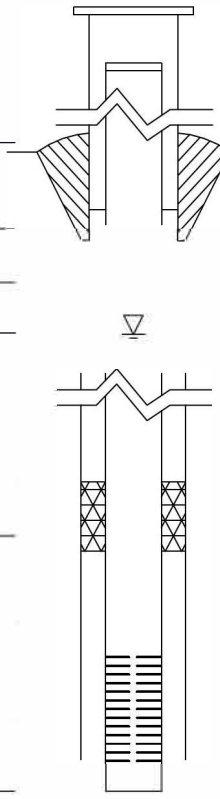
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.37	-2.76	Top of Protective Casing
633.21	-2.60	Top of Riser Pipe
630.61	0.00	Ground Surface
628.61	2.00	Top of Annular Sealant
612.86	17.75	Static Water Level (After Completion) 11/15/2010
614.76	15.85	Top of Seal
613.63	16.98	Top of Sand Pack
612.37	18.24	Top of Screen
607.84	22.77	Bottom of Screen
607.31	23.30	Bottom of Well
606.61	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.84
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	25.90
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G208

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G208

State Plane Coordinate: X 2,514,993.6 Y 875,231.5 (or) Latitude: 39 ° 4 ' 3.9 " Longitude: -89 ° 23 ' 50.6 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/7/2010 Date Finished: 10/7/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/8/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 9 min

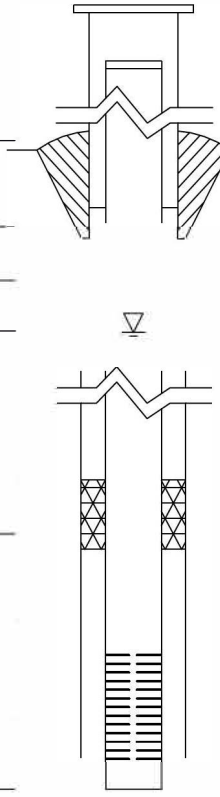
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	633.43	-2.86	Top of Protective Casing
	633.16	-2.59	Top of Riser Pipe
	630.57	0.00	Ground Surface
	627.77	2.80	Top of Annular Sealant
	614.76	15.81	Static Water Level (After Completion) 11/15/2010
	616.07	14.50	Top of Seal
	613.90	16.67	Top of Sand Pack
	613.04	17.53	Top of Screen
	608.51	22.06	Bottom of Screen
	607.97	22.60	Bottom of Well
	606.57	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.12
Bottom of Screen to End Cap	(feet)	0.54
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	25.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G209

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G209

State Plane Coordinate: X 2,515,149.6 Y 875,298.2 (or) Latitude: 39 ° 4 ' 4.5 " Longitude: -89 ° 23 ' 48.7 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/7/2010 Date Finished: 10/7/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/8/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

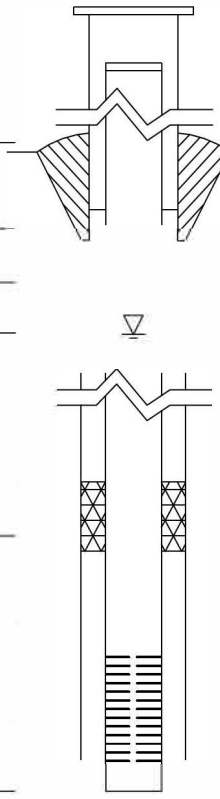
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.16	-2.59	Top of Protective Casing
632.91	-2.34	Top of Riser Pipe
630.57	0.00	Ground Surface
627.57	3.00	Top of Annular Sealant
615.52	15.05	Static Water Level (After Completion) 11/15/2010
616.07	14.50	Top of Seal
614.67	15.90	Top of Sand Pack
612.83	17.74	Top of Screen
608.29	22.28	Bottom of Screen
607.76	22.81	Bottom of Well
606.57	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.08
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	25.15
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G210

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G210

State Plane Coordinate: X 2,515,299.0 Y 875,359.7 (or) Latitude: 39 ° 4 ' 5.1 " Longitude: -89 ° 23 ' 46.8 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

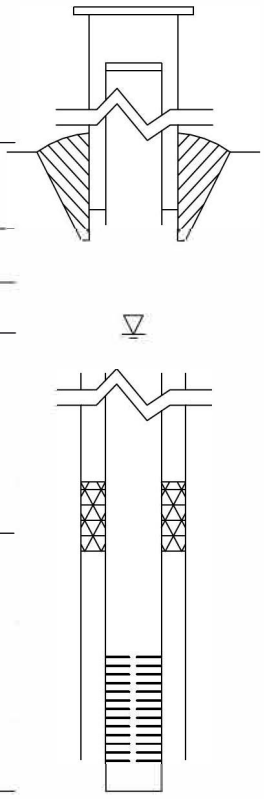
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/6/2010 Date Finished: 10/6/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/8/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 hrs

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.17	-2.69	Top of Protective Casing
632.99	-2.51	Top of Riser Pipe
630.48	0.00	Ground Surface
627.48	3.00	Top of Annular Sealant
615.38	15.10	Static Water Level (After Completion) 11/15/2010
614.03	16.45	Top of Seal
612.98	17.50	Top of Sand Pack
611.09	19.39	Top of Screen
606.55	23.93	Bottom of Screen
606.02	24.46	Bottom of Well
605.48	25.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304 SS316	PTFE	PVC	OTHER:	(Steel)
Riser Pipe Above W.T.	SS304 SS316	PTFE	(PVC)	OTHER:	
Riser Pipe Below W.T.	SS304 SS316	PTFE	(PVC)	OTHER:	
Screen	SS304 SS316	PTFE	(PVC)	OTHER:	

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	21.90
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	26.97
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G211

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G211

State Plane Coordinate: X 2,515,449.1 Y 875,424.5 (or) Latitude: 39 ° 4 ' 5.7 " Longitude: -89 ° 23 ' 44.9 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

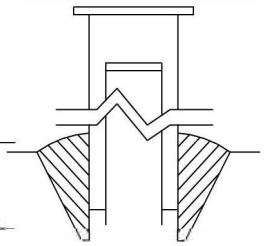
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/11/2010 Date Finished: 10/11/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/15/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
632.83	-2.52	Top of Protective Casing
632.64	-2.33	Top of Riser Pipe
630.31	0.00	Ground Surface
627.31	3.00	Top of Annular Sealant
616.17	14.14	Static Water Level (After Completion) 11/15/2010
616.01	14.30	Top of Seal
614.91	15.40	Top of Sand Pack
612.97	17.34	Top of Screen
608.43	21.88	Bottom of Screen
607.90	22.41	Bottom of Well
606.31	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.67
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	24.74
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G212

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G212

State Plane Coordinate: X 2,515,583.0 Y 875,486.5 (or) Latitude: 39 ° 4 ' 6.3 " Longitude: -89 ° 23 ' 43.1 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/11/2010 Date Finished: 10/11/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 17 min

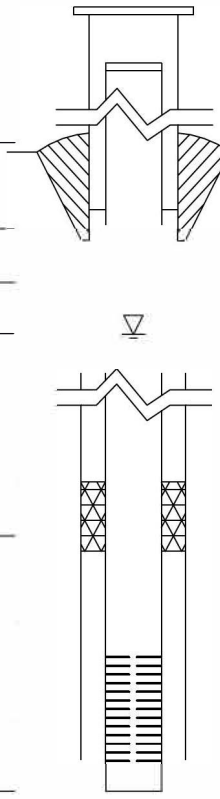
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
633.12	-2.53	Top of Protective Casing
632.89	-2.30	Top of Riser Pipe
630.59	0.00	Ground Surface
627.59	3.00	Top of Annular Sealant
616.10	14.49	Static Water Level (After Completion) 11/15/2010
616.89	13.70	Top of Seal
615.79	14.80	Top of Sand Pack
613.85	16.74	Top of Screen
609.30	21.29	Bottom of Screen
608.78	21.81	Bottom of Well
606.59	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.04
Bottom of Screen to End Cap	(feet)	0.52
Screen Length (1st slot to last slot)	(feet)	4.55
Total Length of Casing	(feet)	24.11
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G213

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G213

State Plane Coordinate: X 2,515,723.5 Y 875,544.4 (or) Latitude: 39 ° 4 ' 6.9 " Longitude: -89 ° 23 ' 41.4 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

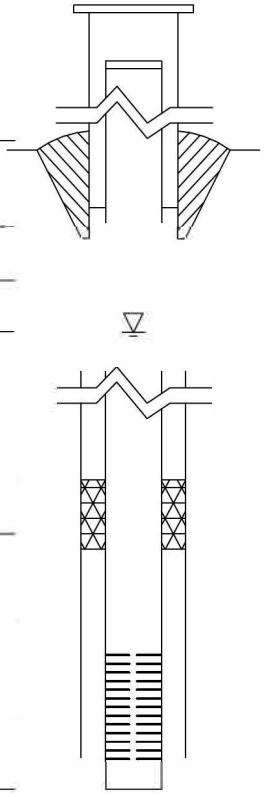
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/12/2010 Date Finished: 10/12/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.08	-2.74	Top of Protective Casing
632.81	-2.47	Top of Riser Pipe
630.34	0.00	Ground Surface
627.64	2.70	Top of Annular Sealant
615.01	15.33	Static Water Level (After Completion) 11/15/2010
616.54	13.80	Top of Seal
615.34	15.00	Top of Sand Pack
613.59	16.75	Top of Screen
609.05	21.29	Bottom of Screen
608.52	21.82	Bottom of Well
606.34	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.22
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	24.29
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G214

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G214

State Plane Coordinate: X 2,515,960.8 Y 875,668.0 (or) Latitude: 39 ° 4 ' 8.1 " Longitude: -89 ° 23 ' 38.3 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/14/20 0 Date Finished: 10/14/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 14 min

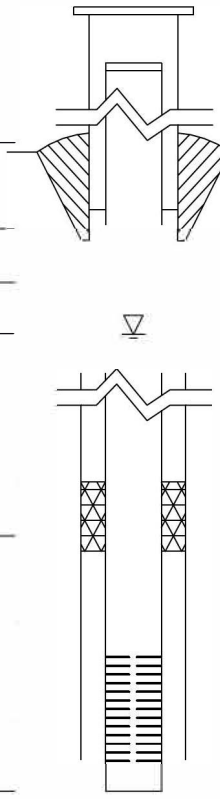
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
633.08	-2.69	Top of Protective Casing
632.85	-2.46	Top of Riser Pipe
630.39	0.00	Ground Surface
626.99	3.40	Top of Annular Sealant
609.48	20.91	Static Water Level (After Completion) 11/15/2010
615.39	15.00	Top of Seal
614.34	16.05	Top of Sand Pack
612.64	17.75	Top of Screen
608.25	22.14	Bottom of Screen
607.74	22.65	Bottom of Well
606.39	24.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.21
Bottom of Screen to End Cap	(feet)	0.51
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	25.11
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G215

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G215

State Plane Coordinate: X 2,515,971.6 Y 875,810.2 (or) Latitude: 39 ° 4 ' 9.5 " Longitude: -89 ° 23 ' 38.2 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

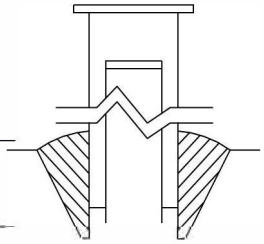
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/13/2010 Date Finished: 10/13/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 20 min

Type of Sand Pack: Quartz sand

Grain Size: 10 20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	633.30	-2.82	Top of Protective Casing
	633.06	-2.58	Top of Riser Pipe
	630.48	0.00	Ground Surface
	627.58	2.90	Top of Annular Sealant
▽	607.64	22.84	Static Water Level (After Completion) 11/15/2010
	614.08	16.40	Top of Seal
	612.98	17.50	Top of Sand Pack
	611.07	19.41	Top of Screen
	606.68	23.80	Bottom of Screen
	606.17	24.31	Bottom of Well
	606.17	24.31	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	21.99
Bottom of Screen to End Cap	(feet)	0.51
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	26.89
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G216

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G216

State Plane Coordinate: X 2,515,968.5 Y 875,976.1 (or) Latitude: 39 ° 4 ' 11.2 " Longitude: -89 ° 23 ' 38.2 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

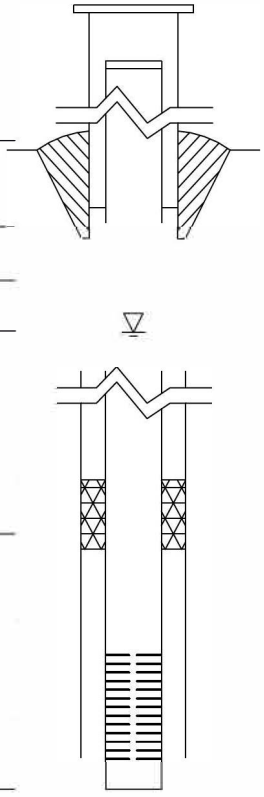
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/13/2010 Date Finished: 10/13/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	633.02	-2.74	Top of Protective Casing
	632.76	-2.48	Top of Riser Pipe
	630.28	0.00	Ground Surface
	627.78	2.50	Top of Annular Sealant
▽	607.52	22.76	Static Water Level (After Completion) 11/15/2010
	613.28	17.00	Top of Seal
	612.08	18.20	Top of Sand Pack
	610.24	20.04	Top of Screen
	605.86	24.42	Bottom of Screen
	605.35	24.93	Bottom of Well
	604.28	26.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	22.52
Bottom of Screen to End Cap	(feet)	0.51
Screen Length (1st slot to last slot)	(feet)	4.38
Total Length of Casing	(feet)	27.41
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G217

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G217

State Plane Coordinate: X 2,515,963.0 Y 876,185.6 (or) Latitude: 39 ° 4 ' 13.2 " Longitude: -89 ° 23 ' 38.3 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/12/2010 Date Finished: 10/12/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 11 min

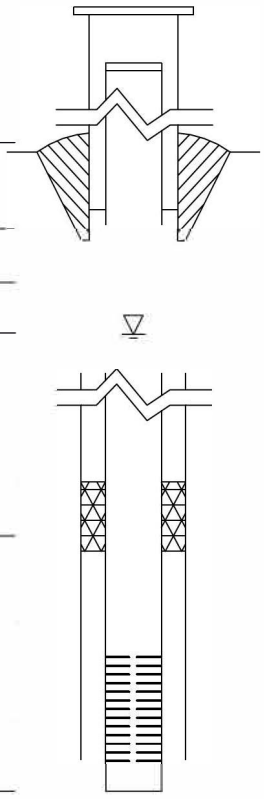
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.34	-2.67	Top of Protective Casing
633.10	-2.43	Top of Riser Pipe
630.67	0.00	Ground Surface
628.27	2.40	Top of Annular Sealant
609.28	21.39	Static Water Level (After Completion) 11/15/2010
612.82	17.85	Top of Seal
611.82	18.85	Top of Sand Pack
610.18	20.49	Top of Screen
605.79	24.88	Bottom of Screen
605.29	25.38	Bottom of Well
604.67	26.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	22.92
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	27.81
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G218

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G218

State Plane Coordinate: X 2,515,962.2 Y 876,380.9 (or) Latitude: 39 ° 4 ' 15.2 " Longitude: -89 ° 23 ' 38.2 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

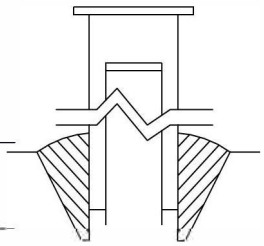
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/12/2010 Date Finished: 10/12/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 17 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.34	-2.70	Top of Protective Casing
633.11	-2.47	Top of Riser Pipe
630.64	0.00	Ground Surface
627.14	3.50	Top of Annular Sealant
609.89	20.75	Static Water Level (After Completion) 11/15/2010
613.14	17.50	Top of Seal
612.14	18.50	Top of Sand Pack
610.31	20.33	Top of Screen
605.87	24.77	Bottom of Screen
605.37	25.27	Bottom of Well
604.64	26.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	22.80
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.44
Total Length of Casing	(feet)	27.74
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G270

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G270

~~State~~ Plant ~~Plane~~ Coordinate: X 874,801.9 Y 2,514,996.8 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/26/2008 Date Finished: 2/26/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

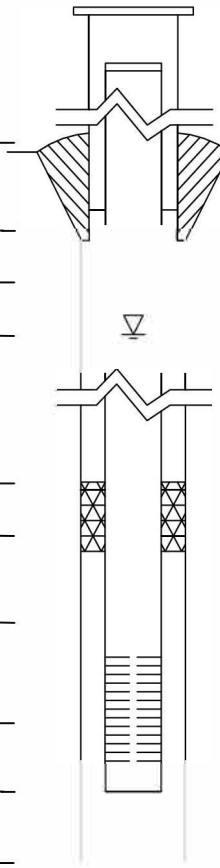
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.41	-3.49	Top of Protective Casing
625.97	-3.05	Top of Riser Pipe
622.92	0.00	Ground Surface
619.92	3.00	Top of Annular Sealant
617.30	5.62	Static Water Level (After Completion) 3/12/2008
619.92	3.00	Top of Seal
610.92	12.00	Top of Sand Pack
609.79	13.13	Top of Screen
605.00	17.92	Bottom of Screen
604.65	18.27	Bottom of Well
604.65	18.27	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.18
Bottom of Screen to End Cap	(feet)	0.35
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	21.32
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G280

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G280

~~State~~ Plant ~~Plane~~ Coordinate: X 875,045.1 Y 2,515,679.5 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/26/2008 Date Finished: 2/26/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

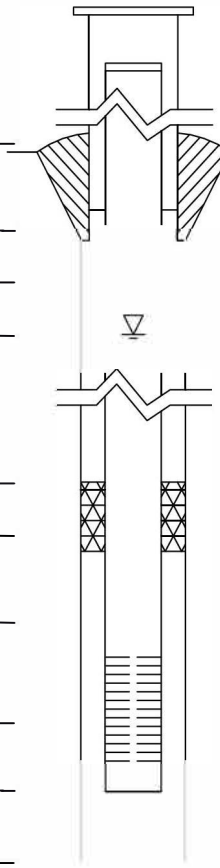
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.79	-2.84	Top of Protective Casing
625.30	-2.35	Top of Riser Pipe
622.95	0.00	Ground Surface
620.85	2.10	Top of Annular Sealant
618.61	4.34	Static Water Level (After Completion) 3/12/2008
620.85	2.10	Top of Seal
611.75	11.20	Top of Sand Pack
610.16	12.79	Top of Screen
605.32	17.63	Bottom of Screen
604.97	17.98	Bottom of Well
604.97	17.98	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.14
Bottom of Screen to End Cap	(feet)	0.35
Screen Length (1st slot to last slot)	(feet)	4.84
Total Length of Casing	(feet)	20.33
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: T202

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: T202

State Plane Coordinate: X 2,514,895.0 Y 876,699.4 (or) Latitude: 39 ° 4 ' 18.4 " Longitude: -89 ° 23 ' 51.7 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

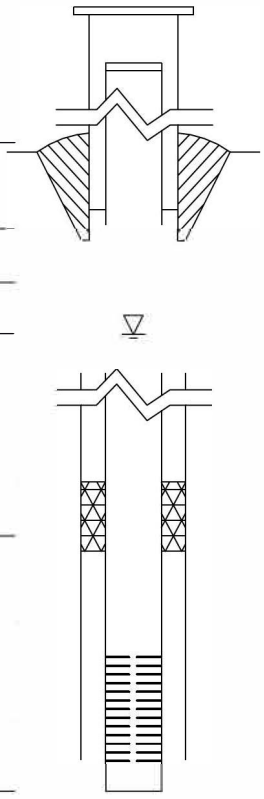
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 10/15/2010 Date Finished: 10/15/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
628.79	-2.57	Top of Protective Casing
628.63	-2.41	Top of Riser Pipe
626.22	0.00	Ground Surface
623.42	2.80	Top of Annular Sealant
613.72	12.50	Static Water Level (After Completion) 11/15/2010
616.50	9.72	Top of Seal
615.27	10.95	Top of Sand Pack
613.95	12.27	Top of Screen
609.57	16.65	Bottom of Screen
609.01	17.21	Bottom of Well
608.22	18.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304 SS316	PTFE	PVC	OTHER:	(Steel)
Riser Pipe Above W.T.	SS304 SS316	PTFE	(PVC)	OTHER:	
Riser Pipe Below W.T.	SS304 SS316	PTFE	(PVC)	OTHER:	
Screen	SS304 SS316	PTFE	(PVC)	OTHER:	

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.68
Bottom of Screen to End Cap	(feet)	0.56
Screen Length (1st slot to last slot)	(feet)	4.38
Total Length of Casing	(feet)	19.62
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A4

LANDFILL

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/2/2010
Finish: 2/2/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G101
Well ID: G101
Surface Elev: 625.27 ft. MSL
Completion: 21.92 ft. BGS
Station: 876,551.76N
2,514,214.31E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.50 - While drilling
▼ = 12.38 - Upon Completion
▽ = 7.31 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	TOPSOIL - Brown (10YR5/3), moist, soft, silty CLAY with slight trace sand and gravel, roots.			
1A	18/24 75%	ss	1-1 2-3 N=3	24			1	Dark grayish brown (10YR4/2), moist, soft, silty CLAY with slight trace sand, trace roots.		624	
2A	18/24 75%	ss	1-3 3-5 N=6	30			2	Dark grayish brown (10YR4/2) with 15% yellowish brown (10YR5/4) mottles, moist, medium, silty CLAY, slight trace roots.			
							3	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/4) mottles, moist, medium, silty CLAY, slight trace roots.		622	
3A	19/24 79%	ss	2-3 4-4 N=7	26			4	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY, slight trace roots.		620	
4A	19/24 79%	ss	1-3 4-3 N=7	21			6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		618	
5A	22/24 92%	ss	1-3 3-4 N=6	23			8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
6A	20/24 83%	ss	1-2 2-3 N=4	24			10	Gray (10YR6/1) with 35% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		614	
7A	22/24 92%	ss	1-2 3-2 N=5	17			12	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, very moist, medium, silty, sandy CLAY with trace gravel.		612	
8A				15			14	Brown (10YR5/3), very moist, medium, silty, clayey, very fine- to coarse-grained SAND with slight trace gravel.			
8B	14/24 58%	ss	1-2 5-8 N=7	13			16	Brown (10YR5/3), very moist, loose, silty, very fine- to coarse-grained SAND with slight trace gravel.		610	
9A	16/24 67%	ss	2-5 15-25 N=20	16			18	Brown (10YR5/3), very moist, medium dense, silty, very fine- to coarse-grained SAND with slight trace gravel.		608	
10A	17/24 71%	ss	19-20 22-18 N=42	14			20	Brown (10YR5/3), very moist, dense, silty, very fine- to coarse-grained SAND with slight trace gravel.		606	
10B				8							

NOTE(S): G101 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/2/2010
Finish: 2/2/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G101
Well ID: G101
Surface Elev: 625.27 ft. MSL
Completion: 21.92 ft. BGS
Station: 876,551.76N
2,514,214.31E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.50 - While drilling
▼ = 12.38 - Upon Completion
▽ = 7.31 - 3/1/2010

SAMPLE			TESTING							
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	16/23 *70%*	ss	*2-16* *42-60/5"* N=58	8				Brown (10YR5/3), slightly moist, hard, clayey SILT with slight trace sand and gravel.			
								Dark gray (10YR4/1), slightly moist, hard, clayey SILT with slight trace sand and slight trace gravel.		604	
								End of Boring = 21.9 ft. BGS			

NOTE(S): G101 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 4/28/2006
Finish: 4/28/2006
WEATHER: Partly cloudy, mild (mid-60's)

CONTRACTOR: TSC
Rig mfg/model: CME-650 Track Drill
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-03a
Well ID: G102 (MW3S)
Surface Elev: 625.70 ft. MSL
Completion: 17.15 ft. BGS
Station: 876,554.77N
2,514,531.48E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 7.03 - 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	SS	2-2 4-6 N=6	17		2.07 SP		soil ery dark grayish brown (10YR3/2), lean CLAY			
1B				20				Grayish brown (10YR5/2), lean CLAY, trace sand			
1C				26		3.30 B	2	Yellowish brown (10YR5/6), lean CLAY, trace sand		624	
2A	17/24 71%	SS	2-3 4-5 N=7	25		3.05 B		Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, lean CLAY, trace sand		622	
3A	20/24 83%	SS	2-3 3-5 N=6	16		1.96 B	4	loess Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, sandy SILT, trace gravel		620	
4A	24/24 100%	SS	4-3 5-6 N=8	21		2.27 B	6	▼ Yellowish brown (10YR5/6) with 50% gray (N5/1) mottles, lean CLAY, trace sand and gravel		618	
5A	21/24 88%	SS	1-3 3-4 N=6	20		2.18 B	8	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel		616	
5B				19			10	Dark gray (10YR4/1), sandy CLAY, trace gravel			
6A	18/24 75%	SS	1-2 2-4 N=4	24		0.87 B		Gray (10YR6/1) with 50% yellowish brown (10YR5/8) mottles, lean CLAY, little sand, trace gravel		614	
7A	23/24 96%	SH SS	3-2 2-4 N=4	19			12				
7B	16/24 67%			12						612	
8A	23/24 96%	SS	3-12 29-50 N=41	13			14	▼ hagarstown Yellowish brown (10YR5/8), silty, fine SAND, little medium sand, trace gravel, wet			
8B				13				Yellowish brown (10YR5/8), silty, fine SAND, little clay, wet		610	
8C				12			16	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel			
9A	12/12 100%	SS	8-82	10		6.98 B		Yellowish brown (10YR5/6), silty SAND, trace gravel, wet			
								Yellowish brown (10YR5/4), clayey SILT, trace sand and gravel			

End of Boring = 17.15 ft. BGS

NOTE(S): G102 (MW03S) installed in blind-drilled borehole within 10 ft of SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: Start: 2/15/2010
Finish: 2/15/2010
WEATHER: Cold, snowy (lo-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: Driller: T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G103
Well ID: G103
Surface Elev: 627.94 ft. MSL
Completion: 18.03 ft. BGS
Station: 876,199.48N
2,514,501.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 16.99 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	5-4 5-7 N=9	16			0			628	
							2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		626	
2A	16/24 67%	ss	3-4 6-7 N=10	25							
							4			624	
3A	17/24 71%	ss	3-5 7-8 N=12	21				Grayish brown (10YR5/2) with 25% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand, slight trace roots.		
							6			622	
4A	16/24 67%	ss	2-3 5-6 N=8	24				Grayish brown (10YR5/2) with 25% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		
							8			620	
5A	24/24 100%	ss	3-4 4-4 N=8	22				Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		
							10			618	
6A	20/24 83%	ss	1-1 3-3 N=4	23							
							12			616	
7A	22/24 92%	ss	1-2 2-4 N=4	26				Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, soft, medium, silty CLAY with trace sand and slight trace gravel.		
							14			614	
8A	20/24 83%	ss	1-2 3-3 N=5	22							
							16			612	
9A	22/24 92%	ss	1-10 21-33 N=31	14			▽	Brown (10YR5/3) with 15% gray (10YR6/1) mottles, very moist, medium dense, silty, very fine- to medium-grained SAND.			
9B				10				Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.			
							18			610	

End of Boring = 18.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 10/8/2010
Finish: 10/8/2010
WEATHER: Sunny, mild

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA (blind drill)
FIELD STAFF: **Driller:** D. Mahurin
Helper: J. Litsch/D. Smail
Eng/Geo: R. Hasenyager

BOREHOLE ID: R104
Well ID: R104
Surface Elev: 629.03 ft. MSL
Completion: 19.85 ft. BGS
Station: 875,857.80N
2,514,503.41E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0			628	
							2	FILL - Brown (10YR5/3) with 5% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with slight trace sand and gravel.		626	
							4	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand, slight trace roots.		624	
							6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		622	
							8			620	
							10			618	
							12	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		616	
							14	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		614	
							16	Gray (10YR6/1), moist, very soft, clayey, very fine- to coarse-grained SAND with trace gravel.		612	
							18	Brown (10YR5/3), slightly moist, hard, very silty CLAY with trace sand and gravel.		610	
								Gray (10YR4/1), slightly moist, hard, very silty CLAY with sand and gravel.			

End of Boring = 19.85 ft. BGS

NOTE(S): R104 blind drilled in borehole approximately 8 ft. north of G104. Lithology taken from G104.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/15/2010
Finish: 2/15/2010
WEATHER: Overcast, cold, windy (lo-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G104
Well ID: G104
Surface Elev: 627.96 ft. MSL
Completion: 20.00 ft. BGS
Station: 875,849.26N
2,514,504.98E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 15.40 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 *67%*	ss	*9-11* *12-14* N=23	16			2	FILL - Brown (10YR5/3) with 5% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with slight trace sand and gravel.		626	
2A	20/24 *83%*	ss	*3-5* *9-12* N=14	21			4			624	
3A	19/24 *79%*	ss	*3-6* *8-9* N=14	21			6	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand, slight trace roots.		622	
4A	17/24 *71%*	ss	*2-3* *4-7* N=7	25			8			620	
5A	22/24 *92%*	ss	*1-2* *5-8* N=7	24			10	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		618	
6A	18/24 *75%*	ss	*1-2* *3-5* N=5	21			12			616	
7A	23/24 *96%*	ss	*woh-2* *3-4* N=5	23			14	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		614	
8A	22/24 *92%*	ss	*1-3* *3-3* N=6	24			▽ 16	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.		612	
9A				16				Gray (10YR6/1), moist, very soft, clayey, very fine- to coarse-grained SAND with trace gravel.			
9B	17/24 *71%*	ss	*woh-6* *27-40* N=33	13			18	Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.		610	
10A	22/24 *92%*	ss	*10-24* *44-66* N=68	7			20	Gray (10YR4/1), slightly moist, hard, clayey SILT with sand and gravel.		608	

End of Boring = 20.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/16/2010
Finish: 2/16/2010
WEATHER: Sunny, cold, windy (mid-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G105
Well ID: G105
Surface Elev: 626.86 ft. MSL
Completion: 19.83 ft. BGS
Station: 875,499.70N
2,514,509.15E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 16.08 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	18/24 75%	ss	4-4 4-7 N=8	20			0			626	
2A	19/24 79%	ss	2-4 6-10 N=10	19			2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, medium, silty CLAY with slight trace sand and gravel.		624	
3A	19/24 79%	ss	2-4 5-6 N=9	29			4	Grayish brown (10YR5/2) with 40% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY, slight trace roots.		622	
4A	20/24 83%	ss	1-4 4-5 N=8	29			6	Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		620	
5A	22/24 92%	ss	1-3 3-3 N=6	20			8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		618	
6A	24/24 100%	ss	1-2 3-4 N=5	25			10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
7A	24/24 100%	ss	1-2 3-5 N=5	22			12			614	
8A	19/24 79%	ss	1-2 2-2 N=4	18			14	Gray (10YR6/1) with 15% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand and gravel.		612	
9A				18			▽ 16	Gray (10YR5/1), very moist to wet, loose, silty, fine- to coarse-grained SAND with slight trace gravel.		610	
9B	18/24 75%	ss	1-2 8-10 N=10	14				Brown (10YR5/3), very moist to wet, loose, silty, very fine- to coarse-grained SAND with slight trace gravel.			
10A	19/22 86%	ss	11-40 53-60/4" N=93	7			18	Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.		608	
								Gray (10YR4/1), slightly moist, hard, clayey SILT with sand and gravel.			

End of Boring = 19.8 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/16/2010
Finish: 2/16/2010
WEATHER: Overcast, cold, windy (mid-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G106
Well ID: G106
Surface Elev: 625.96 ft. MSL
Completion: 18.00 ft. BGS
Station: 875,149.76N
2,514,512.79E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 12.62 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	17/24 71%	ss	7-8 13-16 N=21	18			0			626	
							2	FILL - Brown (10YR5/3) with 15% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		624	
2A	16/24 67%	ss	2-4 5-7 N=9	16							
							4			622	
3A	17/24 71%	ss	2-4 6-7 N=10	21				Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with slight trace sand, slight trace roots.			
							6			620	
4A	20/24 83%	ss	2-3 5-6 N=8	24				Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, medium, silty CLAY with slight trace sand.			
							8			618	
5A	22/24 92%	ss	1-3 3-5 N=6	21				Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.			
							10			616	
6A	22/24 92%	ss	1-2 4-4 N=6	24							
							12			614	
7A	23/24 96%	ss	1-3 4-4 N=7	22				Yellowish brown (10YR5/6) with 10% gray (10YR6/1) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.			
							14			612	
8A	19/24 79%	ss	1-4 7-7 N=11	20				Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with trace sand.			
8B				14				Brown (10YR5/3), moist, medium dense, clayey, very fine- to medium-grained SAND with slight trace gravel.			
							16	Yellowish brown (10YR5/6) with 5% gray (10YR6/1) mottles, moist, medium, clayey SILT with trace sand and gravel.		610	
9A	23/24 96%	ss	7-15 22-22 N=37	8				Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.			
								Gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and gravel.			
							18			608	

End of Boring = 18.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/17/2010
Finish: 2/17/2010
WEATHER: Overcast, cold, windy (mid-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G107
Well ID: G107
Surface Elev: 627.11 ft. MSL
Completion: 20.00 ft. BGS
Station: 874,994.33N
2,514,358.25E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.80 - While drilling
▼ = 11.56 - Upon Completion
▽ = 10.40 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/18 0%	BD					0	GRAVEL FILL		626	
1A	5/6 83%	SS	3	12			2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with trace sand and slight and gravel.		624	
2A	14/24 58%	SS	3-3 6-8 N=9	17			4			622	
3A	16/24 67%	SS	3-5 5-7 N=10	20			6	Grayish brown (10YR5/2) with 30% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		620	
4A	18/24 75%	SS	2-3 6-7 N=9	27			8			618	
5A	22/24 92%	SS	2-3 4-5 N=7	18			10 ▽	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
6A	22/24 92%	SS	1-3 3-4 N=6	23			12 ▼			614	
7A	24/24 100%	SS	1-2 3-4 N=5	27			14	Gray (10YR6/1) with 35% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		612	
8A	2/24 8%	SS	1-3 2-3 N=5	23			16	Brown (10YR5/3), very moist to wet, very loose, clayey, very fine- to coarse-grained SAND.		610	
9A	20/24 83%	SS	woh-3 8-12 N=11	22			16 ▼				
9B				10			18	Brown (10YR5/3), slightly moist, stiff, clayey SILT with trace sand and gravel.		608	
10A	20/24 83%	SS	8-25 26-58 N=51	11			18	Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.			
							20	Gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and gravel.			

End of Boring = 20.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/12/2010
Finish: 2/12/2010
WEATHER: Overcast, cold ~25F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G108
Well ID: G108
Surface Elev: 625.58 ft. MSL
Completion: 20.00 ft. BGS
Station: 874,948.81N
2,514,248.25E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.50 - While drilling
▼ = 19.00 - Upon completion
▽ = 8.93 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	24-25 13-13 N=38	16			0	FILL - Grayish brown (10YR5/2) with 10% yellowish brown (10YR5/6) mottles, moist, hard, silty CLAY with slight trace gravel.		624	
2A	13/24 54%	ss	4-5 8-11 N=13	26			2	FILL - Grayish brown (10YR5/2) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		622	
3A	20/24 83%	ss	2-2 5-7 N=7	28			4	Grayish brown (10YR5/2) with 25% yellowish brown (10YR5/8) and 5% very dark brown (10YR2/2) mottles, moist, medium, clayey SILT with trace sand and slight trace gravel.		620	
4A	24/24 100%	ss	2-3 5-6 N=8	18			6			618	
5A	23/24 96%	ss	1-2 3-4 N=5	20			8 ▽	Gray (10YR5/1) with 10% brownish yellow (10YR6/8) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
6A	24/24 100%	ss	1-3 3-5 N=6	19			10			614	
7A	19/24 79%	ss	1-1 1-2 N=2	19			12	Grayish brown (10YR5/2) with brownish yellow (10YR6/8) mottles, moist, soft, sandy CLAY with trace gravel.		612	
8A	23/24 96%	ss	2-4 7-10 N=11	19			14 ▼	Brownish yellow (10YR6/8), very moist, soft, sandy CLAY with trace gravel.		610	
8B				13				Brownish yellow (10YR6/8), very moist, soft, sandy SILT with trace gravel.			
9A	22/24 92%	ss	10-24 25-10 N=49	11			16	Brownish yellow (10YR6/6), wet, medium, SILT.		608	
9B				8				Light yellowish brown (10YR6/4) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, clayey SILT with trace sand and gravel.			
10A	24/24 100%	ss	10-25 40-40 N=65	10			18 ▼	Gray (10YR5/1), slightly moist, hard, SILT with gravel.		606	
								Gray (10YR5/1), wet, hard, SILT with sand and gravel.			
							20	Gray (10YR5/1), very moist, hard, SILT with gravel.			

End of Boring = 20.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/11/2010
Finish: 2/11/2010
WEATHER: Sunny, cold ~32F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G109
Well ID: G109
Surface Elev: 624.79 ft. MSL
Completion: 18.00 ft. BGS
Station: 874,970.10N
2,514,137.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.20 - While drilling
▼ = 11.50 - Upon completion
▽ = 8.85 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	6-7 7-8 N=14	22			0	FILL - Grayish brown (10YR5/2) with 40% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace gravel.		624	
2A	19/24 79%	ss	3-5 5-6 N=10	27			2			622	
3A	20/24 83%	ss	2-5 6-8 N=11	24			4	Light yellowish brown (10YR6/4) with 50% brownish yellow (10YR6/8) mottles, moist, medium, silty CLAY, slight trace roots.		620	
4A	24/24 100%	ss	2-4 5-6 N=9	19			6	Light brownish gray (10YR6/2) with 10% brownish yellow (10YR6/6) mottles, moist, medium, silty CLAY with slight trace sand and gravel.		618	
5A	22/24 92%	ss	2-3 4-5 N=7	20			8 ▽			616	
6A	24/24 100%	ss	1-3 3-4 N=6	19			10	Light brownish gray (10YR6/2) with 10% brownish yellow (10YR6/6) and 2% very dark gray (10YR3/1) mottles, moist, medium, silty CLAY with slight trace sand and gravel.		614	
7A	23/24 96%	ss	1-1 2-2 N=3	19			12 ▼	Light brownish gray (10YR6/2) with 30% brownish yellow (10YR6/8) mottles, moist, medium, sandy CLAY with slight trace gravel.		612	
8A	22/24 92%	ss	8-15 15-21 N=30	14			14 ▼	Brownish yellow (10YR6/6), wet, dense, silty SAND with trace gravel.		610	
9A	24/24 100%	ss	12-29 44-45 N=73	7			16	Brownish yellow (10YR6/8), wet, dense, SAND with trace gravel.		608	
							18	Grayish brown (10YR5/2), slightly moist, hard, gravelly SILT with sand.			

End of Boring = 18.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/11/2010
Finish: 2/11/2010
WEATHER: Sunny, cold 10-20F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G110
Well ID: G110
Surface Elev: 624.81 ft. MSL
Completion: 18.00 ft. BGS
Station: 875,015.42N
2,514,057.73E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.00 - While drilling
▼ =
▽ = 9.50 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	8-6 6-8 N=12	17			0			624	
							2	FILL - Yellowish brown (10YR5/6) with 20% light brownish gray (10YR6/2) mottles, moist, stiff, silty CLAY with slight trace sand.			
2A	14/24 58%	ss	2-4 5-7 N=9	25						622	
							4				
3A	22/24 92%	ss	1-4 5-9 N=9	22						620	
							6	Grayish brown (10YR5/2) with 20% yellowish brown (10YR5/6) and 5% very dark brown (10YR2/2) mottles, moist, medium, silty CLAY.			
4A	24/24 100%	ss	3-6 8-9 N=14	18						618	
							8				
5A	24/24 100%	ss	1-3 4-6 N=7	21			▽	Grayish brown (10YR5/2) with 20% yellowish brown (10YR5/6) and 5% very dark brown (10YR2/2) mottles, moist, medium, silty CLAY with slight trace sand and gravel.		616	
							10				
6A	24/24 100%	ss	2-4 4-6 N=8	21				Light brownish gray (10YR6/2) with 30% brownish yellow (10YR6/8) mottles, moist, medium, clayey SILT with trace sand and gravel.		614	
							12				
7A	24/24 100%	ss	1-2 3-3 N=5	22				Light brownish gray (10YR6/2) with 30% brownish yellow (10YR6/8) mottles, very moist, medium, sandy CLAY with trace gravel.		612	
							14	Light brownish gray (10YR6/2) with 30% brownish yellow (10YR6/8) mottles, moist, soft, clayey SILT with trace sand and slight trace gravel.			
8A	19/24 79%	ss	1-2 2-1 N=4	24			▼			610	
							16	Gray (10YR6/1) with 30% brownish yellow (10YR6/8) mottles, wet, soft, sandy CLAY.			
9A	24/24 100%	ss	7-26 49-60 N=75	6				Grayish brown (10YR5/2), slightly moist, hard, clayey SILT with trace sand and gravel.		608	
							18				

End of Boring = 18.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/10/2010
Finish: 2/11/2010
WEATHER: Sunny, breezy ~25F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G111
Well ID: G111
Surface Elev: 625.28 ft. MSL
Completion: 18.00 ft. BGS
Station: 875,058.70N
2,513,981.72E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.50 - While drilling
▼ =
▽ = 10.50 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 *83%*	ss	*7-7* *6-9* N=13	18			0			625	
							2	FILL - Grayish brown (10YR5/2) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		624	
2A	13/24 *54%*	ss	*3-5* *7-8* N=12	20							
							4			622	
3A	18/24 *75%*	ss	*2-4* *6-8* N=10	20							
							6	Grayish brown (10YR5/2) with 20% yellowish brown (10YR5/6) and 5% dark brown (10YR3/3) mottles, moist, medium, clayey SILT with slight trace sand, slight trace roots.		620	
4A	16/24 *67%*	ss	*4-12* *20-17* N=32	18							
							8	Grayish brown (10YR5/2) with 5% yellowish brown (10YR5/6) mottles, moist, medium, clayey SILT with trace sand.		618	
5A	22/24 *92%*	ss	*2-3* *4-5* N=7	21							
							10 ▽			616	
6A	24/24 *100%*	ss	*2-3* *6-6* N=9	23							
							12	Grayish brown (10YR5/2) with 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand.		614	
7A	24/24 *100%*	ss	*1-4* *5-6* N=9	20							
							14 ▼	Grayish brown (10YR5/2) with 30% yellowish brown (10YR5/8) mottles, moist, stiff, clayey SILT with trace sand and gravel.		612	
8A	24/24 *100%*	ss	*1-2* *2-2* N=4	17				Yellowish brown (10YR5/8), wet, soft, clayey SAND with trace gravel.		610	
							16				
9A	18/18 *100%*	ss	*12-50* *66* N=116	7				Grayish brown (10YR5/2) with 20% brownish yellow (10YR6/6) mottles, slightly moist, hard, clayey SILT with gravel.		608	
	0/6 *0%*	BD					18	**End of Boring = 18.0 ft. BGS**			

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/9/2010
Finish: 2/9/2010
WEATHER: Cold, snow, windy (lo-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G119
Well ID: G119
Surface Elev: 626.57 ft. MSL
Completion: 20.10 ft. BGS
Station: 875,675.04N
2,513,907.73E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 11.26 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss	3-2 3-3 N=5	21			0			626	
2A	16/24 67%	ss	2-4 5-5 N=9	20			2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		624	
3A	10/24 42%	ss	2-5 5-6 N=10	25			4			622	
4A	17/24 71%	ss	2-5 4-5 N=9	18			6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand.		620	
5A	20/24 83%	ss	2-3 4-5 N=7	19			8			618	
6A	19/24 79%	ss	1-3 4-6 N=7	21			10 ▽	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
7A	20/24 83%	ss	1-3 3-5 N=6	20			12	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and gravel.		614	
8A	18/24 75%	ss	1-2 2-2 N=4	18			14	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, soft, sandy CLAY with slight trace gravel.		612	
9A	22/24 92%	ss	3-9 13-16 N=22	13			16	Brown (10YR5/3), moist, medium, silty CLAY with trace sand and slight trace gravel.		610	
9B				12				Brown (10YR5/3), moist, medium dense, silty, very fine-grained SAND.			
10A	17/24 71%	ss	6-25 33-39 N=58	8			18	Brown (10YR5/3), slightly moist, hard, clayey SILT with trace sand and gravel.		608	
							20	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and gravel.			

End of Boring = 20.1 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/8/2010
Finish: 2/8/2010
WEATHER: Cold, snow, windy (mid-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G120
Well ID: G120
Surface Elev: 627.21 ft. MSL
Completion: 20.00 ft. BGS
Station: 875,854.43N
2,513,905.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 13.85 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	3-3 4-5 N=7	16			0			626	
2A	19/24 79%	ss	3-4 7-9 N=11	20			2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		624	
3A	16/24 67%	ss	2-3 4-5 N=7	26			4				
4A	17/24 71%	ss	3-5 6-6 N=11	24			6	Gray (10YR5/1) with15% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		622	
5A	14/24 58%	ss	2-4 4-6 N=8	22			8	Gray (10YR5/1) with15% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel, slight trace roots.		620	
6A	22/24 92%	ss	1-3 3-4 N=6	23			10	Gray (10YR5/1) with15% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with slight trace sand.		618	
7A	22/24 92%	ss	1-2 3-5 N=5	21			12	Gray (10YR5/1) with brownish yellow (10YR6/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
8A	19/24 79%	ss	woh-2 3-3 N=5	25			▽ 14	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		614	
9A	24/24 100%	ss	woh-3 12-21 N=15	21			16	Brown (10YR5/3), very moist, soft, clayey SAND with slight trace gravel.		612	
9B				10				Brown (10YR5/3), slightly moist, stiff, clayey SILT with trace sand and slight trace gravel.		610	
10A	24/24 100%	ss	13-36 46-70 N=82	7			18	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and gravel.		608	
							20				

End of Boring = 20.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/4/2010
Finish: 2/4/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G121
Well ID: G121
Surface Elev: 627.94 ft. MSL
Completion: 22.00 ft. BGS
Station: 875,964.59N
2,513,904.35E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 14.44 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	22/24 92%	ss	4-4 7-8 N=11	15			2	FILL - Brown (10YR4/3) with 10% gray (10YR5/1) and 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		626	
2A	20/24 83%	ss	3-5 8-12 N=13	16			4			624	
3A	18/24 75%	ss	1-4 5-6 N=9	27			6	Dark yellowish brown (10YR4/4), moist, medium, silty CLAY with slight trace sand.		622	
4A	18/24 75%	ss	2-3 5-6 N=8	25			8	Gray (10YR5/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, medium, clayey SILT with trace sand.		620	
5A	18/24 75%	ss	2-2 3-4 N=5	24			10	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		618	
6A	13/24 54%	ss	2-2 4-4 N=6	23			12			616	
7A	19/24 79%	ss	woh-2 3-4 N=5	23			14 ▽	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		614	
8A	18/24 75%	ss	1-2 2-2 N=4	23			16			612	
9A	23/24 96%	ss	woh-woh 1-2	21			18	Brown, (10YR5/3), very moist, very soft, clayey SAND with slight trace gravel.		610	
10A	22/24 92%	ss	4-12 26-30 N=38	8			20	Brown (10YR5/3), slightly moist, hard, very silty CLAY with trace sand and gravel.		608	

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/4/2010
Finish: 2/4/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G121
Well ID: G121
Surface Elev: 627.94 ft. MSL
Completion: 22.00 ft. BGS
Station: 875,964.59N
2,513,904.35E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 14.44 - 3/1/2010

SAMPLE				TESTING							
Number	Recov / Total (in) *% Recovery*	Type		*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 *100%*	ss		*13-23* *31-48* N=54	7			22	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with sand and gravel.		606	
									End of Boring = 22.0 ft. BGS			

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/4/2010
Finish: 2/4/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G122
Well ID: G122
Surface Elev: 628.05 ft. MSL
Completion: 20.00 ft. BGS
Station: 876,080.14N
2,513,902.82E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 17.00 - While drilling
▼ =
▽ = 12.84 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	23/24 96%	ss	5-5 6-11 N=11	16			0				
							2	FILL - Grayish brown (10YR5/2) with 15% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		626	
2A	20/24 83%	ss	3-3 5-5 N=8	22			4			624	
3A	20/24 83%	ss	3-4 5-6 N=9	25			6	Dark yellowish brown (10YR4/4), moist, medium, silty CLAY.		622	
4A	19/24 79%	ss	1-5 5-6 N=10	29			8	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, medium, silty CLAY.		620	
5A	20/24 83%	ss	1-3 3-3 N=6	21			10	Grayish brown (10YR5/2), moist, medium, clayey SILT with sand.		618	
6A	19/24 79%	ss	1-2 3-3 N=5	22			12	Yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace gravel.		616	
7A	16/24 67%	ss	1-2 3-4 N=5	21			▽	Gray (10YR5/1), moist, medium, clayey SILT with fine sand.			
8A	19/24 79%	ss	1-1 2-2 N=3	21			14	Brown (10YR4/3), moist, medium, silty CLAY with trace gravel.		614	
								Grayish brown (10YR5/2), moist, soft, sandy SILT.			
							16	Yellowish brown (10YR5/4) with 40% dark yellowish brown (10YR4/6) mottles, moist, medium, silty CLAY with slight trace sand.		612	
9A	20/24 83%	ss	1-1 4-16 N=5	14			▼				
							18	Dark yellowish brown (10YR4/6), wet, medium dense, silty SAND.		610	
10A	24/24 100%	ss	10-38 51-58 N=89	6				Brownish yellow (10YR6/6), slightly moist, hard, clayey SILT with trace sand and gravel.			
							20	Gray (10YR5/1), slightly moist, hard, clayey SILT with gravel.			

End of Boring = 20.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/3/2010
Finish: 2/4/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G123
Well ID: G123
Surface Elev: 628.12 ft. MSL
Completion: 24.00 ft. BGS
Station: 876,189.60N
2,513,901.46E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.50 - While drilling
▼ =
▽ = 15.98 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	22/24 92%	ss	6-8 9-11 N=17	16			0			628	
							2	FILL - Grayish brown (10YR5/2) with 10% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		626	
2A	19/24 79%	ss	4-5 6-7 N=11	18							
							4			624	
3A	17/24 71%	ss	2-3 5-6 N=8	24							
							6	Dark grayish brown (10YR4/2) with 20% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand, slight trace roots.		622	
4A	18/24 75%	ss	1-3 5-8 N=8	24				Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.			
							8			620	
5A	20/24 83%	ss	2-3 4-5 N=7	18							
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		618	
6A	19/24 79%	ss	1-2 3-5 N=5	21							
							12			616	
7A	23/24 96%	ss	1-3 4-4 N=7	19				Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with sand and slight trace gravel.			
							14	Dark yellowish brown (10YR3/6) with dark yellowish brown (10YR4/6) mottles, moist, medium, silty CLAY with trace gravel.		614	
8A	22/24 92%	ss	1-2 3-3 N=5	17							
							▽ 16	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, sandy SILT.		612	
							▼				
9A	22/24 92%	ss	1-1 2-2 N=3	19				Dark yellowish brown (10YR4/6), wet, soft, clayey SAND.			
							18			610	
10A	12/24 50%	ss	3-3 3-4 N=6	16				Yellowish brown (10YR5/6), wet, medium, sandy SILT with trace gravel.			
							20				

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/3/2010
Finish: 2/4/2010
WEATHER: Overcast, cold (lo-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G123
Well ID: G123
Surface Elev: 628.12 ft. MSL
Completion: 24.00 ft. BGS
Station: 876,189.60N
2,513,901.46E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.50 - While drilling
▼ =
▽ = 15.98 - 3/1/2010

SAMPLE			TESTING							
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	20/24 *83%*	ss	*6-12* *12-12* N=24	11			22	Yellowish brown (10YR5/6), wet, medium, sandy SILT with trace gravel. *[Continued from previous page]*		608	
								Gray (10YR5/1), moist, very stiff, clayey SILT with trace gravel.		606	
12A	19/24 *79%*	ss	*3-8* *13-9* N=21	9			24	Dark gray (10YR4/1), moist, very stiff, sandy SILT with trace clay and gravel.			

End of Boring = 24.0 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: Start: 2/3/2010
Finish: 2/3/2010
WEATHER: Sunny, cold (mid-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: Driller: T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G124
Well ID: G124
Surface Elev: 628.70 ft. MSL
Completion: 20.00 ft. BGS
Station: 876,304.85N
2,513,900.34E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - While drilling
▼ =
▽ = 10.99 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 *100%*	ss	*6-4 5-6* N=9	17			0			628	
							2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.			
2A	22/24 *92%*	ss	*4-5 7-8* N=12	21						626	
							4				
3A	19/24 *79%*	ss	*2-4 6-7* N=10	25						624	
							6	Dark grayish brown (10YR4/2) with 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY.			
4A	13/24 *54%*	ss	*3-3 6-6* N=9	28				Dark grayish brown (10YR4/2) with 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY, slight trace roots.		622	
							8				
5A	20/24 *83%*	ss	*1-3 5-6* N=8	21				Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand and gravel.		620	
							10				
6A	17/24 *71%*	ss	*1-3 3-4* N=6	22			▽			618	
							12	Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.			
7A	18/24 *75%*	ss	*1-3 3-4* N=6	23						616	
							14				
8A	20/24 *83%*	ss	*woh-woh 2-3*	28						614	
8B				22				Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, very soft, silty CLAY with trace sand and slight trace gravel.			
							16	Gray (10YR6/1) with 5% yellowish brown (10YR5/6) mottles, moist, medium, sandy CLAY with slight trace gravel.			
9A	19/24 *79%*	ss	*1-2 3-3* N=5	22						612	
9B				17				Gray (10YR6/1) with 20% yellowish brown (10YR5/6) mottles, moist, medium, sandy CLAY with slight trace gravel.			
							18	Yellowish brown (10YR5/4), moist, medium, clayey SILT with trace sand and slight trace gravel.			
10A	20/24 *83%*	ss	*4-10 17-23* N=27	12				Yellowish brown (10YR5/4), slightly moist, stiff, clayey SILT with trace sand and slight trace gravel.		610	
							20	Gray (10YR5/1), slightly moist, stiff, clayey SILT with trace sand and slight trace gravel.			
								End of Boring = 20.0 ft. BGS			

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/2/2010
Finish: 2/3/2010
WEATHER: Sunny, cold (mid-30's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: G125
Well ID: G125
Surface Elev: 628.85 ft. MSL
Completion: 20.13 ft. BGS
Station: 876,409.47N
2,513,899.12E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 17.00 - While drilling
▼ = Dry - Upon completion
▽ = 8.58 - 3/1/2010

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	18/24 *75%*	ss	*5-6 7-9* N=13	17			0			628	
2A	16/24 *67%*	ss	*3-4 6-9* N=10	17			2	FILL - Brown (10YR5/3) with 5% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		626	
3A	20/24 *83%*	ss	*2-5 5-7* N=10	25			4			624	
4A	19/24 *79%*	ss	*2-4 5-5* N=9	23			6	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel, slight trace roots.		622	
5A	14/24 *58%*	ss	*3-4 4-6* N=8	25			8 ▽	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand and gravel, slight trace roots.		620	
6A	18/24 *75%*	ss	*2-3 3-5* N=6	22			10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with slight trace sand.		618	
7A	20/24 *83%*	ss	*3-4 3-4* N=7	23			12	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		616	
8A	24/24 *100%*	ss	*3-3 3-3* N=6	23			14	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		614	
9A	24/24 *100%*	ss	*woh-1 2-1* N=3	25			16 ▼			612	
9B				18			18	Brown (10YR5/3), very moist, very soft, clayey SAND with slight trace gravel.		610	
10A	19/24 *79%*	ss	*woh-1 7-19* N=8	22							
10B				11			20	Brown (10YR5/3), slightly moist, medium, clayey SILT with trace sand and slight trace gravel.			

End of Boring = 20.1 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/10/2010
Finish: 2/10/2010
WEATHER: Partly cloudy, wind 10 mph, ~25F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: G126
Well ID: G126
Surface Elev: 622.96 ft. MSL
Completion: 18.00 ft. BGS
Station: 875,062.44N
2,513,895.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.20 - While drilling
▼ = 13.00 - Upon completion
▽ = 8.82 - 3/1/2010

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	9-7 12-10 N=19	15			0	FILL - Dark yellowish brown (10YR4/6), moist, very stiff, sandy CLAY with silt and trace gravel.		622	
							2	Light grayish brown (10YR6/2), slightly moist, stiff, silty CLAY.			
2A	19/24 79%	ss	2-4 6-9 N=10	26			4	Light grayish brown (10YR6/2) with 20% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY, slight trace roots.		620	
3A	22/24 92%	ss	2-4 5-7 N=9	20			6			618	
4A	24/24 100%	ss	2-3 4-5 N=7	22			8	Dark brown (10YR3/3) with 10% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY.		616	
5A	24/24 100%	ss	1-3 4-5 N=7	22			▽			614	
6A	22/24 92%	ss	1-3 4-5 N=7	18			10	Light grayish brown (10YR6/2) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		612	
7A	20/24 83%	ss	1-2 3-4 N=5	19			12	Grayish brown (10YR5/2) with dark yellowish brown (10YR4/6) mottles, moist, medium, clayey SILT with sand and slight trace gravel.		610	
							▼				
8A	24/24 100%	ss	4-15 12-29 N=27	20			14	Gray (10YR6/1). very moist, medium, sandy CLAY with trace gravel.		608	
								Yellowish brown (10YR5/8) with 40% dark yellowish brown (10YR4/6) mottles, slightly moist, very stiff, clayey SILT with trace gravel.			
							16	Brownish yellow (10YR6/8), moist, very stiff, sandy SILT with gravel.			
9A	23/24 96%	ss	29-39 39-29 N=78	8				Grayish brown (10YR5/2), moist, hard, sandy SILT with gravel.		606	
							18	**End of Boring = 18.0 ft. BGS**			

NOTE(S): G126 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/10/2010
Finish: 2/10/2010
WEATHER: Overcast, wind 15mph, ~10-20F

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: D. Lamb

BOREHOLE ID: T127
Well ID: T127
Surface Elev: 625.53 ft. MSL
Completion: 19.80 ft. BGS
Station: 875,359.21N
2,513,911.02E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.30 - While drilling
▼ = 18.00 - Upon completion
▽ = 11.26 - 3/1/10

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1	24/24 100%	ss	8-5 5-8 N=10				2	FILL - yellowish brown (10YR5/6) with 20% grayish brown (10YR5/2) mottles, moist, stiff, silty CLAY with trace sand and gravel.		624	
2	10/24 42%	ss	5-6 7-11 N=13				4			622	
3	20/24 83%	ss	1-4 5-7 N=9				6	Dark yellowish brown (10YR4/6) with 30% brownish yellow (10YR6/6) and 10% very dark gray (10YR3/1) mottles, moist, medium, clayey SILT with trace sand.		620	
4	24/24 100%	ss	2-4 5-6 N=9				8	Grayish brown (10YR5/2) with 20% dark yellowish brown (10YR4/6) mottles, moist, medium, clayey SILT with sand.		618	
5	24/24 100%	ss	2-4 5-6 N=9				10	Grayish brown (10YR5/2) with 20% dark yellowish brown (10YR4/6) and 5% very dark brown (10YR2/2) mottles, moist, medium, clayey SILT with sand and slight trace gravel.		616	
6	24/24 100%	ss	3-3 5-7 N=8				▽				
7	24/24 100%	ss	1-2 3-3 N=5				12	Dark yellowish brown (10YR4/6) with 5% light brownish gray (10YR6/2) mottles, moist, medium, sandy SILT with gravel.		614	
8	24/24 100%	ss	1-1 2-1 N=3				14	Light brownish gray (10YR6/2) with 30% yellowish brown (10YR5/6) mottles, very moist, medium, clayey SAND with silt.		612	
9	24/24 100%	ss	8-12 28-30 N=40				▼ 16	Light brownish gray (10YR6/2) with 30% brownish yellow (10YR6/8) mottles, wet, very loose, silty SAND trace with gravel.		610	
10	22/22 100%	ss	8-44 65-60/4" N=109				▼ 18	Brownish yellow (10YR6/8), wet, medium dense, silty SAND with gravel.		608	
								Grayish brown (10YR5/2), slightly moist, hard, clayey SILT with sand and gravel.		606	

End of Boring = 19.8 ft. BGS

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/9/2010
Finish: 2/9/2010
WEATHER: Cold, windy, snow (lo-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: T128
Well ID: T128
Surface Elev: 626.27 ft. MSL
Completion: 22.00 ft. BGS
Station: 875,509.70N
2,513,909.45E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.84 - While drilling
▼ =
▽ = 12.35 - 3/1/10

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	FILL - Brown (10YR5/3) with 5% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, hard (frozen), silty CLAY with trace sand and slight trace gravel.		626	
1A	12/24 50%	ss	37-17 15-18 N=32	14			1.7	FILL - Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, hard (frozen), silty CLAY with slight trace sand and gravel.			
2A	7/24 29%	ss	4-7 7-13 N=14				2	FILL - Brown (10YR5/3) with 10% gray (10YR5/1) and 5% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand and gravel.		624	
3A	12/24 50%	ss	3-4 6-8 N=10	26			4			622	
4A	19/24 79%	ss	2-4 5-7 N=9	24			6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with slight trace sand, slight trace roots.		620	
5A	22/24 92%	ss	1-3 4-5 N=7	20			8			618	
6A	22/24 92%	ss	1-3 5-5 N=8	20			10	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with trace sand and slight trace gravel.		616	
7A	22/24 92%	ss	2-3 4-5 N=7	19			12 ▽			614	
8A	20/24 83%	ss	2-2 3-3 N=5	18			14	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY with trace sand and slight trace gravel.		612	
9A	22/24 92%	ss	woh-1 8-7 N=9	19			16 ▼	Brown (10YR5/3), moist, soft, clayey SAND with slight trace gravel.		610	
9B				18				Gray (10YR6/1), wet, loose, silty, very fine- to coarse-grained SAND.			
10A							18	Brown (10YR5/3), wet, loose, silty, very fine- to fine-grained SAND.		608	
10B	18/24 75%	ss	3-10 13-11 N=23	17							
							20	Brown (10YR5/3), slightly moist, very stiff, clayey SILT with trace sand and gravel.			

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project:
DATES: **Start:** 2/9/2010
Finish: 2/9/2010
WEATHER: Cold, windy, snow (lo-20's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** T. List
Helper: M. Herbst/S. Hamby
Eng/Geo: S. Simpson

BOREHOLE ID: T128
Well ID: T128
Surface Elev: 626.27 ft. MSL
Completion: 22.00 ft. BGS
Station: 875,509.70N
2,513,909.45E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.84 - While drilling
▼ =
▽ = 12.35 - 3/1/10

SAMPLE				TESTING							
Number	Recov / Total (in) *% Recovery*	Type	Depth ft. BGS	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 *100%*	ss		*8-16 18-25* N=34	16			Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and gravel.		606	
			22					**End of Boring = 22.0 ft. BGS**			

NOTE(S): Well completed prior to construction of berm road. Boring surface elevation is as of the well install date and not the final constructed elevation.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Holdings
Site: Coffeen Power Station
Location: Coffeen, Montgomery County, Illinois
Project: 14E0078
DATES: **Start:** 10/28/2014
Finish: 10/28/2014
WEATHER: Overcast, mild - mid 50's

CONTRACTOR: Ramsey
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: 4¼" Hollow Stem Auger with Split spoon
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: R. Hasenyager

BOREHOLE ID: TA31
Well ID: TA31
Surface Elev: 623.89 ft. MSL
Completion: 20.19 ft. BGS
Station: 876,542.25N
2,513,856.77E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 8.11 - 10/30/2014
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	24/24 100%	ss	1-2 2-2 N=4								
1				26			2			622	
	22/24 92%	ss	2-3 3-4 N=6					Yellowish brown (10YR5/4), moist, soft, SILT with little clay and trace very fine sand.			
2				28		1.44 B	4	Brown (10YR4/3), moist, soft, SILT with little clay and trace very fine sand.		620	
	23/24 96%	ss	2-3 4-4 N=7								
3				20		1.71 Sh	6			618	
	24/24 100%	ss	6-7 6-6 N=13								
4				22		1.55 Sh	▼ 8			616	
	22/24 92%	ss	2-2 2-4 N=4					Gray (10YR5/1) with 20% yellowish brown (10YR5/8) mottles, moist, soft, CLAY with few silt and trace very fine to fine sand.			
5				22		1.55 Sh	10			614	
	24/24 100%	ss	2-1 3-2 N=4					Brownish yellow (10YR6/6) with 20% gray (10YR6/1) mottles, moist, soft, CLAY with few silt and little very fine to fine sand and trace small gravel.			
6				20		0.93 B	12			612	
	24/24 100%	ss	2-3 3-3 N=6					Brownish yellow (10YR6/6), wet, slightly dense, SAND (very fine to coarse) with little sand and silt and trace clay and small gravel.			
7A				19			14	Brownish yellow (10YR6/6), moist, soft, CLAY with few silt and trace very fine to fine sand and small gravel.		610	
7B				22				Brownish yellow (10YR6/6) wet, loose, SAND (very fine to very coarse) and trace small gravel.			
8A	24/24 100%	ss	4-5 8-7 N=13	12				Brownish yellow (10YR6/6) very moist, soft, SAND (very fine to medium) with few clay and silt.			
8B				13			16	Yellowish brown (10YR5/8), moist, soft, CLAY with few silt and trace sand (very fine to very coarse) and small gravel.		608	
	22/24 92%	ss	5-4 4-4 N=8								
9				18			18	Yellowish brown (10YR5/8), wet, loose, very fine to very coarse SAND.		606	
	16/24 67%	ss	2-4 3-5 N=7								
10				12			20	Gray (10YR5/1), moist, hard, CLAY with few silt and (very fine to very coarse) sand and small gravel.		604	

End of Boring at 20.19 ft.

NOTE(S): Monitoring well TA31 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Holdings
Site: Coffeen Power Station
Location: Coffeen, Montgomery County, Illinois
Project: 14E0078
DATES: **Start:** 10/27/2014
Finish: 10/27/2014
WEATHER: Partly sunny, mild - mid 70's

CONTRACTOR: Ramsey
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: 4¼" Hollow Stem Auger with Split spoon
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: R. Hasenyager

BOREHOLE ID: TA32
Well ID: TA32
Surface Elev: 618.93 ft. MSL
Completion: 16.47 ft. BGS
Station: 877,532.57N
2,513,605.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.05 - 10/30/2014
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1	18/24 75%	ss	2-1 2-3 N=3	21			0	Dark yellowish brown (10YR4/4), moist, soft, clayey SILT with trace sand (very fine).		618	
	21/24 88%	ss	2-1 1-1 N=2				2			616	
2				28			4	Black (10YR2/1), moist, soft, clayey SILT with trace sand (very fine).		614	
3A				24							
3B	14/24 58%	ss	1-1 3-3 N=4	22		1.15 Sh	6	Very dark gray (10YR3/1), moist, soft, CLAY with little silt and trace sand (very fine to fine).		612	
4	20/24 83%	ss	4-5 4-7 N=9	22		0.96 B	8	Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist, medium, CLAY with little silt and trace sand (very fine to very coarse) and gravel (small).		610	
5	21/24 88%	ss	4-7 12-22 N=19	9		8.45 Sh	10	Yellowish brown (10YR5/8) with 30% Gray (10YR5/1) mottles, slightly moist, very hard, CLAY with silt and little sand (very fine to very coarse) trace gravel (small).		608	
6	21/24 88%	ss	6-16 27-42 N=43	8		10.47 Sh	12	Yellowish brown (10YR5/8), slightly moist, loose, SAND (very fine to very coarse) and few gravel (small to medium).		606	
7	12/24 50%	ss	36-55 50/4"	6			▼ 14	Gray (10YR5/1), slightly moist, very hard, CLAY with silt and few gravel (small to medium).			
8	16/24 67%	ss	16-35 69 N=104	8				Gray (10YR5/1), moist, dense, SAND (very fine to coarse).		604	
							16	Gray (10YR5/1), slightly moist, very hard, CLAY with silt and few gravel (small to medium).			

End of Boring at 16.47 ft.

NOTE(S): Monitoring well TA32 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Company
Site: Coffeen Well Sealing & Assmt Well Install
Location: Coffeen, Illinois
Project: 14E0078A
DATES: **Start:** 6/2/2015
Finish: 6/2/2015
WEATHER: Sunny, calm, hi-60s

CONTRACTOR: Ramsey
Rig mfg/model: Diedrich D-50
Drilling Method: 3 ¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: TA33a
Well ID: n/a
Surface Elev: 622.5 ft. MSL
Completion: 30.0 ft. BGS
Station: 876,610.00N
2,513,248.00E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.80 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	21/24 88%	ss	2-3 5-5 N=8				0	Yellowish brown (10YR5/4), moist, stiff, clayey SILT, trace very fine-grained sand, roots.		622	
							1	Light brownish gray (10YR6/2) with 35% yellowish brown (10YR5/6) mottles, moist, stiff to very stiff, clayey SILT, trace very fine- to fine-grained sand.			
2A	20/24 83%	ss	3-4 4-5 N=8				2			620	
							3	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, very stiff, clayey SILT, little fine- to medium-grained sand, trace coarse-grained sand.			
3A	23/24 96%	ss	5-6 6-9 N=12				4			618	
							5	Gray (10YR5/1) with 5-10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY, little fine- to medium-grained sand, trace coarse-grained sand.			
4A	24/24 100%	ss	10-10 10-10 N=20				6			616	
							7	Dark yellowish brown (10YR4/6) with 3% gray (10YR6/1) mottles, moist, very stiff, silty CLAY, little fine- to coarse-grained sand, trace small gravel.			
5A	21/24 88%	ss	2-4 6-6 N=10				8			614	
							9	Gray (10YR6/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY, little fine- to coarse-grained sand, trace small gravel.			
6A	24/24 100%	ss	0-3 4-8 N=7				10			612	
							11	Gray (10YR6/1) moist, medium, fine- to coarse-grained sandy CLAY, little silt, trace small to large gravel.			
7A	24/24 100%	ss	15-27 32-41 N=59				12	Brown (10YR5/3) with 5% dark yellowish brown (10YR4/6) mottles, slightly moist, very stiff, very fine- to fine-grained sandy SILT, trace medium- to coarse-grained sand, trace small to large gravel, friable.		610	
7B							▼ 13				
							14	Dark yellowish brown (10YR4/6), very moist, dense, silty,very fine- to medium-grained SAND.		608	
8A	20/24 83%	ss	5-12 18-22 N=30				15				
							16	Brown (10YR5/3), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small gravel.		606	
9A	16/24 67%	ss	23-44 50/5"				17				
							18			604	
10A	22/24 92%	ss	12-12 22-25 N=34				19	Dark gray (10YR4/1), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small to large gravel.			
							20				

NOTE(S): Borehole sealed with high-solids bentonite grout.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Company
Site: Coffeen Well Sealing & Assmt Well Install
Location: Coffeen, Illinois
Project: 14E0078A
DATES: **Start:** 6/2/2015
Finish: 6/2/2015
WEATHER: Sunny, calm, hi-60s

CONTRACTOR: Ramsey
Rig mfg/model: Diedrich D-50
Drilling Method: 3 ¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: TA33a
Well ID: n/a
Surface Elev: 622.5 ft. MSL
Completion: 30.0 ft. BGS
Station: 876,610.00N
2,513,248.00E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.80 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 100%	ss	11-17 25-32 N=42				22			602	
12A	23/24 96%	ss	17-23 35-44 N=58				24			600	
13A	21/24 88%	ss	26-30 30-37 N=60				26	Dark gray (10YR4/1), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small to large gravel. *[Continued from previous page]*		598	
14A	18/24 75%	ss	19-35 47-50 N=82				28			596	
15A	24/24 100%	ss	18-27 34-35 N=61				30			594	

End of boring = 30.0 feet

NOTE(S): Borehole sealed with high-solids bentonite grout.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Company
Site: Coffeen Well Sealing & Assmt Well Install
Location: Coffeen, Illinois
Project: 14E0078A
DATES: **Start:** 6/2/2015
Finish: 6/2/2015
WEATHER: Sunny, calm, hi-60s

CONTRACTOR: Ramsey
Rig mfg/model: Diedrich D-50
Drilling Method: 3 ¼" HSA, blind drill

FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: TA33b
Well ID: TA33
Surface Elev: 622.51 ft. MSL
Completion: 17.44 ft. BGS
Station: 876,605.45N
2,513,248.73E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - during drilling
▼ = 7.00 - 6/16/15
▽ =

SAMPLE			TESTING							
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Yellowish brown (10YR5/4), moist, stiff, clayey SILT, trace very fine-grained sand, roots.		622	
							2	Light brownish gray (10YR6/2) with 35% yellowish brown (10YR5/6) mottles, moist, stiff to very stiff, clayey SILT, trace very fine- to fine-grained sand.		620	
							4	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, very stiff, clayey SILT, little fine- to medium-grained sand, trace coarse-grained sand.		618	
							6	Gray (10YR5/1) with 5-10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY, little fine- to medium-grained sand, trace coarse-grained sand.		616	
							8	Dark yellowish brown (10YR4/6) with 3% gray (10YR6/1) mottles, moist, very stiff, silty CLAY, little fine- to coarse-grained sand, trace small gravel.		614	
							10	Gray (10YR6/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY, little fine- to coarse-grained sand, trace small gravel.		612	
							12	Gray (10YR6/1) moist, medium, fine- to coarse-grained sandy CLAY, little silt, trace small to large gravel.		610	
							14	Brown (10YR5/3) with 5% dark yellowish brown (10YR4/6) mottles, slightly moist, very stiff, very fine- to fine-grained sandy SILT, trace medium- to coarse-grained sand, trace small to large gravel, friable.		608	
							16	Dark yellowish brown (10YR4/6), very moist, dense, silty,very fine- to medium-grained SAND.		606	
								Brown (10YR5/3), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small gravel.			

End of boring = 17.44 feet

NOTE(S): TA33 installed in bore hole.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Company
Site: Coffeen Well Sealing & Assmt Well Install
Location: Coffeen, Illinois
Project: 14E0078A
DATES: **Start:** 6/3/2015
Finish: 6/3/2015
WEATHER: Mostly cloudy, windy, mid-60s

CONTRACTOR: Ramsey
Rig mfg/model: Diedrich D-50
Drilling Method: 3 ¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: TA34
Well ID: TA34
Surface Elev: 624.10 ft. MSL
Completion: 16.10 ft. BGS
Station: 875,906.10N
2,513,466.73E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.00 - during drilling
▼ = 8.10 - 6/16/15
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Gray (10YR5/1) with 10% dark yellowish brown (10YR3/6) mottles, moist, stiff, SILT, some clay, trace very fine-grained, roots.		624	
1A	21/24 88%	ss	3-3 3-3 N=6					Grayish brown (10YR5/2) with 10% yellowish brown (10YR5/6) mottles, moist, very stiff, silty CLAY, trace fine-grained sand.			
							2			622	
2A	17/24 71%	ss	2-2 4-6 N=6					Light grayish brown (10YR6/2) with 15% yellowish brown (10YR5/6) mottles, slightly moist, very stiff, silty CLAY, trace fine-grained sand.			
							4			620	
3A	22/24 92%	ss	3-3 3-4 N=6					Grayish brown (10YR5/2) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY, little fine-grained sand, trace medium- to coarse-grained sand.			
							6			618	
4A	24/24 100%	ss	3-4 6-7 N=10								
							▼ 8			616	
5A	24/24 100%	ss	2-2 5-5 N=7					Grayish brown (10YR5/2) with 25% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY, little fine-grained sand, trace medium- to coarse-grained sand, trace small gravel.			
							10			614	
6A	22/24 92%	ss	3-3 4-5 N=7								
							12			612	
7A	21/24 88%	ss	3-3 4-5 N=7				▼	Dark yellowish brown (10YR4/6) with 15% light gray (10YR7/1) mottles, very moist, very soft, fine- to medium-grained sandy CLAY, trace coarse-grained sand.			
7B								Gray (10YR6/1), very moist, loose, clayey, silty, fine- to medium-grained SAND, trace coarse grained sand.			
8A	24/24 100%	ss	18-28 25-32 N=53				14	Brown (10YR5/3), very moist, very dense, silty,fine- to coarse-grained SAND and small to large GRAVEL.		610	
8B								Yellowish brown (10YR5/6), slightly moist, hard, clayey SILT, little fine- to coarse-grained sand, trace small gravel.			
8C								Gray (10YR6/1), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small gravel.			
							16	Dark gray (10YR4/1), slightly moist, hard, clayey SILT, few fine- to coarse-grained sand, trace small gravel.		608	

End of boring = 16.1 feet

NOTE(S): TA34 installed in bore hole.

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G101

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G101

~~State~~ Plane Coordinate: X 2,514,214.3 Y 876,551.8 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/2/2010 Date Finished: 2/2/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/4/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 20 min

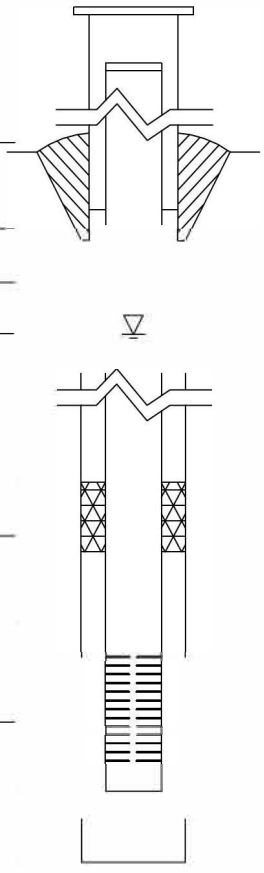
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.89	-2.62	Top of Protective Casing
627.60	-2.33	Top of Riser Pipe
625.27	0.00	Ground Surface
622.27	3.00	Top of Annular Sealant
617.96	7.31	Static Water Level (After Completion) 3/1/2010
614.27	11.00	Top of Seal
612.14	13.13	Top of Sand Pack
609.59	15.68	Top of Screen
604.95	20.32	Bottom of Screen
604.38	20.89	Bottom of Well
603.35	21.92	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.01
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.64
Total Length of Casing	(feet)	23.22
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G102 (MW3S)

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-03a

~~State~~ Plane Coordinate: X 2,514,531.5 Y 876,554.8 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: TSC Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 4/28/2006 Date Finished: 4/28/2006

Report Form Completed By: Rhonald W. Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

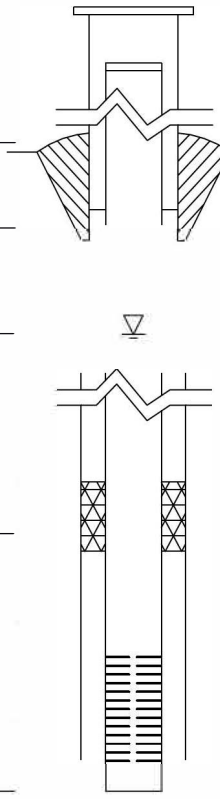
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
629.45	-3.75	Top of Protective Casing
628.96	-3.26	Top of Riser Pipe
625.70	0.00	Ground Surface
623.70	2.00	Top of Annular Sealant
618.67	7.03	Static Water Level (After Completion) 6/1/2006
623.70	2.00	Top of Seal
616.20	9.50	Top of Sand Pack
613.68	12.02	Top of Screen
608.92	16.78	Bottom of Screen
608.55	17.15	Bottom of Well
608.55	17.15	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.28
Bottom of Screen to End Cap	(feet)	0.37
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	20.41
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G103

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G103

~~State~~ Plane Coordinate: X 2,514,501.2 Y 876,199.5 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

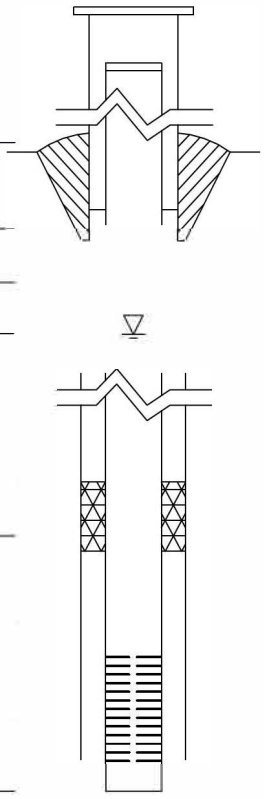
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/15/2010 Date Finished: 2/15/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 8 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
634.07	-3.08	Top of Protective Casing
633.80	-2.81	Top of Riser Pipe
630.99	0.00	Ground Surface
624.93	6.06	Top of Annular Sealant
614.00	16.99	Static Water Level (After Completion) 3/1/2010
618.51	12.48	Top of Seal
617.35	13.64	Top of Sand Pack
615.11	15.88	Top of Screen
610.32	20.67	Bottom of Screen
609.90	21.09	Bottom of Well
609.90	21.09	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.69
Bottom of Screen to End Cap	(feet)	0.42
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	23.90
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: R104

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: R104

State Plane Coordinate: X 2,514,503.4 Y 875,857.8 (or) Latitude: 39 ° 4 ' 10 " Longitude: -89 ° 23 ' 56.8 "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: D. Mahurin

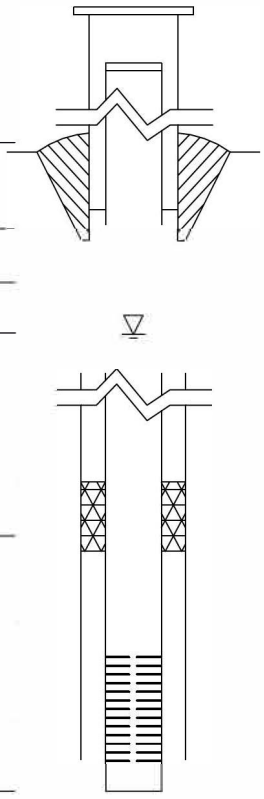
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Rhonald W. Hasenyager Date Started: 10/8/2010 Date Finished: 10/8/2010

Report Form Completed By: Suzanna L. Simpson Date: 10/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a

	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	632.02	-2.99	Top of Protective Casing
	631.84	-2.81	Top of Riser Pipe
	629.03	0.00	Ground Surface
	627.03	2.00	Top of Annular Sealant
▽	612.85	16.18	Static Water Level (After Completion) 11/15/2010
	617.03	12.00	Top of Seal
	616.01	13.02	Top of Sand Pack
	614.44	14.59	Top of Screen
	609.71	19.32	Bottom of Screen
	609.18	19.85	Bottom of Well
	609.18	19.85	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.60
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	22.66
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G104

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G104

~~State~~ Plane Coordinate: X 2,514,505.0 Y 875,849.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/15/2010 Date Finished: 2/15/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

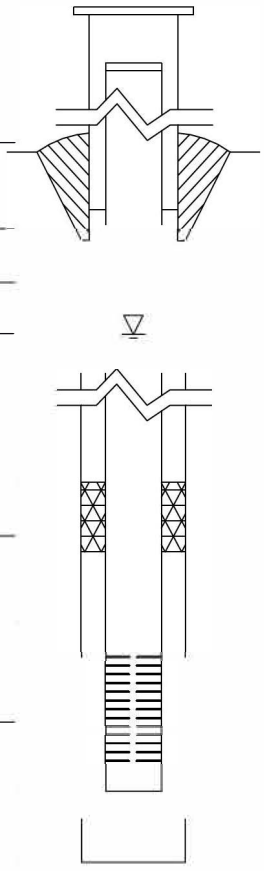
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.29	-3.17	Top of Protective Casing
632.94	-2.82	Top of Riser Pipe
630.12	0.00	Ground Surface
624.92	5.20	Top of Annular Sealant
614.72	15.40	Static Water Level (After Completion) 3/1/2010
619.17	10.95	Top of Seal
617.42	12.70	Top of Sand Pack
615.21	14.91	Top of Screen
610.51	19.61	Bottom of Screen
610.04	20.08	Bottom of Well
607.92	22.20	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.73
Bottom of Screen to End Cap	(feet)	0.47
Screen Length (1st slot to last slot)	(feet)	4.70
Total Length of Casing	(feet)	22.90
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G105

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G105

~~State~~ Plant
~~Plane~~ Coordinate: X 2,514,509.2 Y 875,499.7 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/16/2010 Date Finished: 2/16/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

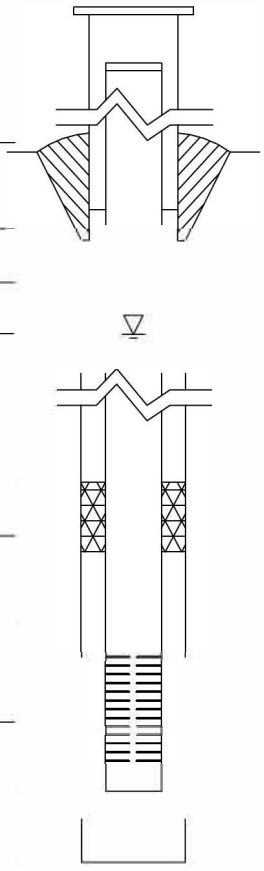
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
632.40	-3.14	Top of Protective Casing
632.08	-2.82	Top of Riser Pipe
629.26	0.00	Ground Surface
623.80	5.46	Top of Annular Sealant
613.18	16.08	Static Water Level (After Completion) 3/1/2010
616.55	12.71	Top of Seal
615.50	13.76	Top of Sand Pack
613.15	16.11	Top of Screen
608.36	20.90	Bottom of Screen
607.89	21.37	Bottom of Well
606.80	22.46	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.93
Bottom of Screen to End Cap	(feet)	0.47
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	24.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G106

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G106

~~State~~ Plane Coordinate: X 2,514,512.8 Y 875,149.8 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/16/2010 Date Finished: 2/16/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

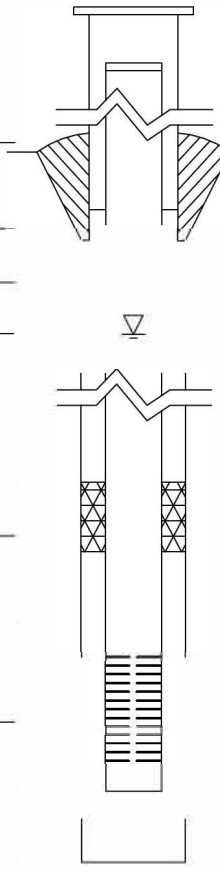
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
631.45	-3.06	Top of Protective Casing
631.15	-2.76	Top of Riser Pipe
628.39	0.00	Ground Surface
622.94	5.45	Top of Annular Sealant
615.77	12.62	Static Water Level (After Completion) 3/1/2010
617.44	10.95	Top of Seal
616.10	12.29	Top of Sand Pack
614.02	14.37	Top of Screen
609.43	18.96	Bottom of Screen
608.95	19.44	Bottom of Well
607.94	20.45	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.13
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	4.69
Total Length of Casing	(feet)	22.30
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G107

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G107

~~State~~ Plane Coordinate: X 2,514,358.3 Y 874,994.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/17/2010 Date Finished: 2/17/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 8 min

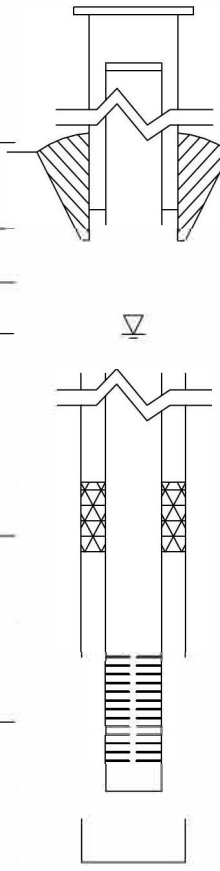
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	630.60	-2.81	Top of Protective Casing
	630.23	-2.44	Top of Riser Pipe
	627.79	0.00	Ground Surface
	624.08	3.71	Top of Annular Sealant
	617.39	10.40	Static Water Level (After Completion) 3/1/2010
	617.41	10.38	Top of Seal
	616.24	11.55	Top of Sand Pack
	613.92	13.87	Top of Screen
	609.29	18.50	Bottom of Screen
	608.82	18.97	Bottom of Well
	607.08	20.71	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.31
Bottom of Screen to End Cap	(feet)	0.47
Screen Length (1st slot to last slot)	(feet)	4.63
Total Length of Casing	(feet)	21.41
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G108

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G108

~~State~~ Plane Coordinate: X 2,514,248.3 Y 874,948.8 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

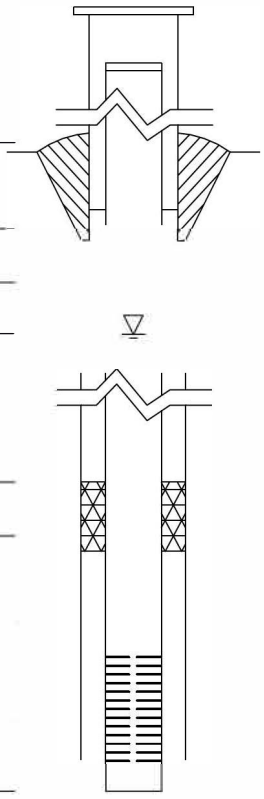
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/12/2010 Date Finished: 2/12/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Granular

Setting Time: 10 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
630.52	-3.02	Top of Protective Casing
630.22	-2.72	Top of Riser Pipe
627.50	0.00	Ground Surface
622.50	5.00	Top of Annular Sealant
618.57	8.93	Static Water Level (After Completion) 3/1/2010
614.00	13.50	Top of Seal
612.80	14.70	Top of Sand Pack
610.68	16.82	Top of Screen
606.00	21.50	Bottom of Screen
605.50	22.00	Bottom of Well
605.50	22.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.54
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.68
Total Length of Casing	(feet)	24.72
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G109

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G109

~~State~~ Plant ~~Plane~~ Coordinate: X 2,514,137.8 Y 874,970.1 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/11/2010 Date Finished: 2/11/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Granular

Setting Time: 10 min

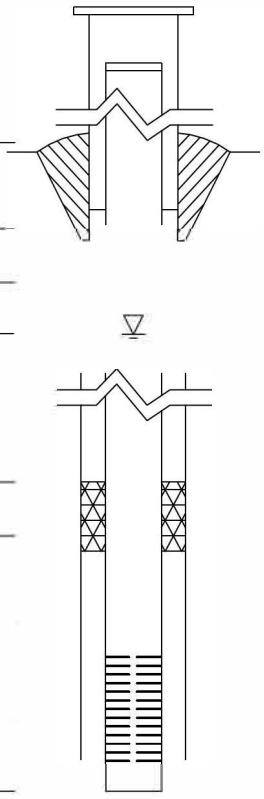
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
630.08	-2.88	Top of Protective Casing
629.76	-2.56	Top of Riser Pipe
627.20	0.00	Ground Surface
621.70	5.50	Top of Annular Sealant
618.35	8.85	Static Water Level (After Completion) 3/1/2010
614.90	12.30	Top of Seal
614.60	12.60	Top of Sand Pack
611.81	15.39	Top of Screen
607.27	19.93	Bottom of Screen
606.70	20.50	Bottom of Well
606.70	20.50	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.95
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	23.06
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G110

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G110

~~State~~ Plane Coordinate: X 2,514,057.7 Y 875,015.4 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/11/2010 Date Finished: 2/11/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Granular

Setting Time: 10 min

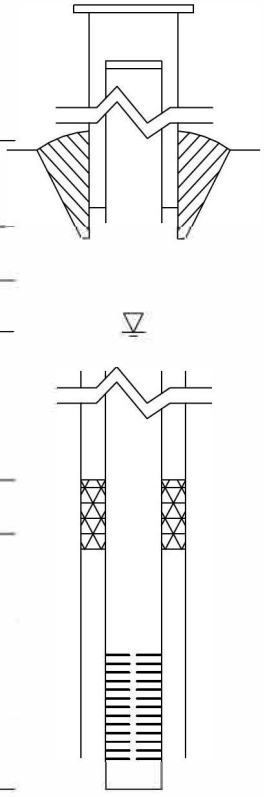
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
629.96	-2.94	Top of Protective Casing
629.65	-2.63	Top of Riser Pipe
627.02	0.00	Ground Surface
621.86	5.16	Top of Annular Sealant
617.52	9.50	Static Water Level (After Completion) 3/1/2010
615.46	11.56	Top of Seal
614.06	12.96	Top of Sand Pack
611.97	15.05	Top of Screen
607.43	19.59	Bottom of Screen
606.86	20.16	Bottom of Well
606.86	20.16	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.68
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	22.79
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G111

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G111

~~State~~ Plane Coordinate: X 2,513,981.7 Y 875,058.7 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/10/2010 Date Finished: 2/11/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Granular

Setting Time: 10 min

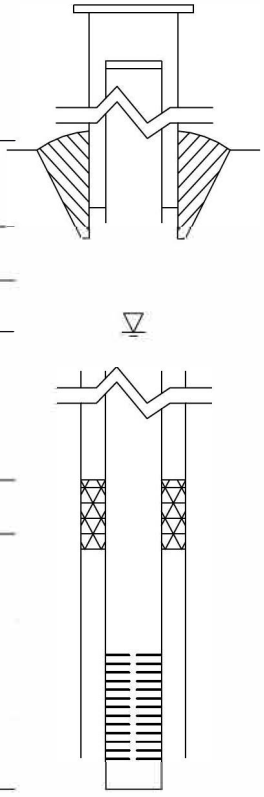
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
630.19	-2.95	Top of Protective Casing
629.90	-2.66	Top of Riser Pipe
627.24	0.00	Ground Surface
622.52	4.72	Top of Annular Sealant
616.74	10.50	Static Water Level (After Completion) 3/1/2010
616.41	10.83	Top of Seal
614.52	12.72	Top of Sand Pack
612.63	14.61	Top of Screen
608.09	19.15	Bottom of Screen
607.52	19.72	Bottom of Well
607.52	19.72	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.27
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	22.38
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G119

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G119

~~State~~ Plant ~~Plane~~ Coordinate: X 2,513,907.7 Y 875,675.0 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

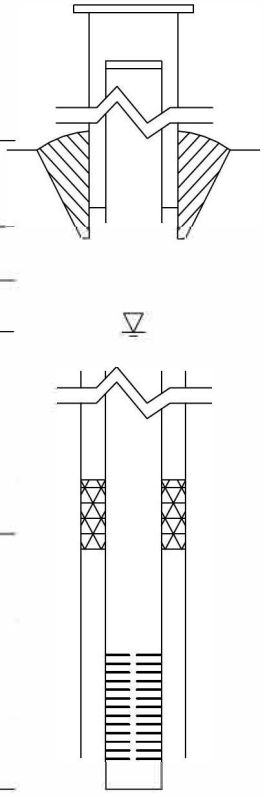
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/9/2010 Date Finished: 2/9/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 15 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
631.85	-3.00	Top of Protective Casing
631.55	-2.70	Top of Riser Pipe
628.85	0.00	Ground Surface
623.57	5.28	Top of Annular Sealant
617.59	11.26	Static Water Level (After Completion) 3/1/2010
614.87	13.98	Top of Seal
613.57	15.28	Top of Sand Pack
611.56	17.29	Top of Screen
607.02	21.83	Bottom of Screen
606.47	22.38	Bottom of Well
606.47	22.38	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.99
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	25.08
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G120

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G120

~~State~~ Plant ~~Plane~~ Coordinate: X 2,513,905.8 Y 875,854.4 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

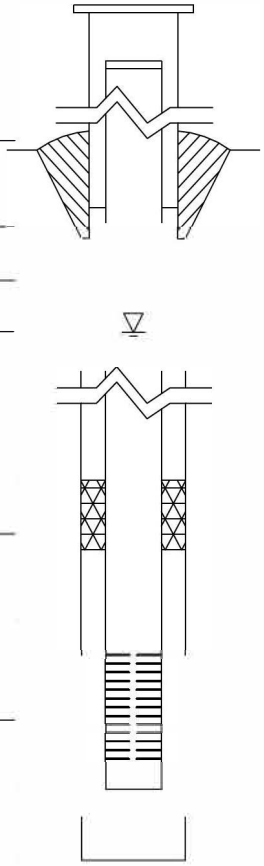
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/8/2010 Date Finished: 2/8/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 8 min

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity

	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	632.18	-2.88	Top of Protective Casing
	631.87	-2.57	Top of Riser Pipe
	629.30	0.00	Ground Surface
	624.22	5.08	Top of Annular Sealant
▽	615.45	13.85	Static Water Level (After Completion) 3/1/2010
	618.14	11.16	Top of Seal
	616.22	13.08	Top of Sand Pack
	614.20	15.10	Top of Screen
	609.68	19.62	Bottom of Screen
	609.09	20.21	Bottom of Well
	607.22	22.08	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.67
Bottom of Screen to End Cap	(feet)	0.59
Screen Length (1st slot to last slot)	(feet)	4.52
Total Length of Casing	(feet)	22.78
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G121

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G121

~~State~~ Plane Coordinate: X 2,513,904.4 Y 875,964.6 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/4/2010 Date Finished: 2/4/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 7 min

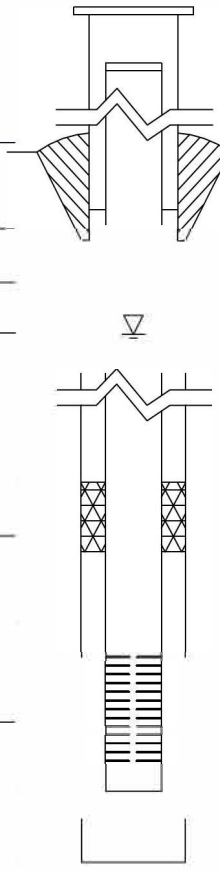
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	633.14	-3.57	Top of Protective Casing
	632.83	-3.26	Top of Riser Pipe
	629.57	0.00	Ground Surface
	624.41	5.16	Top of Annular Sealant
	615.13	14.44	Static Water Level (After Completion) 3/1/2010
	616.81	12.76	Top of Seal
	615.49	14.08	Top of Sand Pack
	612.78	16.79	Top of Screen
	608.10	21.47	Bottom of Screen
	607.62	21.95	Bottom of Well
	605.41	24.16	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.05
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	4.68
Total Length of Casing	(feet)	25.21
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G122

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G122

~~State~~ Plane Coordinate: X 2,513,902.8 Y 876,080.1 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/4/2010 Date Finished: 2/4/2010

Report Form Completed By: Diane M. Lamb Date: 2/9/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

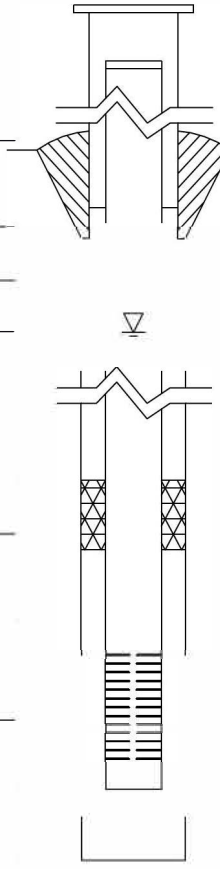
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	632.98	-3.12	Top of Protective Casing
	632.69	-2.83	Top of Riser Pipe
	629.86	0.00	Ground Surface
	625.01	4.85	Top of Annular Sealant
▽	617.02	12.84	Static Water Level (After Completion) 3/1/2010
	617.01	12.85	Top of Seal
	615.41	14.45	Top of Sand Pack
	613.35	16.51	Top of Screen
	608.81	21.05	Bottom of Screen
	608.20	21.66	Bottom of Well
	608.01	21.85	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.34
Bottom of Screen to End Cap	(feet)	0.61
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	24.49
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G123

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G123

~~State~~ Plant
~~Plane~~ Coordinate: X 2,513,901.5 Y 876,189.6 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/3/2010 Date Finished: 2/4/2010

Report Form Completed By: Diane M. Lamb Date: 2/9/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

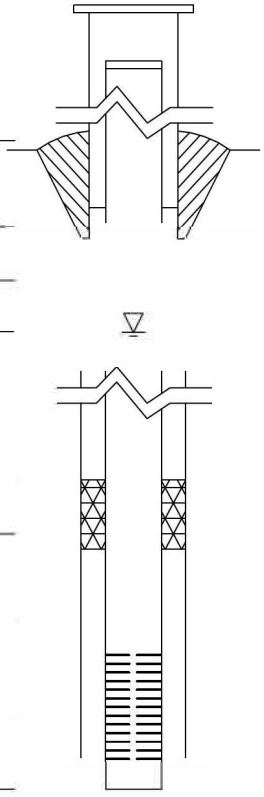
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.29	-3.16	Top of Protective Casing
632.96	-2.83	Top of Riser Pipe
630.13	0.00	Ground Surface
625.06	5.07	Top of Annular Sealant
614.15	15.98	Static Water Level (After Completion) 3/1/2010
612.31	17.82	Top of Seal
611.14	18.99	Top of Sand Pack
609.19	20.94	Top of Screen
604.67	25.46	Bottom of Screen
604.06	26.07	Bottom of Well
604.06	26.07	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	23.77
Bottom of Screen to End Cap	(feet)	0.61
Screen Length (1st slot to last slot)	(feet)	4.52
Total Length of Casing	(feet)	28.90
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G124

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G124

~~State~~ Plane Coordinate: X 2,513,900.3 Y 876,304.9 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/3/2010 Date Finished: 2/3/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/5/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

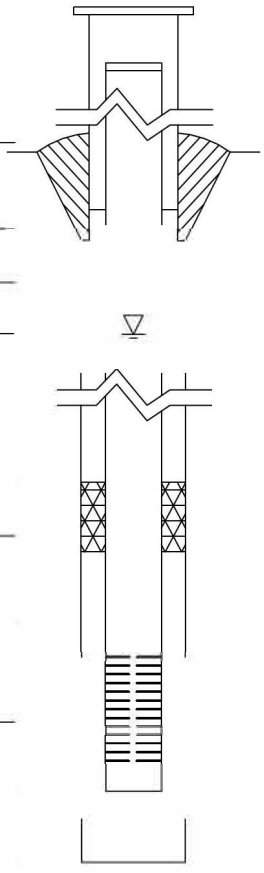
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	633.70	-3.28	Top of Protective Casing
	633.39	-2.97	Top of Riser Pipe
	630.42	0.00	Ground Surface
	625.45	4.97	Top of Annular Sealant
▽	619.43	10.99	Static Water Level (After Completion) 3/1/2010
	618.34	12.08	Top of Seal
	616.50	13.92	Top of Sand Pack
	614.44	15.98	Top of Screen
	609.91	20.51	Bottom of Screen
	609.36	21.06	Bottom of Well
	608.45	21.97	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.95
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	24.03
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G125

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G125

~~State~~ Plane Coordinate: X 2,513,899.1 Y 876,409.5 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/2/2010 Date Finished: 2/3/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/5/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 10 min

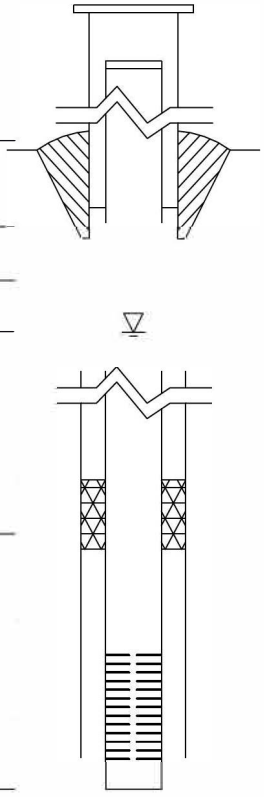
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
633.82	-3.14	Top of Protective Casing
633.51	-2.83	Top of Riser Pipe
630.68	0.00	Ground Surface
625.77	4.91	Top of Annular Sealant
622.10	8.58	Static Water Level (After Completion) 3/1/2010
617.15	13.53	Top of Seal
615.95	14.73	Top of Sand Pack
613.65	17.03	Top of Screen
609.12	21.56	Bottom of Screen
608.64	22.04	Bottom of Well
608.64	22.04	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	19.86
Bottom of Screen to End Cap	(feet)	0.58
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	24.97
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G126

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G126

~~State~~ Plant ~~Plane~~ Coordinate: X 2,513,895.4 Y 875,062.4 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/10/2010 Date Finished: 2/10/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Granular

Setting Time: 10 min

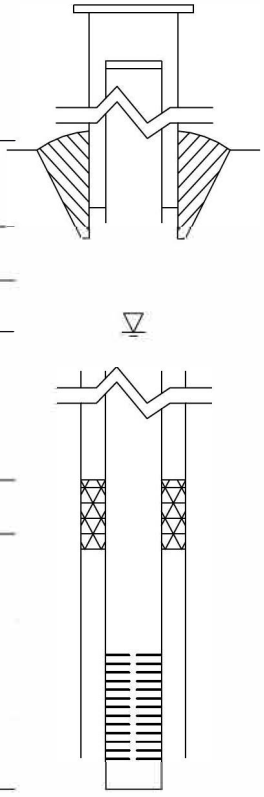
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.69	-2.73	Top of Protective Casing
625.39	-2.43	Top of Riser Pipe
622.96	0.00	Ground Surface
619.96	3.00	Top of Annular Sealant
614.14	8.82	Static Water Level (After Completion) 3/1/2010
613.96	9.00	Top of Seal
612.86	10.10	Top of Sand Pack
610.07	12.89	Top of Screen
605.53	17.43	Bottom of Screen
604.96	18.00	Bottom of Well
604.96	18.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.32
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	20.43
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: T127

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: T127

~~State~~ Plant ~~Plane~~ Coordinate: X 2,513,911.0 Y 875,359.2 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: _____ IL Registration #: _____

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Diane M. Lamb Date Started: 2/10/2010 Date Finished: 2/10/2010

Report Form Completed By: Diane M. Lamb Date: 2/19/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Granular

Setting Time: 10 min

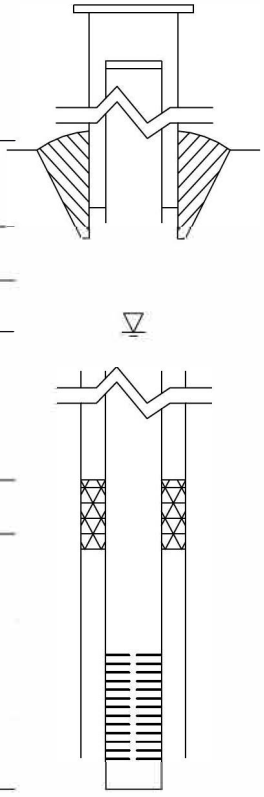
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
631.29	-3.22	Top of Protective Casing
630.96	-2.89	Top of Riser Pipe
628.07	0.00	Ground Surface
622.43	5.64	Top of Annular Sealant
616.81	11.26	Static Water Level (After Completion) 3/1/2010
613.43	14.64	Top of Seal
612.32	15.75	Top of Sand Pack
610.54	17.53	Top of Screen
606.00	22.07	Bottom of Screen
605.43	22.64	Bottom of Well
605.43	22.64	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.42
Bottom of Screen to End Cap	(feet)	0.57
Screen Length (1st slot to last slot)	(feet)	4.54
Total Length of Casing	(feet)	25.53
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: T128

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: T128

~~State~~ Plant ~~Plane~~ Coordinate: X 2,513,909.5 Y 875,509.7 (or) Latitude: ° ' " Longitude: ° ' "

Surveyed By: _____ IL Registration #: _____

Drilling Contractor: Layne-Western Co Driller: T. List

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Suzanna L. Simpson Date Started: 2/9/2010 Date Finished: 2/9/2010

Report Form Completed By: Suzanna L. Simpson Date: 2/18/2010

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Granular

Setting Time: 10 min

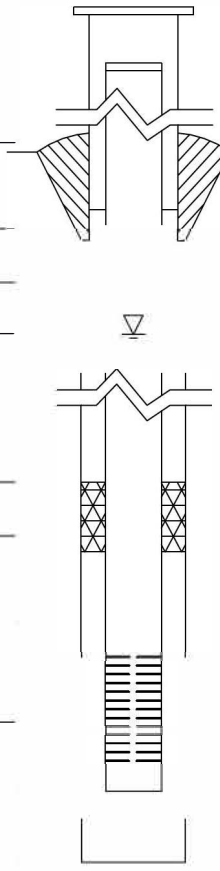
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand
(if applicable)

Installation Method: Gravity



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	631.23	-2.79	Top of Protective Casing
	630.93	-2.49	Top of Riser Pipe
	628.44	0.00	Ground Surface
	623.38	5.06	Top of Annular Sealant
	616.09	12.35	Static Water Level (After Completion) 3/1/2010
	615.53	12.91	Top of Seal
	614.13	14.31	Top of Sand Pack
	611.91	16.53	Top of Screen
	607.40	21.04	Bottom of Screen
	606.80	21.64	Bottom of Well
	604.38	24.06	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	20.02
Bottom of Screen to End Cap	(feet)	0.60
Screen Length (1st slot to last slot)	(feet)	4.51
Total Length of Casing	(feet)	25.13
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: _____ Well #: TA31

Site Name: Coffeen Power Station Borehole #: TA31

State Plane Coordinate: X 2,513,856.8 Y 876,542.2 (or) Latitude: 39° 4' 16.930" Longitude: 89° 24' 4.920"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 10/28/2014 Date Finished: 10/28/2014

Report Form Completed By: Rhonald W. Hasenyager Date: 11/5/2014

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite

Installation Method: tremie

Setting Time: 45 min.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 30 min.

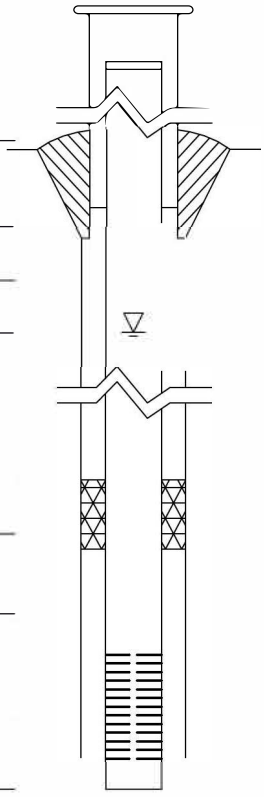
Type of Sand Pack: Quartz Sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity & Surge

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.90	-3.01	Top of Protective Casing
626.55	-2.66	Top of Riser Pipe
623.89	0.00	Ground Surface
620.89	3.00	Top of Annular Sealant
615.78	8.11	Static Water Level (After Completion) 10/30/2014
613.56	10.33	Top of Seal
610.81	13.08	Top of Sand Pack
608.80	15.09	Top of Screen
604.32	19.57	Bottom of Screen
603.70	20.19	Bottom of Well
603.70	20.19	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.82
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	4.48
Total Length of Casing	(feet)	22.85
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: _____ Well #: TA32

Site Name: Coffeen Power Station Borehole #: TA32

State Plane Coordinate: X 2,513,605.2 Y 877,532.6 (or) Latitude: 39° 4' 26.730" Longitude: 89° 24' 8.000"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 10/27/2014 Date Finished: 10/27/2014

Report Form Completed By: Rhonald W. Hasenyager Date: 11/5/2014

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite

Installation Method: tremie

Setting Time: 30 min.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 35 min.

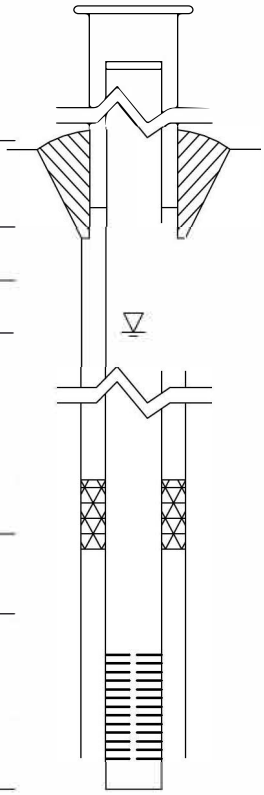
Type of Sand Pack: Quartz Sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
621.76	-2.83	Top of Protective Casing
621.42	-2.49	Top of Riser Pipe
618.93	0.00	Ground Surface
616.03	2.90	Top of Annular Sealant
604.88	14.05	Static Water Level (After Completion) 10/30/2014
611.09	7.84	Top of Seal
609.18	9.75	Top of Sand Pack
607.62	11.31	Top of Screen
603.25	15.68	Bottom of Screen
602.46	16.47	Bottom of Well
602.46	16.47	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.94
Bottom of Screen to End Cap	(feet)	0.65
Screen Length (1st slot to last slot)	(feet)	4.37
Total Length of Casing	(feet)	18.96
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: TA33

Site Name: Coffeen Well Sealing & Assmt Well Install Borehole #: TA33b

State Plane Coordinate: X 2,513,248.7 Y 876,605.4 (or) Latitude: 39° 4' 17.500" Longitude: 89° 24' 12.700"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): None

Logged By: Suzanna L. Keim Date Started: 6/2/2015 Date Finished: 6/2/2015

Report Form Completed By: Suzanna L. Keim Date: 6/4/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hrs.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 30 minutes

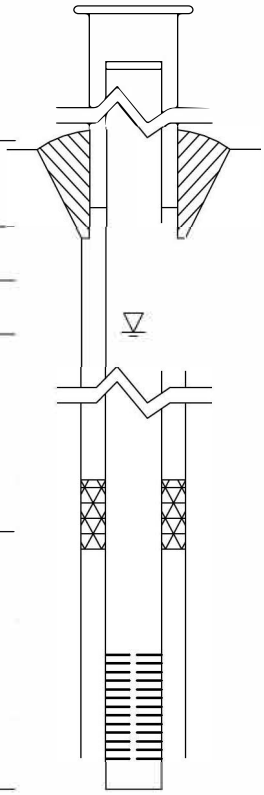
Type of Sand Pack: Quartz sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.05	-2.54	Top of Protective Casing
625.27	-2.76	Top of Riser Pipe
622.51	0.00	Ground Surface
620.51	2.00	Top of Annular Sealant
615.51	7.00	Static Water Level (After Completion) 6/16/2015
614.51	8.00	Top of Seal
612.11	10.40	Top of Sand Pack
610.28	12.23	Top of Screen
605.62	16.89	Bottom of Screen
605.07	17.44	Bottom of Well
605.07	17.44	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.5
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.99
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	4.66
Total Length of Casing	(feet)	20.20
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: TA34

Site Name: Coffeen Well Sealing & Assmt Well Install Borehole #: TA34

State Plane Coordinate: X 2,513,466.7 Y 875,906.1 (or) Latitude: 39° 4' 10.500" Longitude: 89° 24' 10.000"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): None

Logged By: Suzanna L. Keim Date Started: 6/3/2015 Date Finished: 6/3/2015

Report Form Completed By: Suzanna L. Keim Date: 6/4/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: 1 hour

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: n/a

Setting Time: n/a

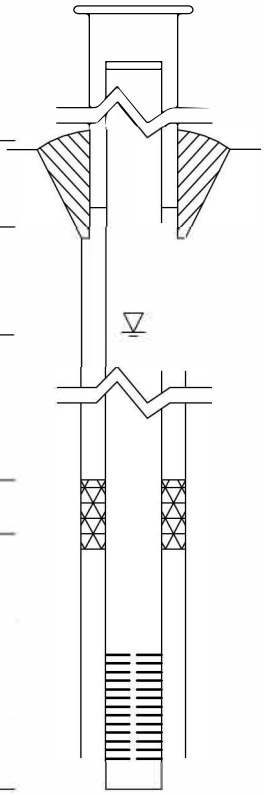
Type of Sand Pack: Quartz sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.77	-2.67	Top of Protective Casing
626.52	-2.42	Top of Riser Pipe
624.10	0.00	Ground Surface
623.10	1.00	Top of Annular Sealant
616.00	8.10	Static Water Level (After Completion) 6/16/2015
n/a	n/a	Top of Seal
615.10	9.00	Top of Sand Pack
613.18	10.92	Top of Screen
608.69	15.41	Bottom of Screen
608.00	16.10	Bottom of Well
608.00	16.10	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.5
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.34
Bottom of Screen to End Cap	(feet)	0.69
Screen Length (1st slot to last slot)	(feet)	4.49
Total Length of Casing	(feet)	18.52
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A5

SOUTHWEST POND

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/19/2011
Finish: 12/19/2011
WEATHER: Cloudy, rain (mid-60's)

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G151
Well ID: G151
Surface Elev: 622.82 ft. MSL
Completion: 20.46 ft. BGS
Station: 875,023.67N
2,513,805.93E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.00 - While drilling
▼ = 11.50 - Upon completion
▽ = 7.79 - 12/21/2011

Number	Recov / Total (in) / % Recovery	Type	Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
1A	21/24 *88%*	ss	*2-3* *4-5* N=7				0	FILL - Light yellowish brown (10YR6/4), silty CLAY with some sand and gravel.	622	
2A	19/24 *79%*	ss	*2-3* *6-9* N=9				2	FILL - Brown (10YR5/3), silty CLAY with some sand and slight trace gravel.	620	
	19/24 *79%*	ss	*2-4* *6-8* N=10				4	FILL - Brown (10YR5/3), silty CLAY with some sand and slight trace gravel.	618	
3A 4A	19/24 *79%*	ss	*15-15* *18-11* N=33				6	Brown (10YR5/3) with 30% gray (10YR6/1) mottles, clayey SILT with trace sand and slight trace gravel.	616	
5A	18/24 *75%*	ss	*1-3* *4-4* N=7				▽ 8	Brown (10YR5/3) with 30% gray (10YR6/1) mottles, silty CLAY with sand and gravel.	614	
6A	16/24 *67%*	ss	*3-3* *4-6* N=7				10		612	
7A	22/24 *92%*	ss	*9-9* *10-9* N=19				▼ 12	Light gray (10YR5/1) with 40% yellowish brown (10YR5/6) mottles, sandy CLAY with some silt and slight trace gravel.	610	
	19/24 *79%*	ss	*15-15* *35-70* N=50				14	Light brown (10YR5/3) silty SAND with slight trace gravel.	608	
8A 9A	4/4 *100%*	ss	*50/4"*				▼ 16	Light gray (10YR6/1), silty SAND with slight trace gravel. Light brown (10YR6/4), silty SAND with some gravel.	606	
10A	10/23 *43%*	ss	*12-18* *70-99/5"* N=88				18	Dark gray (10YR5/1), very silty CLAY with sand and trace gravel.	604	
							20	**End of Boring = 20.5 ft. BGS**		

NOTE(S): G151 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/20/2011
Finish: 12/20/2011
WEATHER: Cloudy, (mid-40's), rainy later.

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G152
Well ID: G152
Surface Elev: 623.06 ft. MSL
Completion: 18.57 ft. BGS
Station: 874,687.53N
2,513,894.46E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.50 - While drilling
▼ = 3.05 - Upon completion
▽ = 17.00 - 12/21/2011

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Dark brown (10YR4/2), silty CLAY with trace sand and slight trace gravel.			
1A	12/24 50%	ss	2-2 2-3 N=4					Light yellowish brown (10YR6/4), silty CLAY with trace sand and slight trace gravel.		622	
2A	22/24 92%	ss	2-4 9-7 N=13				2	Gray (10YR6/1), silty CLAY with trace sand and slight trace gravel.		620	
2B							4				
3A	15/24 63%	ss	3-4 5-6 N=9					Gray (10YR6/1) and 25% brown (10YR5/6) mottles, silty CLAY with trace sand and slight trace gravel.		618	
3B							6				
5A	19/24 79%	ss	10-10 12-10 N=22					Gray (10YR5/1), clayey SILT silty CLAY with sand and slight trace gravel.		616	
	20/24 83%	ss	2-4 6-7 N=10				8			614	
5B								Gray (10YR5/1) with 25% brown (10YR5/6) mottles, silty CLAY with trace sand and slight trace gravel.			
6A	21/24 88%	ss	2-3 5-7 N=8				10	Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, silty CLAY with trace sand and slight trace gravel.		612	
7A	20/24 83%	ss	5-7 9-10 N=16				12	Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, clayey SAND with some silt and slight trace gravel.		610	
							14	Yellowish brown (10YR5/6) with 20% gray (10YR6/1), mottles, clayey SAND with some silt and slight trace gravel.			
8A	21/24 88%	ss	3-4 7-11 N=11					Yellowish brown (10YR5/6), silty SAND.		608	
8B								Yellowish brown (10YR5/6), silty SAND with slight trace gravel.			
							16	Dark grayish brown (10YR4/2), very silty CLAY with sand and trace gravel.			
9A	23/24 96%	ss	14-35 60-70 N=95					Grayish brown (10YR5/2) silty CLAY with sand and trace gravel.		606	
							18				

End of Boring = 18.6 ft. BGS

NOTE(S): G152 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/15/2011
Finish: 12/15/2011
WEATHER: Cloudy, windy, (mid-high 30's)

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G153
Well ID: G153
Surface Elev: 623.30 ft. MSL
Completion: 20.76 ft. BGS
Station: 874,532.71N
2,513,532.68E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.00 - While drilling
▼ = 15.70 - Upon completion
▽ = 17.55 - 12/21/2011

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss					0	FILL - Light yellowish brown (10YR6/4), silty CLAY with sand and slight trace gravel.		622	
1B							2	FILL - Gray (10YR6/1), silty CLAY with sand and slight trace gravel.			
	17/24 71%	ss	woh-3 4-6 N=7							620	
2A							4	Gray (10YR6/1) with 50% brownish yellow (10YR6/8) mottles, silty CLAY with trace sand.			
3A	18/24 75%	ss	3-4 5-5 N=9							618	
							6	Gray (10YR5/1), silty CLAY with trace sand.			
4A	21/24 88%	ss	4-5 6-8 N=11							616	
							8				
5A	20/24 83%	ss	1-4 4-5 N=8					Gray (10YR6/1), silty CLAY with sand and slight trace gravel.		614	
							10	Gray (10YR6/1), silty CLAY with sand and slight trace gravel.			
	20/24 83%	ss	1-4 4-6 N=8					Gray (10YR6/1) with 50% brownish yellow (10YR6/8) mottles, silty CLAY with sand and slight trace gravel.		612	
6A							12				
	23/24 96%	ss	7-6 6-15 N=12					Gray (10YR6/1) with 25% brownish yellow (10YR6/8) mottles, clayey SAND with trace silt.		610	
7A							14				
8A	19/24 79%	ss	15-23 37-50 N=60					Yellowish brown (10YR5/8), silty SAND with slight trace gravel.		608	
							▼ 16				
9A	9/12 75%	ss	50-99				▽	Brownish yellow (10YR6/8), silty CLAY with sand and trace gravel.		606	
							18				
	20/24 83%	ss	23-50 58-109 N=108					Dark gray (10YR4/1), silty CLAY with sand and trace gravel.		604	
10A	6/7 86%	ss	75-99/1"				20				
11A								**End of Boring = 20.8 ft. BGS**			

NOTE(S): G153 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/16/2011
Finish: 12/16/2011
WEATHER: Ptly. cloudy (mid-30's)

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G154
Well ID: G154
Surface Elev: 623.52 ft. MSL
Completion: 20.00 ft. BGS
Station: 874,978.38N
2,513,243.10E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.45 - While drilling
▼ =
▽ = 11.10 - 12/21/2011

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	14/24 58%	ss	3-4 4-5 N=8				0	FILL - Light yellowish brown (10YR6/4), silty CLAY with trace sand and slight trace gravel.		622	
2A	10/24 42%	ss	woh-1 4-5 N=5				2	Brownish yellow (10YR6/6) with 25% gray (10YR6/1) mottles, silty CLAY with trace sand.		620	
3A	14/24 58%	ss	2-4 6-7 N=10				4	Gray (10YR5/1) with 25% yellowish brown (10YR5/4) mottles, silty CLAY with trace sand.		618	
4A	21/24 88%	ss	6-8 10-10 N=18				6	Gray (10YR6/1) with 25% brownish yellow (10YR6/6) mottles, silty CLAY with trace sand and slight trace gravel.		616	
5A	16/24 67%	ss	1-4 6-8 N=10				8			614	
6A	13/24 54%	ss	1-4 6-8 N=10				10 ▽			612	
7A	20/24 83%	ss	4-6 8-12 N=14				12	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) mottles, silty CLAY with trace sand and slight trace gravel.			
7B							▼	Gray (10YR6/1), silty CLAY with trace sand and slight trace gravel.		610	
8A	23/24 96%	ss	4-18 30-37 N=48				14	Gray (10YR6/1), clayey SAND with trace silt.			
8B								Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, silty SAND with slight trace gravel.		608	
8C							16	Dark yellowish brown (10YR4/4), silty CLAY with sand and trace gravel.			
9A	21/24 88%	ss	40-75 86-84 N=161					Brown (10YR4/3), silty CLAY with sand and trace gravel.		606	
10A	20/24 83%	ss	28-28 30-34 N=58				18	Dark gray (10YR4/1), silty CLAY with sand and trace gravel.		604	
							20	**End of Boring = 20.0 ft. BGS**			

NOTE(S): G154 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/19/2011
Finish: 12/19/2011
WEATHER: Cloudy, rainy, (mid-40's)

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G155
Well ID: G155
Surface Elev: 622.89 ft. MSL
Completion: 20.23 ft. BGS
Station: 875,127.65N
2,513,501.75E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.30 - While drilling
▼ = 12.90 - Upon completion
▽ = 7.90 - 12/21/2011

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tst) Qp (tst) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	20/24 83%	ss	4-6 8-6 N=14				0	FILL - Yellow (10YR7/6), silty CLAY with trace sand and slight trace gravel.		622	
							1	FILL - Brown (10YR5/3), silty CLAY with sand and trace gravel.			
								FILL - Brown (10YR5/3), silty CLAY with trace sand and slight trace gravel.			
2A	20/24 83%	ss	2-4 6-7 N=10				2	FILL - Brownish yellow (10YR6/6), silty CLAY with trace sand and slight trace gravel.		620	
								FILL - Dark grayish brown (10YR4/2), silty CLAY with trace sand and slight trace gravel.			
							4	Gray (10YR5/1), silty CLAY with trace sand and slight trace gravel.		618	
3A	17/24 71%	ss	2-4 5-8 N=9				6	Brownish yellow (10YR6/6) with 10% gray (10YR6/1) mottles, silty CLAY with trace sand and slight trace gravel.		616	
4A	24/24 100%	ss	6-7 11-11 N=18				▽ 8	Dark gray (10YR4/1) with10% brown (10YR4/3) mottles, silty CLAY with trace sand and slight trace gravel.		614	
5A	22/24 92%	ss	woh-3 6-6 N=9				10	Dark yellowish brown (10YR4/6) with 30% grayish brown (10YR5/2) mottles,silty CLAY with trace sand and slight trace gravel.		612	
6A	17/24 71%	ss	2-4 6-6 N=10				12	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, clayey SAND with trace silt.		610	
7A	24/24 100%	ss	6-8 10-12 N=18				▼ 14	Yellowish brown (10YR6/4), clayey SAND with trace silt.		608	
8A	23/24 96%	ss	woh-woh 4-15					Yellowish brown (10YR5/6), silty SAND with slight trace gravel.			
8B	16/16 100%	ss	15-50 99/4"				16	Yellowish brown (10YR5/6), silty SAND with slight trace gravel.		606	
9A								Light brownish gray (10YR6/2), silty CLAY with sand and trace gravel.			
10A	15/17 88%	ss	24-68 99/5"				18	Light gray (10YR6/2), silty CLAY with sand and trace gravel.		604	
							20				

End of Boring = 20.2 ft. BGS

NOTE(S): G155 installed in borehole.

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G151

Site Name: CCB Management Facility Borehole #: G151

State Plane Coordinate: X 2,513,805.9 Y 875,023.7 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/19/2011 Date Finished: 12/19/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 24 min

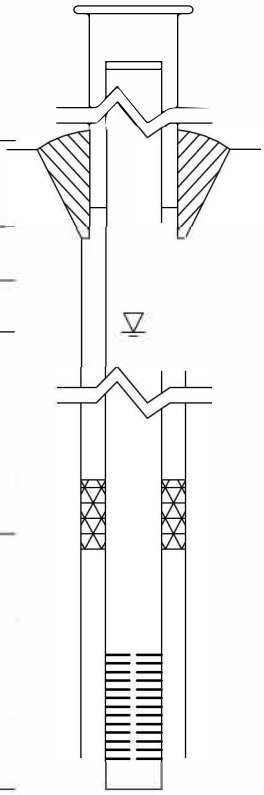
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.24	-3.42	Top of Protective Casing
625.93	-3.11	Top of Riser Pipe
622.82	0.00	Ground Surface
620.49	2.33	Top of Annular Sealant
615.03	7.79	Static Water Level (After Completion) 12/21/2011
611.82	11.00	Top of Seal
609.07	13.75	Top of Sand Pack
607.48	15.34	Top of Screen
602.98	19.84	Bottom of Screen
602.36	20.46	Bottom of Well
602.36	20.46	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.45
Bottom of Screen to End Cap	(feet)	0.62
Screen Length (1st slot to last slot)	(feet)	4.50
Total Length of Casing	(feet)	23.57
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G152

Site Name: CCB Management Facility Borehole #: G152

State Plane Coordinate: X 2,513,894.5 Y 874,687.5 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

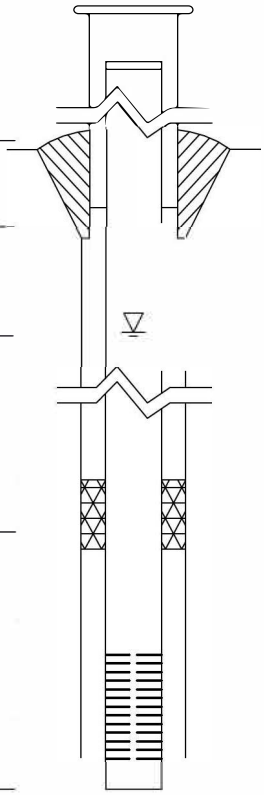
Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/20/2011 Date Finished: 12/20/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: Seal extended to near surface

Installation Method:

Setting Time: _____

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: >24 hr.

Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a

Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.67	-3.61	Top of Protective Casing
626.52	-3.46	Top of Riser Pipe
623.06	0.00	Ground Surface
621.06	2.00	Top of Annular Sealant
606.06	17.00	Static Water Level (After Completion) 12/21/2011
621.06	2.00	Top of Seal
611.56	11.50	Top of Sand Pack
609.47	13.59	Top of Screen
604.97	18.09	Bottom of Screen
604.49	18.57	Bottom of Well
604.49	18.57	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: ( )
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.05
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	4.50
Total Length of Casing	(feet)	22.03
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G153

Site Name: CCB Management Facility Borehole #: G153

State Plane Coordinate: X 2,513,532.7 Y 874,532.7 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/15/2011 Date Finished: 12/15/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: >24 hr.

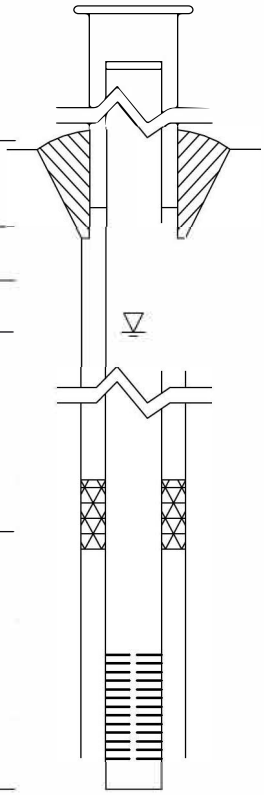
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.59	-3.29	Top of Protective Casing
626.35	-3.05	Top of Riser Pipe
623.30	0.00	Ground Surface
622.63	0.67	Top of Annular Sealant
605.75	17.55	Static Water Level (After Completion) 12/21/2011
610.30	13.00	Top of Seal
608.30	15.00	Top of Sand Pack
607.40	15.90	Top of Screen
602.96	20.34	Bottom of Screen
602.54	20.76	Bottom of Well
602.54	20.76	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.95
Bottom of Screen to End Cap	(feet)	0.42
Screen Length (1st slot to last slot)	(feet)	4.44
Total Length of Casing	(feet)	23.81
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G154

Site Name: CCB Management Facility Borehole #: G154

State Plane Coordinate: X 2,513,243.1 Y 874,978.4 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/16/2011 Date Finished: 12/16/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 24 min

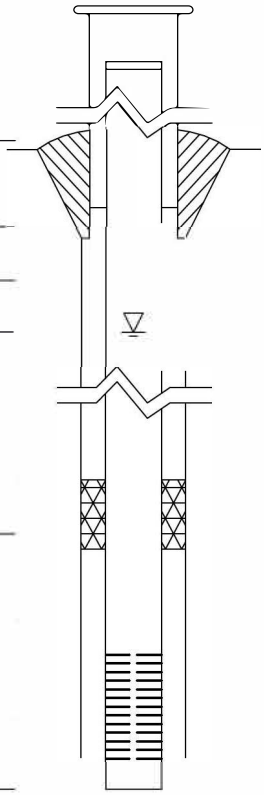
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.55	-3.03	Top of Protective Casing
626.35	-2.83	Top of Riser Pipe
623.52	0.00	Ground Surface
622.44	1.08	Top of Annular Sealant
612.42	11.10	Static Water Level (After Completion) 12/21/2011
613.02	10.50	Top of Seal
610.02	13.50	Top of Sand Pack
609.26	14.26	Top of Screen
604.76	18.76	Bottom of Screen
604.42	19.10	Bottom of Well
603.52	20.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.09
Bottom of Screen to End Cap	(feet)	0.34
Screen Length (1st slot to last slot)	(feet)	4.50
Total Length of Casing	(feet)	21.93
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G155

Site Name: CCB Management Facility Borehole #: G155

State Plane Coordinate: X 2,513,501.8 Y 875,127.7 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/19/2011 Date Finished: 12/19/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 27 min

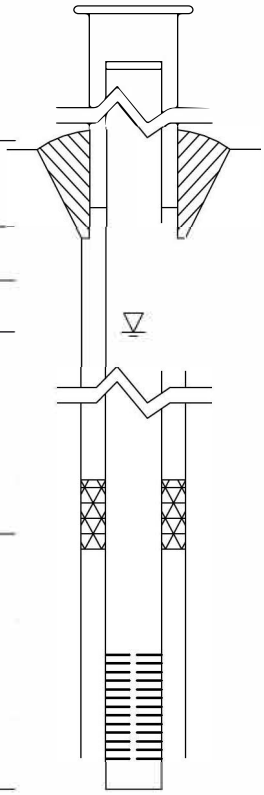
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.07	-3.18	Top of Protective Casing
625.86	-2.97	Top of Riser Pipe
622.89	0.00	Ground Surface
621.39	1.50	Top of Annular Sealant
614.99	7.90	Static Water Level (After Completion) 12/21/2011
611.89	11.00	Top of Seal
609.14	13.75	Top of Sand Pack
607.80	15.09	Top of Screen
603.31	19.58	Bottom of Screen
602.66	20.23	Bottom of Well
602.66	20.23	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	18.28
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.49
Total Length of Casing	(feet)	23.20
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A6

ASH POND 1

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/8/2015
Finish: 9/8/2015
WEATHER: Sunny, hi 70's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G281
Well ID: G281
Surface Elev: 623.82 ft. MSL
Completion: 20.29 ft. BGS
Station: 2,514,455.48N
874,375.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Light gray (10YR7/2), dry, very stiff, SILT with little clay and trace gravel.			
1A	17/24 *71%*	SS	*15-10* *7-6* N=17	14			2	Yellowish brown (10YR5/4) with 5% dark brown (10YR3/3) mottles, dry, very stiff, SILT with few clay and trace gravel.		622	
2A	19/24 *79%*	SS	*2-4* *5-5* N=9	25		*1.50*	4	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with few clay.		620	
3A	22/24 *92%*	SS	*2-2* *3-4* N=5	23		*0.40*	6	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) mottles, moist, medium, CLAY with some silt and trace fine-grained sand and small gravel.		618	
4A	24/24 *100%*	SS	*5-5* *6-6* N=11	19		*1.20*	8	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, CLAY with some silt and trace fine-grained sand and small gravel.		616	
5A	20/24 *83%*	SS	*2-2* *3-4* N=5	21		*1.40*	10	Yellowish brown (10YR5/4) with 30% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with some clay and trace very fine- to fine-grained sand and small gravel.		614	
6A	22/24 *92%*	SS	*2-2* *3-3* N=5	18		*0.50*	12	Dark yellowish brown (01YR4/6) with 30% yellowish brown (10YR5/4) mottles, moist, soft, SILT with few clay and little fine- to coarse-grained sand and small gravel, trace wood fragments.		612	
7A	17/24 *71%*	SS	*3-4* *5-5* N=9	19		*0.30*	14 ▼	Dark yellowish brown (01YR4/6) with 15% yellowish brown (10YR5/4) mottles, moist, soft, SILT with few clay and very fine- to fine-grained sand and trace small gravel.		610	
	19/24 *79%*	SS	*3-11* *21-28* N=32				16	Dark yellowish brown (10YR4/4), wet, dense, very fine- to fine-grained SAND with some silt, few clay and trace small gravel.		608	
	24/24 *100%*	SS	*21-36* *39-50* N=75				18	Dark yellowish brown (10YR4/4), wet, dense, very fine- to fine-grained SAND with few silt, little clay and trace small gravel.		606	
8A	11/24 *46%*	SS	*16-9* *30-50* N=39	7		*4.50*		Yellowish brown (10YR5/6) with 5% strong brown (7.5YR5/6) mottles, moist, hard, SILT with few clay and little fine-grained sand and small gravel.			
	0/3 *0%*	BD					20	Dark grayish brown (10YR4/2) with 5% strong brown (7.5YR5/6) mottles, moist, hard, SILT with few clay and little fine-grained sand and small gravel.		604	

End of boring = 20.29 feet

NOTE(S): G281 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/4/2015
Finish: 9/4/2015
WEATHER: Sunny, hi 70's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G301
Well ID: G301
Surface Elev: 620.27 ft. MSL
Completion: 16.21 ft. BGS
Station: 2,515,582.97N
872,234.82E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	SS	4-4 3-5 N=7	18		1.80	0	Brown (10YR4/3), moist, stiff, SILT with few clay, trace organics.		620	
							2	Brown (10YR5/3) with 30% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with few clay, trace organics.		618	
2A	22/24 92%	SS	2-4 4-6 N=8	26		2.40	4	Brown (10YR5/3) with 30% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with few clay, trace very fine- to medium-grained sand.		616	
3A	21/24 88%	SS	2-2 3-4 N=5	22		1.30	6	Brown (10YR5/3) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt and trace very fine- to medium-grained sand.		614	
4A	24/24 100%	SS	6-4 6-6 N=10	19		1.10	8	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, medium to stiff, CLAY with some silt and little very fine- to coarse-grained sand and small gravel.		612	
5A	21/24 88%	SS	1-2 3-4 N=5	21				Brown (10YR5/3) with 5% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with some clay and little very fine- to coarse-grained sand and small gravel.			
6A	24/24 100%	SS	3-2 3-3 N=5	19		0.80	10	Brown (10YR5/3) with 20% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with some clay and little very fine- to coarse-grained sand and small gravel.		610	
7A	24/24 100%	SS	2-4 6-21 N=10	13		1.60	▼ 12	Yellowish brown (10YR5/6) with 10% grayish brown (10YR5/2) and 5% yellowish brown (10YR5/4) mottles, wet, stiff, SILT with few clay and little fine- to coarse-grained sand and small gravel.		608	
8A	21/24 88%	SS	20-27 50 N=77	7		4.50	14	Grayish brown (10YR5/2) with 5% brown (10YR5/3) mottles, dry, hard, SILT with few clay, very fine- to coarse-grained sand and small gravel.		606	
	0/3 0%	BD					16	**End of boring = 16.21 feet**			

NOTE(S): G301 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/3/2015
Finish: 9/4/2015
WEATHER: Sunny, hi 70's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G302
Well ID: G302
Surface Elev: 617.95 ft. MSL
Completion: 18.39 ft. BGS
Station: 2,516,214.19N
872,252.95E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Yellowish brown (10YR5/6) to dark yellowish brown (10YR4/6), moist, hard, SILT with some clay and trace fine-grained sand and small gravel.			
1A	23/24 96%	SS	5-5 5-6 N=10	17		1.50	2	Very dark brown (10YR3/1), moist, hard, SILT with some clay and trace fine-grained sand and small gravel.		616	
2A	20/24 83%	SS	2-3 4-4 N=7	27		2.60	4	Dark grayish brown (10YR4/2) with very dark gray (10YR3/1) mottles, moist, stiff, CLAY with some silt and trace sand.		614	
3A	21/24 88%	SS	1-2 3-4 N=5	26		1.80	6	Brown (10YR5/3) with dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with some silt and trace sand.		612	
4A	24/24 100%	SS	4-7 8-8 N=15	18		1.60	8	Brown (10YR5/3) with dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with some silt and few very fine- to fine-grained sand.		610	
5A	24/24 100%	SS	2-3 5-5 N=8	17		1.80	10	Brown (10YR4/3) with dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with some clay and few sand.		608	
6A	18/24 75%	SS	2-2 4-5 N=6	19			12	Dark gray (10YR4/1), moist, stiff, SILT with some clay and few sand. Yellowish brown (10YR5/8) with reddish brown (5YR4/4) inclusions, moist, stiff, SILT with some clay and few sand.		606	
7A	24/24 100%	SS	7-7 8-8 N=15	16		1.70	▼ 14	Dark gray (10YR4/1), moist, stiff, SILT with some clay, few sand and trace small gravel.		604	
8A				18		0.80					
8B	22/24 92%	SS	2-5 25-32 N=30	12		4.50	16	Grayish brown (10YR5/2), wet, hard, SILT with little clay and very fine-grained sand and trace small gravel.		602	
9A	24/24 100%	SS	7-24 48-38 N=72	8		4.50	18	Brown (10YR5/3), wet, hard, SILT with little clay and very fine-grained sand and trace small gravel. Brown (10YR5/3) grading to yellowish brown (10YR5/4), moist, hard, SILT with some clay, few small gravel.		600	
	0/5 0%	BD						**End of boring = 18.39 feet**			

NOTE(S): G302 installed in borehole.

printed 04/29/2015 10:25AM by Sharon.Dowson p. 14/58

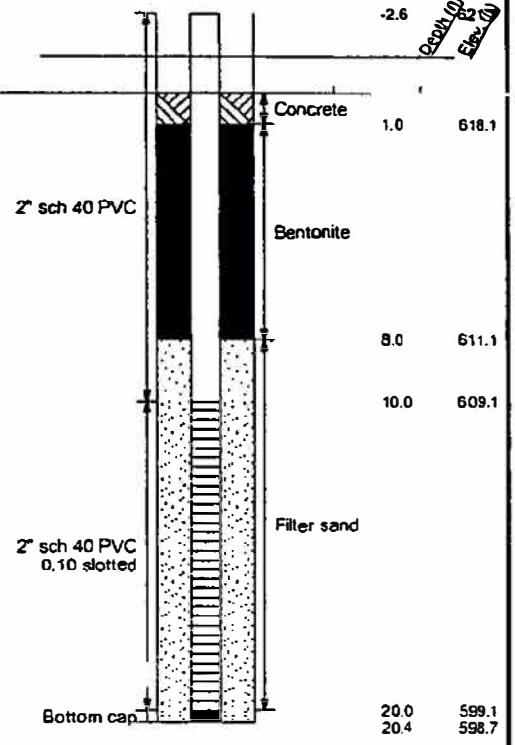
Surface Elevation: 619.10
Datum msl

Completion Date: 8/26/10
Northing: 871382.45
Easting: 2516641.06

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	FILL: brown, silty clay		1-2-3	SS1
	Medium stiff, grayish-brown, silty CLAY with lignite - CL		1-3-3	SS2
5			1-3-4	SS3
	Soft, brown, silty CLAY - CL		2-3-3	SS4
10	Stiff to hard, brown to grayish-brown, silty CLAY - CL (TILL)			
			27-44 -50/1"	SS5
15				
			44-50/2"	SS6
20	Boring terminated at 20 feet.			
25				
30				
35				

WELL DIAGRAM

Stickup
Diameter: 6 inches



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01-COFFEEN.GPJ GTINC.0636301.GPJ 12/13/10

GROUNDWATER DATA

ENCOUNTERED AT 9 FEET ▽

DRILLING DATA

__ AUGER _4 1/4"_ HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER _SWG_ LOGGER
CME 55TRK DRILL RIG
HAMMER TYPE _Auto_

REMARKS:

Drawn by: KSA	Checked by: DJK	App'vd. by: KBC
Date: 9/10/10	Date: 1-4-11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren-Coffeen Ash Pond Evaluation

LOG OF BORING: APW-3
G303

Project No. J017150.01

Surface Elevation: 623.46

Datum msl

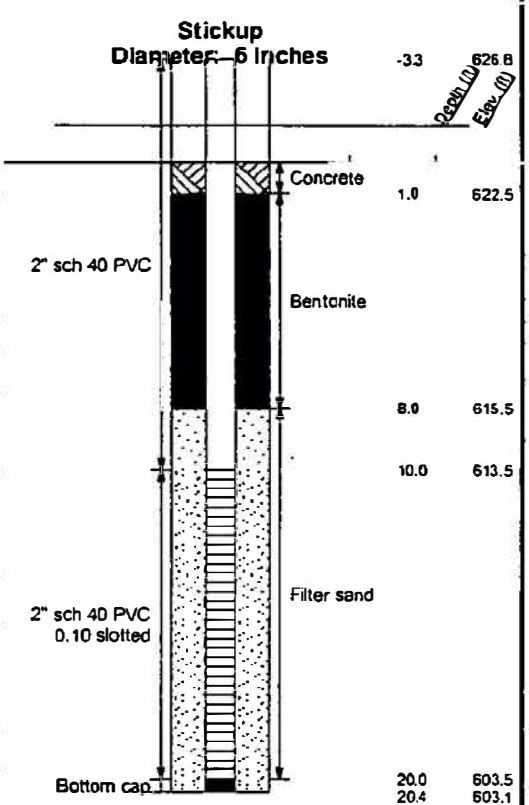
Completion Date: 8/26/10

Northing: 871397.48

Easting: 2515520.23

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff, grayish-brown, silty CLAY - CL		0-1-1	SS1
5			1-2-5	SS2
			1-3-4	SS3
10			1-2-3	SS4
	Medium to fine SAND - SP		1-2-1	SS5
15	Hard, gray, silty CLAY - CL (TILL)			
			14-47	SS6
20	Boring terminated at 20 feet.			
25				
30				
35				

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01-COFFEEN.GPJ GTINC 0638301.GPJ 12/13/10

GROUNDWATER DATA

ENCOUNTERED AT 14 FEET ▽

DRILLING DATA

__ AUGER _4 1/4"_ HOLLOW STEM

WASHBORING FROM __ FEET

MVU DRILLER _SWG_ LOGGER

CME 55TRK DRILL RIG

HAMMER TYPE _Auto_

Drawn by: KSA Date: 9/10/10

Checked by: DTK Date: 1-4-11

App'vd. by: RJS Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

REMARKS:

Ameren-Coffeen Ash Pond Evaluation

LOG OF BORING: APW-4

G304

Project No. J017150.01

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Power Station
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/3/2016
Finish: 5/3/2016
WEATHER: Cloudy, breezy, warm, lo 60s

CONTRACTOR: Ramsey Geotechnical Engineering LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: 4 ¼" HSA, split spoon sampler

FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: G305
Well ID: G305
Surface Elev: 622.54 ft. MSL
Completion: 18.45 ft. BGS
Station: 2,515,199.36N
871,156.33E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 14, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 3.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	14/24 58%	SS	2-2 5-7 N=7	12			0	FILL - Grayish brown (10YR5/2), moist, soft, silty CLAY with few small to coarse sand and few small to large gravel.		622	
							2	FILL - Black (10YR2/1), moist, loose, silty, fine- to coarse-grained SAND with little coal fragments.		620	
2A	17/24 71%	SS	6-7 7-6 N=14	19			▼ 4	Gray (10YR6/1) and light yellowish brown (10YR6/4), moist, very stiff, SILT with little clay.		618	
3A	18/24 75%	SS	3-3 6-4 N=9	28			6	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with trace very fine-grained sand.		616	
4A	16/24 67%	SS	6-6 7-8 N=13	24			8	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with trace very fine- to coarse-grained sand.		614	
5A	23/24 96%	SS	1-3 5-6 N=8	21			10	Dark gray (10YR4/1) with 25% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with few fine- to coarse-grained sand and trace small gravel.		612	
6A	21/24 88%	SS	3-4 6-6 N=10	21			12	Gray (10YR5/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with few fine- to coarse-grained sand and trace small gravel.		610	
7A	24/24 100%	SS	8-8 9-9 N=17	18			14	Yellowish brown (10YR5/8) with 15% gray (10YR5/1) mottles, moist, very stiff, silty CLAY with few fine- to coarse-grained sand and trace small gravel.		608	
8A	19/24 79%	SS	3-3 4-4 N=7	18			16	Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with little fine- to coarse-grained sand and trace small gravel. Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with some fine- to coarse-grained sand and trace small gravel.		606	
9A	22/24 92%	SS	1-3 7-14 N=10	19				Brown (10YR5/3), wet, loose, very silty, very fine- to coarse-grained SAND with trace small gravel.			
9B	0/5 0%	BD		15			18	Brown (10YR5/3) with 40% yellowish brown (10YR5/8) mottles, moist, very stiff, SILT with little clay and trace fine- to coarse-grained sand. **End of boring = 18.45 feet**			

NOTE(S): G305 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Power Station
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/3/2016
Finish: 5/3/2016
WEATHER: Sunny, calm, warm, lo 60s

CONTRACTOR: Ramsey Geotechnical Engineering LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: 4 ¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** B. Williamson
Helper: D. Crump
Eng/Geo: S. Keim

BOREHOLE ID: G306
Well ID: G306
Surface Elev: 622.84 ft. MSL
Completion: 18.00 ft. BGS
Station: 2,516,120.41N
871,140.98E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 14, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 5.50 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	12/24 50%	ss	1-3 3-4 N=6	14			0	Very dark brown (10YR2/2), moist, medium, SILT with little clay and few very fine- to medium-grained sand, roots, trace coal fragments.		622	
2A	24/24 100%	ss	5-4 5-4 N=9	21			2	Dark gray (10YR4/1) with 5% dark yellowish brown (10YR3/6) mottles, moist, stiff, SILT with little clay and trace very fine- to medium-grained sand.		620	
2B				19			4	Gray (10YR6/1) with 10% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with little clay and trace very fine-grained sand.		618	
3A	22/24 92%	ss	2-2 3-3 N=5	30			6	Gray (10YR6/1) with 20% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with some clay and trace very fine-grained sand.		616	
4A	20/24 83%	ss	3-4 6-6 N=10	26			8	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with trace very fine- to coarse-grained sand.		614	
5A	24/24 100%	ss	2-2 3-3 N=5	23			10	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, silty CLAY with few very fine- to coarse-grained sand.		612	
6A	22/24 92%	ss	1-2 3-4 N=5	20			12	Yellowish brown (10YR5/6), wet, soft, very fine- to coarse-grained sandy CLAY with little silt.		610	
7A	20/24 83%	ss	5-6 6-6 N=12	21			14	Yellowish brown (10YR5/6), wet, medium dense, silty, very fine- to medium-grained SAND with trace coarse-grained sand.		608	
8A	20/24 83%	ss	2-2 8-14 N=10	15			16	Yellowish brown (10YR5/6), moist, dense, fine- to coarse-grained SAND with little silt, little very fine-grained sand, and trace small gravel.		606	
8B				12			18	Brown (10YR5/3) with 20% dark yellowish brown (10YR4/6) mottles, moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel.			
9A	23/24 96%	ss	14-17 28-50/5" N=45	10				**End of boring = 18.0 feet**			
9B				13							

NOTE(S): G306 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Co.
Site: Coffeen Power Station Ash Pond 1
Location: Coffeen, Illinois
Project: 16E0108
DATES: **Start:** 07/26/2016
Finish: 07/27/2016
WEATHER: Overcast, warm & humid (mid-80s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME 55LC Track Drill
Drilling Method: 4¼" Hollow Stem Auger w/Continuous Split Spoon
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G307
Well ID: G307
Surface Elev: 622.08 ft. MSL
Completion: 18.22 ft. BGS
Station: 871,398.55N
2,515,553.26E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - during drilling
▼ = -1.76 - 7/27/2016 @ 07:30
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	18/24 75%	ss	1-3 3-2 N=6	22			0	Brown (10YR5/3), moist, stiff, SILT with few clay, trace sand, gravel and roots.			
2A	22/24 92%	ss	2-1 3-3 N=4	28			2	Gray (10YR5/1), moist, soft, CLAY, with some silt, trace sand, gravel and roots.		620	
3A	24/24 100%	ss	1-2 3-4 N=5	26			4	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, CLAY with some silt, trace sand, gravel and roots.		618	
4A	24/24 100%	ss	1-3 3-3 N=6	18			6			616	
5A	24/24 100%	ss	3-3 4-5 N=7	19			8	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, moist, medium CLAY,with some silt, few very fine- to medium-grained sand, and trace gravel.		614	
6A	24/24 100%	ss	3-3 4-5 N=7	20			10			612	
7A	24/24 100%	ss	woh-2 5-13 N=7	20			12	Gray (10YR5/1), moist, medium, CLAY with little silt and very fine to very coarse sand, trace gravel. Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, soft, CLAY with some silt, trace sand and gravel.		610	
7B				11			▼ 14	Gray (10YR6/1), wet, medium dense, very fine- to very coarse-grained SAND with few silt and trace clay.		608	
8A	24/24 100%	ss	12-9 6-9 N=15	20				Yellow brown (10YR5/6), wet. medium dense, very fine- to very coarse-grained SAND, with little silt and trace gravel.			
9A	18/18 100%	ss	8-30 50 N=80	8			16	Yellowish brown (10YR5/8), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand and trace gravel.		606	
	0/9 0%	BD						Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand and trace gravel.			
							18			604	

End of boring = 18.2 feet

NOTE(S):

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G281

Site Name: Coffeen Power Station Borehole #: G281

State Plane Coordinate: X 874,375.4 Y 2,514,455.5 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/8/2015 Date Finished: 9/8/2015

Report Form Completed By: Suzanna L. Keim Date: 10/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 25 minutes

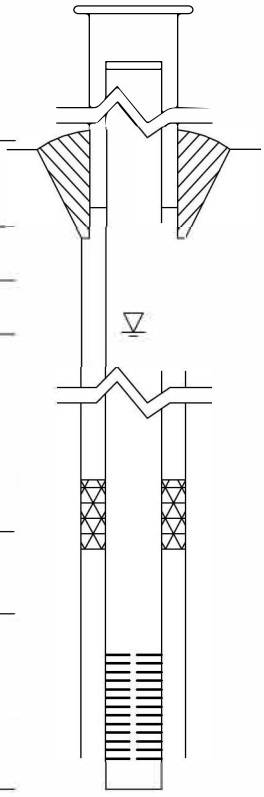
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.64	-2.82	Top of Protective Casing
626.36	-2.54	Top of Riser Pipe
623.82	0.00	Ground Surface
622.82	1.00	Top of Annular Sealant
		Static Water Level (After Completion)
612.59	11.23	Top of Seal
610.37	13.45	Top of Sand Pack
608.31	15.51	Top of Screen
603.66	20.16	Bottom of Screen
603.53	20.29	Bottom of Well
603.53	20.29	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.80
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.65
Total Length of Casing	(feet)	22.83
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G301

Site Name: Coffeen Power Station Borehole #: G301

State Plane Coordinate: X 872,234.8 Y 2,515,583.0 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/4/2015 Date Finished: 9/4/2015

Report Form Completed By: Suzanna L. Keim Date: 10/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 25 minutes

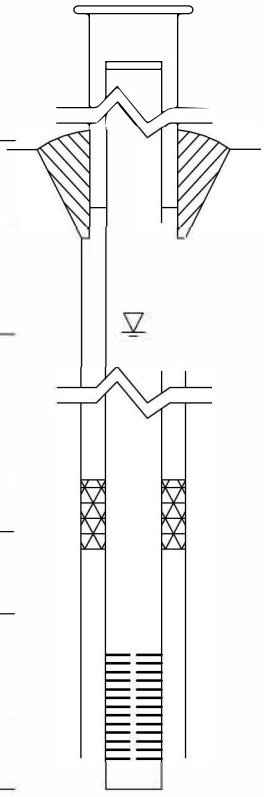
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
622.98	-2.71	Top of Protective Casing
622.65	-2.38	Top of Riser Pipe
620.27	0.00	Ground Surface
618.20	2.07	Top of Annular Sealant
		Static Water Level (After Completion)
n/a	n/a	Top of Seal
612.75	7.52	Top of Sand Pack
608.96	11.31	Top of Screen
604.31	15.96	Bottom of Screen
604.06	16.21	Bottom of Well
604.06	16.21	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.56
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.65
Total Length of Casing	(feet)	18.59
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G302

Site Name: Coffeen Power Station Borehole #: G302

State Plane Coordinate: X 872,253.0 Y 2,516,214.2 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/3/2015 Date Finished: 9/4/2015

Report Form Completed By: Suzanna L. Keim Date: 10/7/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 25 minutes

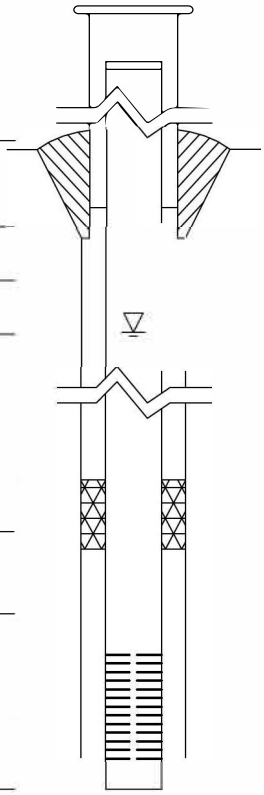
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
620.34	-2.39	Top of Protective Casing
620.04	-2.09	Top of Riser Pipe
617.95	0.00	Ground Surface
615.95	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
607.78	10.17	Top of Seal
605.88	12.07	Top of Sand Pack
604.74	13.21	Top of Screen
600.09	17.86	Bottom of Screen
599.56	18.39	Bottom of Well
599.56	18.39	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.30
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.65
Total Length of Casing	(feet)	20.48
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G305

Site Name: Coffeen Power Station Borehole #: G305

State Plane Coordinate: X 871,156.3 Y 2,515,199.4 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Suzanna L. Keim Date Started: 5/3/2016 Date Finished: 5/3/2016

Report Form Completed By: Suzanna L. Keim Date: 5/19/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: n/a

Setting Time: n/a

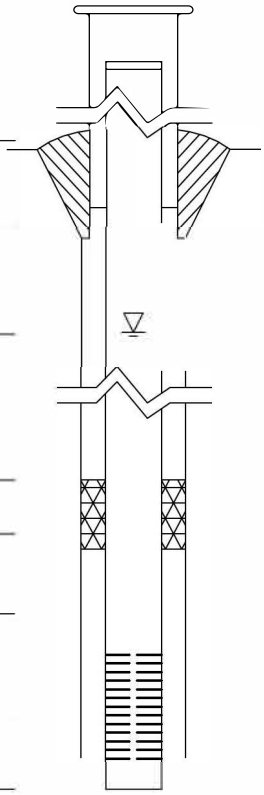
Type of Sand Pack: Quartz Sand

Grain Size: 10-40 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.88	-3.34	Top of Protective Casing
625.55	-3.01	Top of Riser Pipe
622.54	0.00	Ground Surface
621.54	1.00	Top of Annular Sealant
		Static Water Level (After Completion)
n/a	n/a	Top of Seal
611.04	11.50	Top of Sand Pack
609.10	13.44	Top of Screen
604.27	18.27	Bottom of Screen
604.09	18.45	Bottom of Well
604.09	18.45	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.45
Bottom of Screen to End Cap	(feet)	0.18
Screen Length (1st slot to last slot)	(feet)	4.83
Total Length of Casing	(feet)	21.46
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G306

Site Name: Coffeen Power Station Borehole #: G306

State Plane Coordinate: X 871,141.0 Y 2,516,120.4 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Suzanna L. Keim Date Started: 5/3/2016 Date Finished: 5/3/2016

Report Form Completed By: Suzanna L. Keim Date: 5/19/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: n/a

Setting Time: n/a

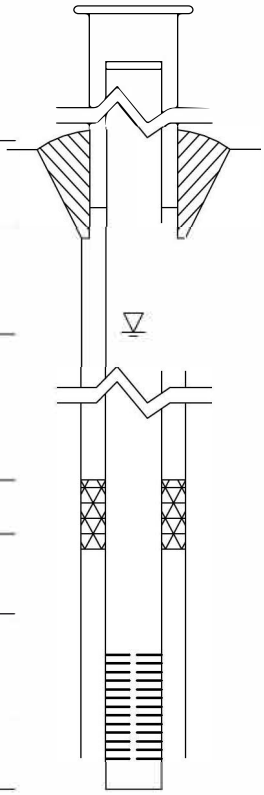
Type of Sand Pack: Quartz Sand

Grain Size: 10-40 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.12	-3.28	Top of Protective Casing
625.72	-2.88	Top of Riser Pipe
622.84	0.00	Ground Surface
621.84	1.00	Top of Annular Sealant
		Static Water Level (After Completion)
n/a	n/a	Top of Seal
611.24	11.60	Top of Sand Pack
609.77	13.07	Top of Screen
605.16	17.68	Bottom of Screen
604.98	17.86	Bottom of Well
604.84	18.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.95
Bottom of Screen to End Cap	(feet)	0.18
Screen Length (1st slot to last slot)	(feet)	4.61
Total Length of Casing	(feet)	20.74
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G307

Site Name: Coffeen Power Station Ash Pond 1 Borehole #: G307

State Plane Coordinate: X 2,515,553.3 Y 871,398.6 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Gates

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 7/26/2016 Date Finished: 7/27/2016

Report Form Completed By: Rhonald W. Hasenyager Date: 7/28/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: 18 hrs.

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method:

Setting Time:

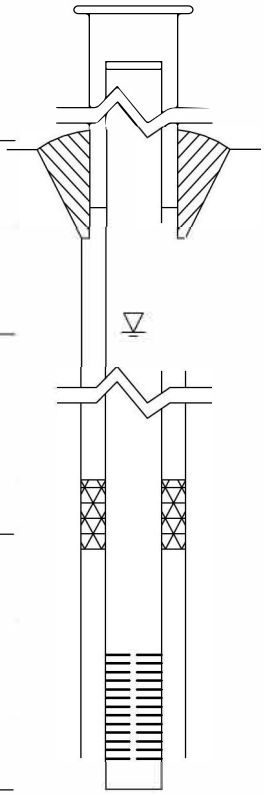
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: none (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.72	-2.64	Top of Protective Casing
624.47	-2.39	Top of Riser Pipe
622.08	0.00	Ground Surface
620.08	2.00	Top of Annular Sealant
623.84	-1.76	Static Water Level (After Completion) 7/27/2016
n/a	n/a	Top of Seal
610.10	11.98	Top of Sand Pack
609.12	12.96	Top of Screen
604.28	17.80	Bottom of Screen
603.86	18.22	Bottom of Well
603.86	18.22	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.37
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.84
Total Length of Casing	(feet)	20.61
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A7

HISTORICAL BORING LOGS

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-01
Well ID: MW1D
Surface Elev: 607 ft. MSL
Completion: 40 ft. BGS
Station: 874,972.6N
2,513,478.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 34.00 - While drilling
▼ =
▽ = 36.28 - MW01D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	16/24 67%	ss	1-1 1-2 N=2	22		0.78 B	0	Very dark gray (10YR3/1), clayey SILT, trace sand		607	
							2			606	
2A	20/24 83%	ss	2-3 5-5 N=8	13		3.71 BSh		Light gray (10YR7/1) with 40% yellowish brown (10YR5/8) mottles, clayey SILT, trace sand and gravel			
							4			604	
3A	22/24 92%	ss	2-2 3-6 N=5	14		2.62 BSh		Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, clayey SILT, trace sand and gravel			
							6			602	
4A	23/24 96%	ss	8-12 19-19 N=31	13		3.30 BSh		Yellowish brown (10YR5/6) with 20% black (10YR2/1) mottles, clayey SILT, little sand and gravel			
							8			600	
5A	24/24 100%	ss	4-9 13-19 N=22	13		4.80 BSh		Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, clayey SILT, trace sand and gravel			
							10			598	
6A	22/24 92%	ss	3-6 12-15 N=18	12		8.73 B					
							12			596	
7A	24/24 100%	ss	14-19 23-30 N=42	12		7.86 B		Dark gray (N4/1) with 25% yellowish brown (10YR5/6) mottles, clayey SILT, trace sand and gravel			
							14			594	
8A	24/24 100%	ss	4-8 12-14 N=20	13		7.56 B					
							16			592	
9A	24/24 100%	ss	16-16 20-21 N=36	14		7.01 B		Dark gray (N4/1), clayey SILT, trace sand and gravel			
							18			590	
10A	24/24 100%	ss	3-5 8-11 N=13	14		5.24 B					
							20			588	

NOTE(S): MW01D installed in SB-01.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-01
Well ID: MW1D
Surface Elev: 607 ft. MSL
Completion: 40 ft. BGS
Station: 874,972.6N
2,513,478.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 34.00 - While drilling
▼ =
▽ = 36.28 - MW01D on 6/1/06

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							20			588	Shelby tube taken from shallow well borehole at indicated depth.
11A	24/24 100%	SH		15		3.69 B	22			586	
12A	24/24 100%	SS	10-11 12-16 N=23	14		5.24 B	24			584	
13A	6/24 25%	SH		14		3.69 B	26			582	Shelby tube taken from shallow well borehole at indicated depth.
14A	24/24 100%	SS	10-12 18-18 N=30	15		4.27 B	28	Dark gray (N4/1), clayey SILT, trace sand and gravel *[Continued from previous page]*		580	
15A	24/24 100%	SS	5-9 11-16 N=20	14		4.27 B	30			578	
16A	24/24 100%	SS	5-8 10-12 N=18	17		2.72 BSh	32			576	
17A	24/24 100%	SS	8-14 14-16 N=28	14		5.62 B	▼ 34			574	
18A	23/24 96%	SS	8-28 40-65 N=68	14				Gray (N4/1), silty, fine to medium SAND, little coarse sand, trace gravel, wet		572	
19A				13			▽ 36				
19B	24/24 100%	SS	24-14 17-16 N=31	19		5.43 B	38	Very dark gray (10YR3/1), silty CLAY		570	
20A	24/24 100%	SS	3-5 6-10 N=11	24		3.50 BSh	40	Dark gray (N4/1) with 30% dark yellowish brown (10YR4/6) mottles, silty CLAY **End of Boring = 40.0 ft. BGS**		568	

NOTE(S): MW01D installed in SB-01.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 50 ft. BGS
Station: 876,410.0N
2,513,210.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil grayish brown (10YR4/2), clayey SILT, trace sand		624	
1A	24/24 100%	ss	3-3 4-5 N=7	23				loess Gray (10YR6/1), clayey SILT, trace sand			
1B				18		1.96 B		Yellowish brown (10YR5/4) with 20% gray (10YR6/1) mottles, lean CLAY, trace sand			
1C				29		1.94 B	2			622	
2A	24/24 100%	ss	3-4 4-6 N=8	25		2.89 B		Yellowish brown (10YR5/8) with 15% gray (10YR6/1) mottles, lean CLAY, trace sand			
							4			620	
3A	24/24 100%	ss	3-5 5-7 N=10	20		2.91 B		Yellowish brown (10YR5/8) with 40% gray (10YR6/1)mottles, lean CLAY, trace sand			
							6			618	
4A	24/24 100%	ss	10-8 8-10 N=16	17		2.91 B		Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
							8			616	
5A	24/24 100%	ss	3-3 4-5 N=7	19		1.94 B		Gray (10YR5/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
6A				18		2.13 B	10			614	
6B	24/24 100%	ss	2-3 6-5 N=9	17				Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, clayey SAND, trace gravel			
							12			612	
7A	24/24 100%	ss	4-4 7-10 N=11	14		2.06 B		Gray (10YR6/1) with 30% white (10YR8/1) mottles, sandy CLAY, trace gravel			
7B				17				Yellowish brown (10YR5/4), silty, fine SAND, little medium sand, wet			
							14			610	
8A	24/24 100%	ss	15-23 33-68 N=56	10							
9A	10/10 100%	ss	48-62/4"	10		3.92 Sh	16	Pale brown (10YR6/3), silty, fine SAND, trace gravel, wet		608	
							18			606	
10A	12/12 100%	ss	15-45	9		8.07 BSh		Dark gray (10YR4/1), clayey SILT, little sand and gravel			
							20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 50 ft. BGS
Station: 876,410.0N
2,513,210.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A				9						604	
	36/60 60%	cs					22	Brown (10YR5/3), clayey SILT, little sand, trace gravel		602	
11B				11			24			600	
12A				21			26			598	
	60/60 100%	cs					28	Blueish gray (5B5/1), with 30% dark yellowish brown (10YR4/6) mottles, lean CLAY, trace coal		596	
12B				23			30			594	
	60/60 100%	cs					32			592	
13A				14			34			590	
							36	Very dark gray (10Y3/1), lean CLAY, trace sand and gravel		588	
	60/60 100%	cs					38			586	
14A				14			40				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 50 ft. BGS
Station: 876,410.0N
2,513,210.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							42			584	
	60/60 *100%*	CS								582	
15A				14			44			580	
								Very dark gray (10Y3/1), lean CLAY, trace sand and gravel *[Continued from previous page]*			
							46			578	
	60/60 *100%*	CS									
							48			576	
16A				13							
							50				

End of Boring = 50.0 ft. BGS

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02a
Well ID: MW2S
Surface Elev: 624 ft. MSL
Completion: 16 ft. BGS
Station: 876,408.9N
2,513,210.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE			TESTING						
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil grayish brown (10YR4/2), clayey SILT, trace sand		624	
							1	loess Gray (10YR6/1), clayey SILT, trace sand			
								Yellowish brown (10YR5/4) with 20% gray (10YR6/1) mottles, lean CLAY, trace sand			
							2			622	
								Yellowish brown (10YR5/8) with 15% gray (10YR6/1) mottles, lean CLAY, trace sand			
							4			620	
								Yellowish brown (10YR5/8) with 40% gray (10YR6/1)mottles, lean CLAY, trace sand			
							6			618	
								Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
							8			616	
								Gray (10YR5/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
							10			614	
								Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, clayey SAND, trace gravel			
							12			612	
								Gray (10YR6/1) with 30% white (10YR8/1) mottles, sandy CLAY, trace gravel			
								Yellowish brown (10YR5/4), silty, fine SAND, little medium sand, wet			
							14			610	
								Pale brown (10YR6/3), silty, fine SAND, trace gravel, wet			

End of Boring = 15.51 ft. BGS
See SB-02 for sample & testing details

NOTE(S): MW02S installed in blind-drilled borehole within 10 ft of SB-02.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02b
Well ID: MW2D
Surface Elev: 624 ft. MSL
Completion: 27 ft. BGS
Station: 876,414.0N
2,513,209.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil: grayish brown (10YR4/2), clayey SILT, trace sand		624	
							1	loess: Gray (10YR6/1), clayey SILT, trace sand			
								Yellowish brown (10YR5/4) with 20% gray (10YR6/1) mottles, lean CLAY, trace sand			
							2			622	
								Yellowish brown (10YR5/8) with 15% gray (10YR6/1) mottles, lean CLAY, trace sand			
							4			620	
								Yellowish brown (10YR5/8) with 40% gray (10YR6/1)mottles, lean CLAY, trace sand			
							6			618	
								Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
							8			616	
								Gray (10YR5/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand			
							10			614	
								Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, clayey SAND, trace gravel			
							12	Gray (10YR6/1) with 30% white (10YR8/1) mottles, sandy CLAY, trace gravel		612	
								Yellowish brown (10YR5/4), silty, fine SAND, little medium sand, wet			
							14			610	
							16	Pale brown (10YR6/3), silty, fine SAND, trace gravel, wet		608	
							18			606	
								Dark gray (10YR4/1), clayey SILT, little sand and gravel			
							20				

NOTE(S): MW02D installed in blind-drilled borehole within 10 ft of SB-02.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/5/2006
WEATHER: Partly cloudy, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-02b
Well ID: MW2D
Surface Elev: 624 ft. MSL
Completion: 27 ft. BGS
Station: 876,414.0N
2,513,209.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 7.42 - MW02S on 6/1/06
▽ = 7.36 - MW02D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22	Brown (10YR5/3), clayey SILT, little sand, trace gravel		604	
							24			602	
							26	Blueish gray (5B5/1), with 30% dark yellowish brown (10YR4/6) mottles, lean CLAY, trace coal		600	
										598	

End of Boring = 27.22 ft. BGS
See SB-02 for sample & testing details

NOTE(S): MW02D installed in blind-drilled borehole within 10 ft of SB-02.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/27/2006
Finish: 4/27/2006
WEATHER: Sunny, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-03
Well ID: MW3D
Surface Elev: 626 ft. MSL
Completion: 58 ft. BGS
Station: 876,554.5N
2,514,535.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 7.03 - MW03S on 6/1/06
▽ = 55.40 - MW03D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	20/24 83%	ss	2-2 4-6 N=6	17		2.07 SP
1B				20		
1C				26		3.30 B
2A	17/24 71%	ss	2-3 4-5 N=7	25		3.05 B
3A	20/24 83%	ss	2-3 3-5 N=6	16		1.96 B
4A	24/24 100%	ss	4-3 5-6 N=8	21		2.27 B
5A	21/24 88%	ss	1-3 3-4 N=6	20		2.18 B
5B				19		
6A	18/24 75%	ss	1-2 2-4 N=4	24		0.87 B
7A	23/24 96%	SH SS	3-2	19		
7B	16/24 67%		2-4 N=4	12		
8A	23/24 96%	ss	3-12 29-50 N=41	13		
8B				13		
8C				12		
9A	14/24 58%	ss	8-82 85-72 N=167	10		6.98 B
9B				13		6.18 BSh
10A	18/24 75%	ss	6-21 32-49 N=53	8		11.95 Sh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	soil Very dark grayish brown (10YR3/2), lean CLAY			
	Grayish brown (10YR5/2), lean CLAY, trace sand			
	Yellowish brown (10YR5/6), lean CLAY, trace sand		624	
2				
	Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, lean CLAY, trace sand		622	
4	loess			
	Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, sandy SILT, trace gravel		620	
6				
▼	Yellowish brown (10YR5/6) with 50% gray (N5/1) mottles, lean CLAY, trace sand and gravel		618	
8				
	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel		616	
10	Dark gray (10YR4/1), sandy CLAY, trace gravel			
	Gray (10YR6/1) with 50% yellowish brown (10YR5/8) mottles, lean CLAY, little sand, trace gravel		614	Shelby tube taken from shallow well borehole at indicated depth.
12				
▼ 14	hagarstown Yellowish brown (10YR5/8), silty, fine SAND, little medium sand, trace gravel, wet		612	
	Yellowish brown (10YR5/8), silty, fine SAND, little clay, wet		610	
16	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel			
	Yellowish brown (10YR5/6), silty SAND, trace gravel, wet			
18	vandalia brown (10YR5/4), clayey SILT, trace sand and gravel		608	
	Gray (10YR5/1), sandy SILT, trace gravel		606	
20				

NOTE(S): MW03D installed in SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/27/2006
Finish: 4/27/2006
WEATHER: Sunny, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-03
Well ID: MW3D
Surface Elev: 626 ft. MSL
Completion: 58 ft. BGS
Station: 876,554.5N
2,514,535.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 7.03 - MW03S on 6/1/06
▽ = 55.40 - MW03D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22			604	Wood fragments
11A	19/24 79%	ss	3-20 35-29 N=55	10		5.36 Sh		Gray (10YR5/1), sandy SILT, trace gravel *[Continued from previous page]*			
12A	20/24 83%	ss	15-25 89-69 N=114	8		13.00 Sh	24			602	
13A	23/24 96%	ss	14-19 24-22 N=43	9							
13B				13		6.98 BSh	26	Yellowish brown (10YR5/4), lean CLAY, trace sand and gravel		600	
14A	24/24 100%	ss	19-21 26-32 N=47	15		7.01 BSh		Gray (10YR4/1), clayey SILT, trace sand and gravel			
15A	21/24 88%	ss	10-25 25-23 N=50	12			28			598	
15B				13		8.53 BSh		Light gray (10YR6/1), SILT, trace sand			
16A	24/24 100%	ss	7-12 19-30 N=31	13		9.16 BSh				596	
17A				14		6.59 B	30				
17B	24/24 100%	ss	29-35 39-42 N=74	14		3.49 Sh				594	
18A	23/24 96%	ss	6-8 11-17 N=19	13		7.21 BSh	32	Gray (10YR4/1), lean CLAY, trace sand and gravel			
										592	
							34				
							36	smithboro		590	
19A	24/24 100%	ss	19-21 31-31 N=52	13		6.98 BSh		Gray (10YR4/1), clayey SILT, trace sand and gravel			
							38			588	
20A	24/24 100%	ss	6-10 15-24 N=25	14		6.76 BSh		Gray (10YR4/1), lean CLAY, trace sand and gravel			
							40			586	

NOTE(S): MW03D installed in SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/27/2006
Finish: 4/27/2006
WEATHER: Sunny, mild (high-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-03
Well ID: MW3D
Surface Elev: 626 ft. MSL
Completion: 58 ft. BGS
Station: 876,554.5N
2,514,535.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 7.03 - MW03S on 6/1/06
▽ = 55.40 - MW03D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
21A	19/24 79%	ss	4-10 16-23 N=26	13		8.04 BSh
22A	21/24 88%	ss	19-27 28-32 N=55	13		7.56 BSh
23A	23/24 96%	ss	4-9 14-18 N=23	14		6.98 BSh
24A	24/24 100%	ss	20-26 30-33 N=56	14		6.59 BSh
25A	24/24 100%	ss	6-10 13-12 N=23	20		3.30 BSh
26A	24/24 100%	ss	4-7 6-7 N=13	22		2.91 BSh
27A	24/24 100%	ss	7-18 37-85 N=55	16		4.05 BSh
27B				13		
28A	23/24 96%	ss	15-34 34-19 N=68	11		3.22 SP
28B				13		5.82 B
29A	24/24 100%	ss	19-22 28-18 N=50	20		4.36 BSh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	Gray (10YR4/1), lean CLAY, trace sand and gravel *[Continued from previous page]*			
42			584	
	Gray (10YR4/1), clayey SILT, trace sand and gravel			
44			582	
46			580	
48			578	
	Gray (10YR4/1), lean CLAY, trace sand and gravel			
50			576	
52			574	
	yarmouth (10Y4/1), silty, fine to medium SAND, wet			
54			572	
	Gray (10YR4/1), silty, fine SAND, trace clay, wet			
▽				
56	lierle		570	
	Very dark gray (10YR3/1), lean CLAY, trace sand and gravel			
58			568	

End of Boring = 58.0 ft. BGS

NOTE(S): MW03D installed in SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/28/2006
Finish: 4/28/2006
WEATHER: Partly cloudy, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-03a
Well ID: MW3S
Surface Elev: 626 ft. MSL
Completion: 17 ft. BGS
Station: 876,554.8N
2,514,531.5E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 7.03 - MW03S on 6/1/06
▽ = 55.40 - MW03D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil ry dark grayish brown (10YR3/2), lean CLAY			
								Grayish brown (10YR5/2), lean CLAY, trace sand			
								Yellowish brown (10YR5/6), lean CLAY, trace sand		624	
							2	Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, lean CLAY, trace sand			
										622	
							4	loess Yellowish brown (10YR5/6) with 40% gray (N5/1) mottles, sandy SILT, trace gravel			
										620	
							6	Yellowish brown (10YR5/6) with 50% gray (N5/1) mottles, lean CLAY, trace sand and gravel			
										618	
							8	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel			
							10	Dark gray (10YR4/1), sandy CLAY, trace gravel		616	
								Gray (10YR6/1) with 50% yellowish brown (10YR5/8) mottles, lean CLAY, little sand, trace gravel		614	
							12				
							14	Yellowish brown (10YR5/8), silty, fine SAND, little medium sand, trace gravel, wet		612	
								Yellowish brown (10YR5/8), silty, fine SAND, little clay, wet		610	
							16	Yellowish brown (10YR5/6), lean CLAY, little sand, trace gravel Yellowish brown (10YR5/6), silty SAND, trace gravel, wet Yellowish brown (10YR5/4), clayey SILT, trace sand and gravel			

End of Boring = 17.15 ft. BGS
See SB-03 for sample & testing details

NOTE(S): MW03S installed in blind-drilled borehole within 10 ft of SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-04
Well ID: n/a
Surface Elev: 622 ft. MSL
Completion: 55 ft. BGS
Station: 878,000.0N
2,514,445.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 8.00 - While drilling
▼ = 5.67 - MW04S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	21/24 88%	ss	1-2 2-4 N=4	24		1.09 B	0	soil y dark gray (10YR3/1), clayey SILT, trace sand		622	
1B				29				Dark grayish brown (10YR4/2) with 15% yellowish brown (10YR5/6) mottles, lean CLAY			
2A	18/24 75%	ss	2-4 5-6 N=9	27		2.72 BSh	2	Yellowish brown (10YR5/8) with 50% grayish brown (10YR5/2) mottles, lean CLAY		620	
3A	16/24 67%	ss	2-3 4-6 N=7	23		1.71 B	4	loess Dark gray (10YR4/1), clayey SILT, trace sand		618	
4A	24/24 100%	ss	4-5 5-7 N=10	20		1.40 BSP	6	Gray (10YR5/1), lean CLAY, trace sand and gravel		616	
5A	24/24 100%	ss	1-2 2-2 N=4	23		0.70 B	8	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, sandy SILT		614	
6A	24/24 100%	ss	0-1 2-3 N=3	24		0.31 BSh	10			612	
6B				28				Very dark gray (10YR3/1) with 35% gray (10YR6/1) mottles, clayey SILT, wet			
7A	22/24 92%	ss	0-1 3-7 N=4	20		0.08 B	12			610	
7B				16				Yellowish brown (10YR5/6), clayey SAND, trace gravel			
7C				12				Light gray (10YR7/1) with 20% brown (10YR5/3) mottles, clayey SILT, trace sand and gravel			
8A	23/24 96%	ss	4-9 22-35 N=31	14		4.36 SP	14	Yellowish brown (10YR5/8), silty, fine to medium SAND, trace coarse sand, wet		608	
8B				11							
9A	24/24 100%	ss	27-38 54-50 N=92	7			16	Gray (10YR4/1), sandy SILT, trace gravel		606	
10A	24/24 100%	ss	24-29 39-34 N=68	9		2.18 BSh	18			604	
							20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-04
Well ID: n/a
Surface Elev: 622 ft. MSL
Completion: 55 ft. BGS
Station: 878,000.0N
2,514,445.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 8.00 - While drilling
▼ = 5.67 - MW04S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	60/60 100%	CS					22			602	
11A				7			24			600	
	60/60 100%	CS					26			598	
12A				7			28			596	
	60/60 100%	CS					30	Gray (10YR4/1), sandy SILT, trace gravel *[Continued from previous page]*		594	
13A				8			32			592	
	60/60 100%	CS					34			590	
14A				13			36			588	
	60/60 100%	CS					38			586	
							40			584	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

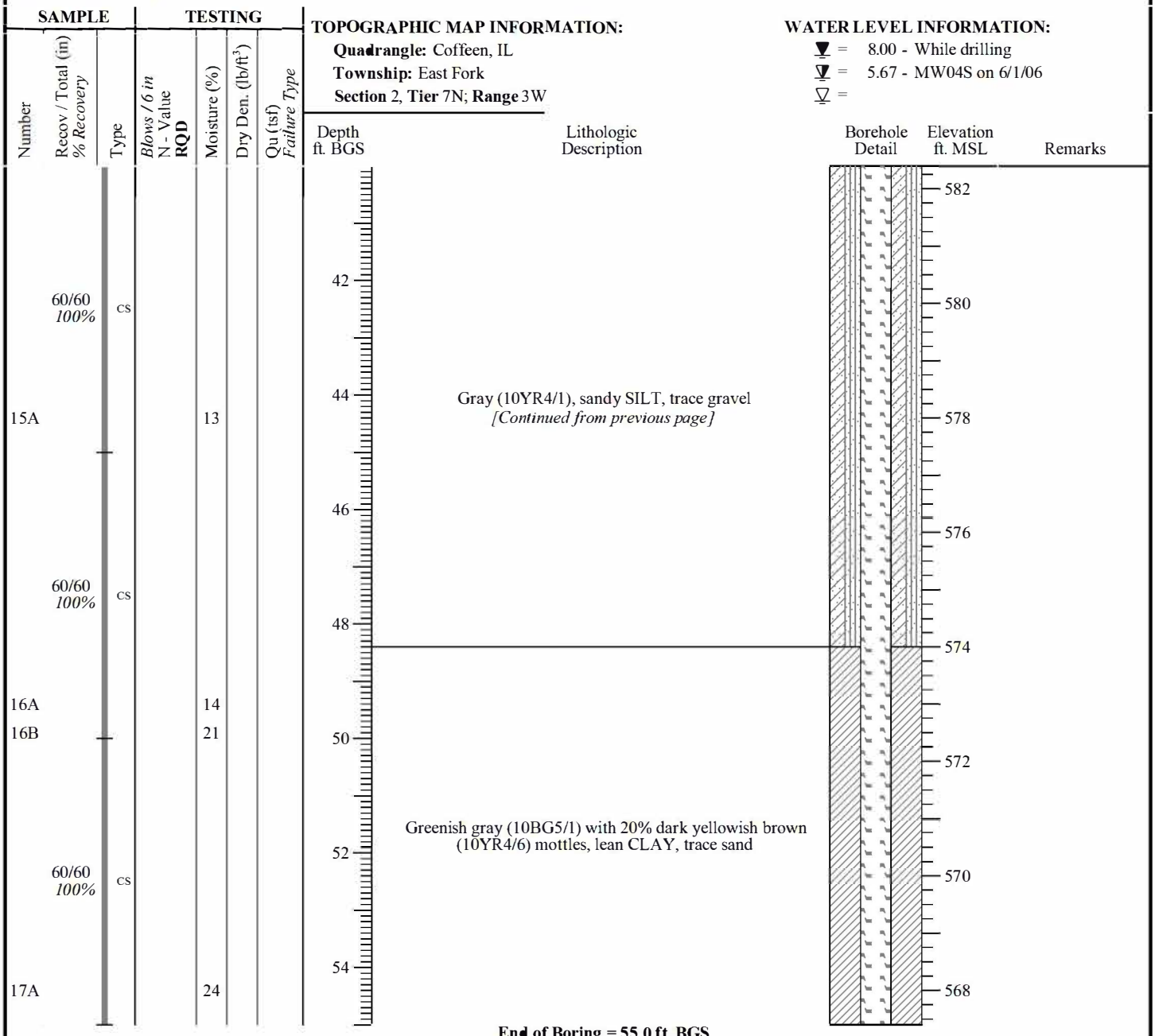
CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-04
Well ID: n/a
Surface Elev: 622 ft. MSL
Completion: 55 ft. BGS
Station: 878,000.0N
2,514,445.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 8.00 - While drilling
▼ = 5.67 - MW04S on 6/1/06
▽ =



End of Boring = 55.0 ft. BGS

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-04a
Well ID: MW4S
Surface Elev: 622 ft. MSL
Completion: 15 ft. BGS
Station: 877,999.7N
2,514,450.6E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 8.00 - While drilling
▼ = 5.67 - MW04S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil ly dark gray (10YR3/1), clayey SILT, trace sand		622	
								Dark grayish brown (10YR4/2) with 15% yellowish brown (10YR5/6) mottles, lean CLAY			
							2			620	
								Yellowish brown (10YR5/8) with 50% grayish brown (10YR5/2) mottles, lean CLAY			
							4	loess		618	
								Dark gray (10YR4/1), clayey SILT, trace sand			
							▼ 6			616	
								Gray (10YR5/1), lean CLAY, trace sand and gravel			
							▼ 8			614	
								Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, sandy SILT			
							10			612	
								Very dark gray (10YR3/1) with 35% gray (10YR6/1) mottles, clayey SILT, wet			
							12			610	
								Yellowish brown (10YR5/6), clayey SAND, trace gravel			
								Light gray (10YR7/1) with 20% brown (10YR5/3) mottles, clayey SILT, trace sand and gravel			
							14	Yellowish brown (10YR5/8), silty, fine to medium SAND, trace coarse sand, wet		608	
								Gray (10YR4/1), sandy SILT, trace gravel			

End of Boring = 14.77 ft. BGS

See SB-04 for sample & testing details

NOTE(S): MW04S installed in blind-drilled borehole within 10 ft of SB-03.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/12/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-05
Well ID: MW5D
Surface Elev: 623 ft. MSL
Completion: 54 ft. BGS
Station: 878,174.8N
2,513,290.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.00 - While drilling
▼ = 6.74 - MW05S on 6/1/06
▽ = 50.44 - MW05D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	19/24 79%	ss	0-2 3-4 N=5	29		
1B				28		
2A	22/24 92%	ss	2-5 5-7 N=10	27		2.47 BSh
2B				22		2.13 B
3A	24/24 100%	ss	2-2 3-6 N=5	21		2.33 BSP
4A	24/24 100%	ss	7-6 6-8 N=12	21		1.90 BSh
5A	18/24 75%	ss	1-3 4-5 N=7	22		1.78 B
6A				16		
6B	20/24 83%	ss	0-1 3-4 N=4	22		0.70 BSh
7A	24/24 100%	ss	3-6 17-20 N=23	19		
7B				16		
8A	20/24 83%	ss	4-16 25-25 N=41	20		
8B				11		
9A	24/24 100%	ss	14-18 38-62 N=56	12		
9B				8		
10A	18/24 75%	ss	14-39 77 N=116	9		3.27 Sh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	soil / loess — grayish brown (10YR4/2), clayey SILT, trace sand		622	
2	Gray (10YR5/1 with 50% yellowish brown (10YR5/6) mottles, clayey SILT		620	
4	Very dark brown (10YR2/2) with 20% dark gray (10YR4/1) mottles, clayey SILT, trace sand		618	
6	Dark gray (10YR4/1) with 30% light gray (10YR7/1) mottles, lean CLAY		616	
▼	Gray (10YR6/1), lean CLAY, trace sand			
8	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand		614	
▼ 10	Yellowish brown (10YR5/6), clayey SAND, trace gravel, wet		612	
	Yellowish brown (10YR5/6) with 50% gray 10YR5/1) mottles, sandy CLAY			
12	Gray 10YR6/1), clayey, fine to medium SAND, trace gravel, wet		610	
	Brownish yellow (10YR6/6), silty, fine SAND, trace medium sand			
14	Yellowish brown (10YR5/6), silty, fine SAND, wet		608	
16	Brown (10YR5/3), silty SAND and GRAVEL, wet		606	
18	Dark gray (10YR4/1), sandy SILT, trace clay and gravel		604	
20				

NOTE(S): MW05D installed in SB-05.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 5/12/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-05
Well ID: MW5D
Surface Elev: 623 ft. MSL
Completion: 54 ft. BGS
Station: 878,174.8N
2,513,290.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.00 - While drilling
▼ = 6.74 - MW05S on 6/1/06
▽ = 50.44 - MW05D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Dark gray (10YR4/1), sandy SILT, trace clay and gravel *[Continued from previous page]*		602	
							22				
11A	60/60 *100%*	cs		7				Dark gray (10YR4/1), silty, fine SAND, trace medium sand		600	
							24				
11B				7						598	
							26				
										596	
	60/60 *100%*	cs					28				
										594	
12A				7							
							30	Dark gray (10YR4/1), sandy SILT, trace clay and gravel		592	
	60/60 *100%*	cs					32				
										590	
							34				
13A				8						588	
							36				
										586	
14A	48/60 *80%*	cs		7				Gray (10YR6/1), fine to medium SAND			
							38	Dark gray (10YR4/1), sandy SILT, trace clay and gravel		584	
14B				14							
							40				

NOTE(S): MW05D installed in SB-05.

FIELD BORING LOG

HANSON

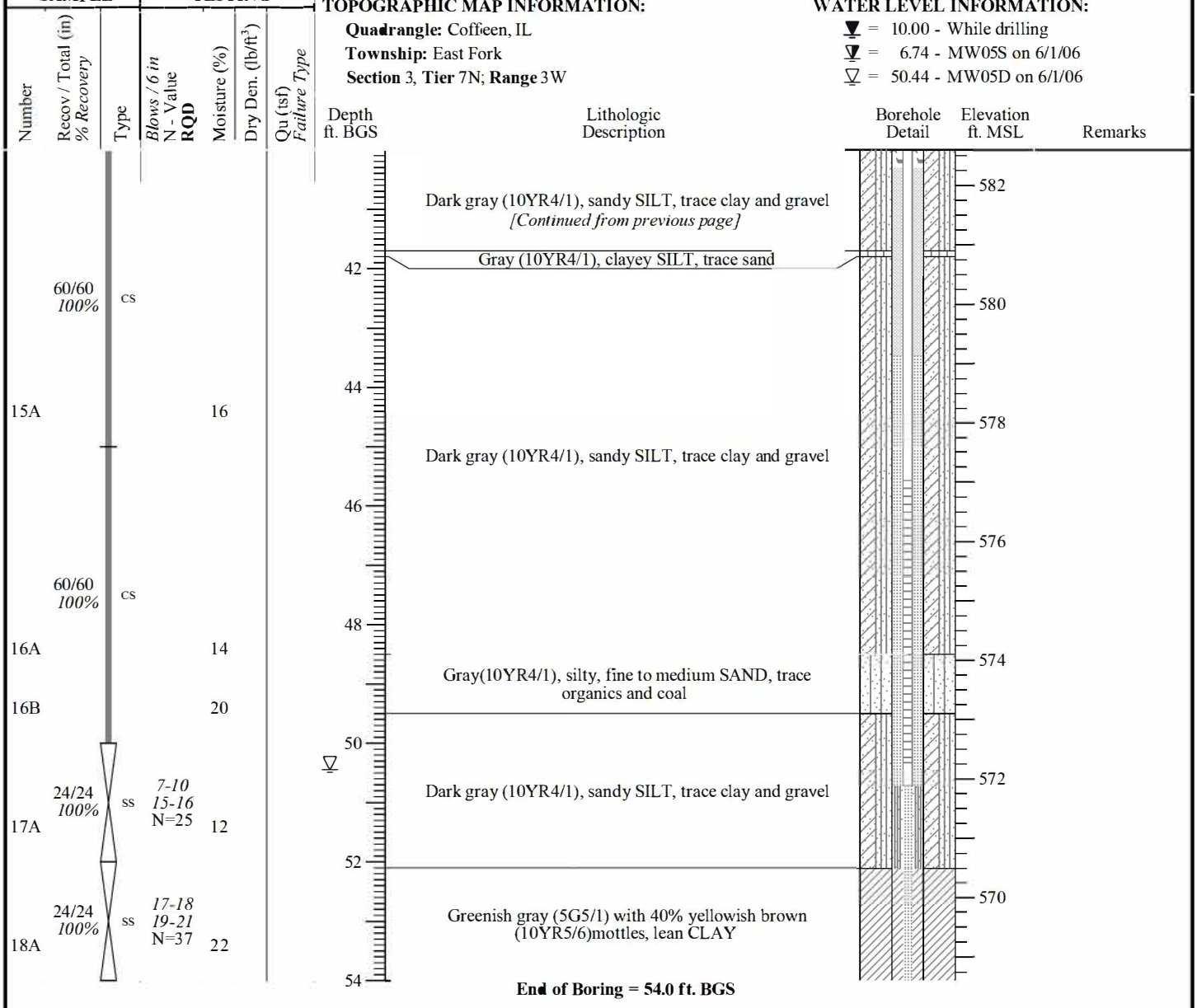
CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/12/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-05
Well ID: MW5D
Surface Elev: 623 ft. MSL
Completion: 54 ft. BGS
Station: 878,174.8N
2,513,290.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.00 - While drilling
▼ = 6.74 - MW05S on 6/1/06
▽ = 50.44 - MW05D on 6/1/06



NOTE(S): MW05D installed in SB-05.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/17/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-05a
Well ID: MW5S
Surface Elev: 623 ft. MSL
Completion: 18 ft. BGS
Station: 878,175.6N
2,513,285.5E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.00 - While drilling
▼ = 6.74 - MW05S on 6/1/06
▽ = 50.44 - MW05D on 6/1/06

SAMPLE			TESTING							
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil: grayish brown (10YR4/2), clayey SILT, trace sand		622	
								loess			
							2	Gray (10YR5/1 with 50% yellowish brown (10YR5/6) mottles, clayey SILT		620	
							4	Very dark brown (10YR2/2) with 20% dark gray (10YR4/1) mottles, clayey SILT, trace sand		618	
								Dark gray (10YR4/1) with 30% light gray (10YR7/1) mottles, lean CLAY			
							6			616	
							▼	Gray (10YR6/1), lean CLAY, trace sand			
							8	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand		614	
							▼ 10	Yellowish brown (10YR5/6), clayey SAND, trace gravel, wet		612	
								Yellowish brown (10YR5/6) with 50% gray 10YR5/1) mottles, sandy CLAY			
							12	Gray 10YR6/1), clayey, fine to medium SAND, trace gravel, wet		610	
								Brownish yellow (10YR6/6), silty, fine SAND, trace medium sand			
							14	Yellowish brown (10YR5/6), silty, fine SAND, wet		608	
							16	Brown (10YR5/3), silty SAND and GRAVEL, wet		606	
								Dark gray (10YR4/1), sandy SILT, trace clay and gravel			

End of Boring = 17.71 ft. BGS
See SB-05 for sample & testing details

NOTE(S): MW05S installed in blind-drilled borehole within 10 ft of SB-05.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-06
Well ID: n/a
Surface Elev: 623 ft. MSL
Completion: 60 ft. BGS
Station: 879,015.0N
2,513,190.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 9.30 - While drilling
▼ = 6.21 - MW06S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	24/24 100%	ss	2-3 3-5 N=6	25		1.22 SP
1B				28		1.96 B
2A	24/24 100%	ss	2-4 5-6 N=9	27		1.94 BSh
2B				19		2.52 BSh
3A	24/24 100%	ss	1-3 4 N=7	21		1.36 B
4A	24/24 100%	ss	4-6 6 N=12	17		1.78 B
5A				18		0.85 BSh
5B	22/24 92%	ss	1-2 3-3 N=5	17		0.81 None
5C				21		0.31 None
6A	20/24 83%	ss	0-1 2-4 N=3	25		
7A	24/24 100%	ss	2-4 7-8 N=11	15		
7B				12		1.48 BSh
8B	22/24 92%	ss	11-33 57-35 N=90	8		7.18 Sh
9A	22/24 92%	ss	30-39 46-55 N=85	9		11.35 Sh
8A				11		
10A	24/24 100%	ss	4-23 50-51 N=73	7		11.64 Sh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	soil: grayish brown (10YR4/2), clayey SILT, trace sand			
	loess: Light brownish gray (10YR6/2) with 20% yellowish brown (10YR5/8) mottles, clayey SILT, trace sand		622	
2	Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand		620	
4			618	
6	▼ Gray (10YR5/1) with 15% yellowish brown (10YR5/6) mottles, clayey SILT, trace sand		616	
8	Gray (10YR6/1) with 20% yellowish brown (10YR5/8) mottles, clayey, fine SAND		614	
	▼ Yellowish brown (10YR5/6), silty, fine SAND, trace clay, wet			
10	Dark yellowish brown (10YR4/6), silty, fine SAND, wet		612	
12	Brownish yellow (10YR6/6), silty, fine to medium SAND, little coarse sand, trace gravel, wet		610	
	Yellowish brown (10YR5/4), sandy SILT, trace gravel, wet			
14	Brown (10YR5/3), silty, fine SAND, little medium sand, trace gravel, wet		608	
	Gray (N5/1), clayey SILT, little sand, trace gravel			
16			606	
18	Dark gray (N4/1), clayey SILT, trace sand and gravel		604	
20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-06
Well ID: n/a
Surface Elev: 623 ft. MSL
Completion: 60 ft. BGS
Station: 879,015.0N
2,513,190.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 9.30 - While drilling
▼ = 6.21 - MW06S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	20/24 83%	ss	6-16 33-58 N=49	11		3.49 BSh	22			602	
12A	20/24 83%	ss	45-56 54-50/3" N=110	9		11.64 Sh	24			600	
13A	12/24 50%	ss	26-78	12		2.84 Sh	26			598	
14A	8/24 33%	ss	52-48/2"	9		5.43 BSh	28			596	
15A	24/24 100%	ss	10-24 30-40 N=54	13		4.95 BSh	30	Dark gray (N4/1), clayey SILT, trace sand and gravel *[Continued from previous page]*		594	
16A	21/24 88%	ss	10-16 37-38 N=53	8		10.91 BSh	32			592	
17A	17/24 71%	ss	36-47 61/5"	9			34			590	
18A	22/24 92%	ss	11-36 45-60 N=81	9		10.04 Sh	36			588	
19A	22/24 92%	ss	40-35 34-29 N=69	10		9.60 Sh	38			586	
19B				13		8.92 B					
20A	24/24 100%	ss	3-8 12-15 N=20	14		8.53 BSh	40	Very dark greenish gray (10Y3/1), lean CLAY, trace sand		584	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-06
Well ID: n/a
Surface Elev: 623 ft. MSL
Completion: 60 ft. BGS
Station: 879,015.0N
2,513,190.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 9.30 - While drilling
▼ = 6.21 - MW06S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
21A	23/24 96%	ss	3-5 8-12 N=13	15		4.27 B	42			582	
22A	22/24 92%	ss	6-6 7-8 N=13	14		3.49 B	44			580	
23A	24/24 100%	ss	5-7 9-12 N=16	16		2.72 B	46	Very dark greenish gray (10Y3/1), lean CLAY, trace sand and gravel		578	
24A	24/24 100%	ss	4-8 10-11 N=18	15		4.07 B	48			576	
25A	24/24 100%	ss	5-6 9-13 N=15	15		3.10 B	50			574	
26A	24/24 100%	ss	5-6 8-12 N=14	22		1.94 B	52			572	
27A	24/24 100%	ss	5-6 8-8 N=14	23		2.13 B	54	Dark greenish gray (10BG4/1), lean CLAY		570	
28A	24/24 100%	ss	3-5 6-8 N=11	24		2.33 BSh	56			568	
29A	24/24 100%	ss	12-10 12-14 N=22	24		3.30 BSh	58	Greenish gray (5G4/1) with 10% dark yellowish brown (10YR3/4) mottles, lean CLAY, trace sand		566	
30A	24/24 100%	ss	5-8 12-13 N=20	27		2.13 BSh	60	Dark greenish gray (10G4/1), lean CLAY, trace sand **End of Boring = 60.0 ft. BGS**		564	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

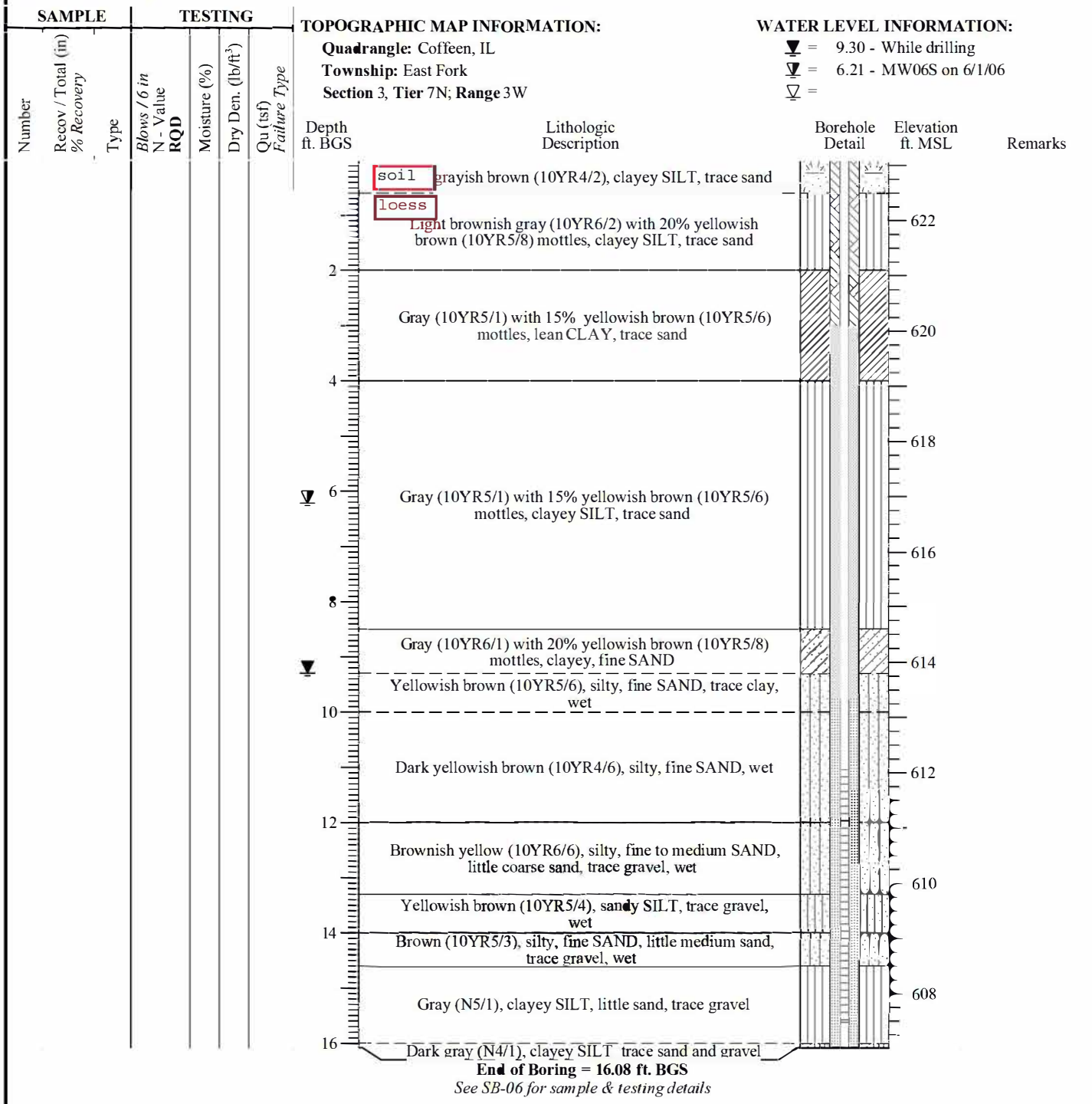
CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-06a
Well ID: MW6S
Surface Elev: 623 ft. MSL
Completion: 16 ft. BGS
Station: 879,021.2N
2,513,189.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 9.30 - While drilling
▼ = 6.21 - MW06S on 6/1/06
▽ =



End of Boring = 16.08 ft. BGS

See SB-06 for sample & testing details

NOTE(S): MW06S installed in blind-drilled borehole within 10 ft of SB-06.

R001147

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/8/2006
WEATHER: Partly cloudy, mild (mid-70s)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: P. McIntire
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-07
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,180.0N
2,514,390.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.80 - While drilling
▼ = 4.90 - MW07S on 6/1/06
▽ =

Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	18/24 75%	ss	1-1 1-1 N=2	23		2.40 B
1B				24		
2A	24/24 100%	ss	0-0 1-1 N=1	26		2.33 B
3A	24/24 100%	ss	0-1 1-2 N=2	25		4.33 BSh
3B				25		2.52 BSh
3C				22		3.05 B
4A	24/24 100%	ss	0-1 1-2 N=2	22		1.75 B
5A	24/24 100%	ss	0-0 1-1 N=1	22		1.24 B
6A	24/24 100%	ss	0-0 0-1 N=0	24		0.54 B
6B				20		1.65 B
7A	24/24 100%	ss	0-0 1-2 N=1	24		
7B				13		2.89 B
8A	24/24 100%	ss	2-5 7-9 N=12	8		5.04 BSh
9A	24/24 100%	ss	3-6 6-8 N=12	9		9.27 BSh
10A	24/24 100%	ss	3-6 8-11 N=14	9		11.13 BSh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	soil Dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.		624	
	Dark gray (10YR4/1), moist, soft, silty CLAY with trace and and trace gravel.			
2	Gray (10YR5/1) with 20% yellowish brown mottles, moist, soft, silty CLAY with trace sand and trace gravel.		622	
4	loess Black (10YR2/1), very moist, soft, clayey SILT.		620	I question whether this is some type of ash based on how soft this is + color
	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist soft, silty CLAY with trace sand and trace gravel.			
6	Black (10YR2/1), moist, soft, silty CLAY with trace sand and trace gravel.		618	
8	Dark gray (10YR4/1), very moist, soft, silty CLAY with some sand and trace gravel.		616	
10	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with sand and gravel.		614	
	Yellowish brown (10YR5/8) wet, very soft, clayey, very fine- to fine-grained, SAND with trace gravel.			
12	Yellowish brown (10YR5/8) wet, soft, clayey, very fine- to fine-grained, SAND with trace gravel.		612	
14			610	
16	Gray (10YR4/1), moist, very hard, sandy, clayey SILT with gravel.		608	
18			606	
20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/8/2006
WEATHER: Partly cloudy, mild (mid-70s)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: P. McIntire
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-07
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,180.0N
2,514,390.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.80 - While drilling
▼ = 4.90 - MW07S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A				8			22	Gray (10YR4/1), moist, very hard, sandy, clayey SILT with gravel. *[Continued from previous page]*		604	
	35/48 *73%*	cs									
11B				14			24	Gray (10YR6/1), wet, loose, fine- to medium-grained SAND.		602	
	50/60 *83%*	cs					26			600	
12A				7			28	Gray (10YR5/1), moist, very hard, sandy, clayey SILT with gravel.		598	
13A				6			30			596	
	56/60 *93%*	cs					32	Gray (10YR5/1), wet, loose, medium- to very coarse-grained SAND and GRAVEL.		594	
13B				6							
13C				8				Gray (10YR5/1), wet, dense, very fine- to fine-grained SAND.		592	
							34	Gray (10YR5/1), moist, very hard, sandy, clayey SILT with gravel.		590	
	60/60 *100%*	cs					36			588	
14A				14			38	Gray (10YR5/1), moist, firm, sandy, clayey SILT with gravel.		586	
							40				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/5/2006
Finish: 5/8/2006
WEATHER: Partly cloudy, mild (mid-70s)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: P. McIntire
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-07
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,180.0N
2,514,390.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.80 - While drilling
▼ = 4.90 - MW07S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
15A	60/60 *100%*	cs		14			42			584	
							44	Gray (10YR5/1), moist, firm, sandy, clayey SILT with gravel. *[Continued from previous page]*		582	
	60/60 *100%*	cs					46			580	
16A				15			48			578	
							50	Dark greenish gray (10BG4/1), moist, soft, silty CLAY with trace sand and trace gravel.		576	
17A				24				Very dark gray (10YR3/1), moist firm, clayey SILT.		574	
	60/60 *100%*	cs					52			572	
17B								Dark greenish gray (10BG4/1), moist, soft, silty CLAY with trace sand and trace gravel.			
							54	**End of Boring = 54.0 ft BGS**			

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/9/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: P. McIntire
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-07a
Well ID: MW7S
Surface Elev: 625 ft. MSL
Completion: 14 ft. BGS
Station: 879,181.1N
2,514,397.5E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 10.80 - While drilling
▼ = 4.90 - MW07S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil — Dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.		624	
								Dark gray (10YR4/1), moist, soft, silty CLAY with trace and and trace gravel.			
							2	Gray (10YR5/1) with 20% yellowish brown mottles, moist, soft, silty CLAY with trace sand and trace gravel.		622	
							4	loess — Black (10YR2/1), very moist, soft, clayey SILT.		620	
							▼	Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist soft, silty CLAY with trace sand and trace gravel.			
							6	Black (10YR2/1), moist, soft, silty CLAY with trace sand and trace gravel.		618	
							8	Dark gray (10YR4/1), very moist, soft, silty CLAY with some sand and trace gravel.		616	
							10	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, soft, silty CLAY with sand and gravel.		614	
							▼	Yellowish brown (10YR5/8) wet, very soft, clayey, very fine- to fine-grained, SAND with trace gravel.			
							12	Yellowish brown (10YR5/8) wet, soft, clayey, very fine- to fine-grained, SAND with trace gravel.		612	
							14	Gray (10YR4/1), moist, very hard, sandy, clayey SILT with gravel.			

End of Boring = 14.39 ft. BGS
See SB-07 for sample & testing details

NOTE(S): MW07S installed in blind-drilled borehole within 10 ft of SB-07.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-08
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 59 ft. BGS
Station: 879,770.0N
2,514,480.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.70 - While drilling
▼ = 5.33 - MW08S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil Very dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.		624	
	24/24 100%	ss	1-1 1 N=2				2	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		622	
2A	24/24 100%	ss	1-1 1 N=2	25		1.59 B	4	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		620	
3A	24/24 100%	ss	1-1 1 N=2	20		1.86 B		Gray (10YR5/1) with 40% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.			
3B				21		1.20 B	6	loess Gray (10YR5/1), moist, soft, clayey SILTwith little sand and trace gravel.		618	
	24/24 100%	ss	0-1 1 N=2				8	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, moist, soft, sandy CLAY with sl. trace gravel.		616	
4A				25		1.01 None					
	24/24 100%	ss	0-1 1 N=2				10	Yellowish brown (10YR5/6) with 10% gray (10YR5/1) mottles, moist, soft, sandy CLAY with sl. trace gravel.		614	
5A				21							
6A	24/24 100%	ss	0-1 1 N=2	21		0.70 BSh					
6B				31			12	Gray (10YR5/1), wet, soft, very silty, very fine- to coarse-grained SAND.		612	
7A	20/24 83%	ss	0-1 3 N=4	13							
7B				15			14	Light gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, wet, very dense, very fine- to fine-grained SAND.		610	
8A	23/24 96%	ss	7-11 16 N=27	9		5.45 Sh		Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, wet, dense, fine- to very coarse-grained SAND.			
8B				8			16			608	
	24/30 80%	cs									
9A				5			18	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		606	
							20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-08
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 59 ft. BGS
Station: 879,770.0N
2,514,480.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.70 - While drilling
▼ = 5.33 - MW08S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	60/60 *100%*	cs					22			604	
10A				7			24			602	
	36/60 *60%*	cs					26			600	
11A				10			28			598	
	60/60 *100%*	cs					30	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		596	
12A				6			32			594	
	60/60 *100%*	cs					34			592	
13A				7			36			590	
							38			588	
							40			586	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-08
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 59 ft. BGS
Station: 879,770.0N
2,514,480.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.70 - While drilling
▼ = 5.33 - MW08S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	60/60 100%	cs						Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		584	
							42	Greenish gray (10BG5/1) with 10% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with little sand and trace gravel		582	
14A				14							
14B				11				Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			
							44	Dark yellowish brown (10YR4/4), moist, firm, clayey SILT with some sand and trace gravel.		580	
15A				12							
15B				15							
	60/60 100%	cs					46	Gray (10YR4/1), moist, hard, clayey, sandy SILT with trace gravel.		578	
							48	Gray (10YR4/1) with 50% very dark grayish brown (10YR3/2), moist, firm, silty CLAY with sand and trace gravel.		576	
15C				13							
							50	Gray (10YR4/1), moist, hard, clayey, sandy SILT with trace gravel.		574	
16A				14							
	60/60 100%	cs									
							52			572	
16B				19							
							54	Greenish gray (10BG4/1), moist, soft, silty CLAY with little sand and sl. trace gravel.		570	
17A				24							
	60/60 100%	cs					56			568	
								Yellowish brown (10YR5/6) with 20% Greenish gray (10BG4/1) mottles, moist, soft, silty CLAY with little sand and sl. trace gravel.			
							58				
17B				19				**End of Boring = 58.5 ft.**			

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/10/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-08a
Well ID: MW8S
Surface Elev: 625 ft. MSL
Completion: 17 ft. BGS
Station: 879,776.6N
2,514,478.8E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.70 - While drilling
▼ = 5.33 - MW08S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil Very dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.		624	
							2	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		622	
							4	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		620	
							5.33 ▼	Gray (10YR5/1) with 40% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.			
							6	loess Gray (10YR5/1), moist, soft, clayey SILTwith little sand and trace gravel.		618	
							8	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, moist, soft, sandy CLAY with sl. trace gravel.		616	
							10	Yellowish brown (10YR5/6) with 10% gray (10YR5/1) mottles, moist, soft, sandy CLAY with sl. trace gravel.		614	
							12.70 ▼			612	
							14	Gray (10YR5/1), wet, soft, very silty, very fine- to coarse-grained SAND.		610	
							16	Light gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, wet, very dense, very fine- to fine-grained SAND. Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, wet, dense, fine- to very coarse-grained SAND. Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		608	

End of Boring = 17.08 ft. BGS
See SB-08 for sample & testing details

NOTE(S): MW08S installed in blind-drilled borehole within 10 ft of SB-08.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-09
Well ID: MW9D
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,679.7N
2,515,666.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 5.23 - MW09S on 6/1/06
▽ = 52.46 - MW09D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil Dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.		624	
1A	22/24 92%	ss	0-1 1-1 N=2	24	1.65 B		2	Yellowish brown (10YR5/6), moist, soft, silty CLAY with little sand.		622	
2A	20/24 83%	ss	1-2 1-1 N=3	27	2.06 B		4			620	
3A	24/24 100%	ss	1-1 1-1 N=2	24	1.65 B		6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		618	
4A	24/24 100%	ss	1-1 1-2 N=2	23	1.57 B		8	Gray (10YR5/1) with 50% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with sand.		616	
5A	24/24 100%	ss	0-1 1-1 N=2	27	1.85 B		10	Yellowish brown (10YR5/6) with 10% Gray (10YR5/1) mottles, moist, soft, silty CLAY with sand.		614	
6A	24/24 100%	ss	0-0 0-0 N=0	22	1.44 B		12	Yellowish brown (10YR5/8), very moist, soft, sandy CLAY with trace gravel.		612	
7A				21	0.93 BSh			Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist to very moist, clayey SILT with sand and trace gravel.			
7B	24/24 100%	ss	0-0 1-2 N=1	18	0.97 BSh						
7C				15			▼ 14	Gray (10YR5/1), wet, soft, clayey very fine- to fine-grained SAND.			
8A				18				Gray (10YR5/1), wet, loose, fine- to very coarse-grained SAND with trace gravel.		610	
8B	24/24 100%	ss	1-3 6-6 N=9	18				Gray (10YR5/1), wet, dense, silty very fine- to fine-grained SAND.			
9A	24/24 100%	ss	7-13 19-25 N=32	8	7.86 Sh		16			608	
	12/12 100%	cs					18	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		606	
							20				

NOTE(S): MW09D installed in SB-09.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-09
Well ID: MW9D
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,679.7N
2,515,666.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 5.23 - MW09S on 6/1/06
▽ = 52.46 - MW09D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
										604	
	60/60 100%	CS					22				
11A				2						602	
							24				
										600	
							26				
	49/60 82%	CS								598	
12A				3							2" Sand stringer
							28	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*			
										596	
							30				
										594	
	60/60 100%	CS					32				
13A				3						592	
							34				
										590	
							36	Yellowish brown (10YR5/6) with 40% gray (10YR5/1) mottles, moist, very hard, clayey SILT with little sand and occasional dry, silt stringers (<1").			
14A	60/60 100%	CS		10						588	
							38	Gray (10YR5/1), moist, very hard, clayey SILT with little sand and trace gravel.			
14B				11						586	
								Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			DRILLER NOTE: Appears more plastic
							40				

NOTE(S): MW09D installed in SB-09.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-09
Well ID: MW9D
Surface Elev: 625 ft. MSL
Completion: 54 ft. BGS
Station: 879,679.7N
2,515,666.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 5.23 - MW09S on 6/1/06
▽ = 52.46 - MW09D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		584	
	60/60 *100%*	cs					42				
15A				12						582	
							44	Very dark grayish brown (10YR3/2), moist, hard, silty CLAY with trace sand and trace organic matter.			
								Very dark grayish brown (10YR3/2), moist, firm, PEAT.		580	
19				22			46	Dark greenish gray (10BG4/1), moist, firm, silty CLAY with little sand and trace gravel.			
	60/60 *100%*	cs								578	
							48	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			
16A				17				Dark gray (10YR3/1), moist, hard, clayey SILT.		576	
							50				
										574	
17A											
	60/60 *100%*	cs						Dark greenish gray (10BG4/1), moist, firm, silty CLAY with little sand and trace gravel.			
							52 ▽			572	
							54	**End of Boring = 54.0 ft.**			

NOTE(S): MW09D installed in SB-09.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/3/2006
Finish: 5/3/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-09a
Well ID: MW9S
Surface Elev: 625 ft. MSL
Completion: 16 ft. BGS
Station: 879,684.9N
2,515,666.2E

SAMPLE			TESTING				
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 5.23 - MW09S on 6/1/06
▽ = 52.46 - MW09D on 6/1/06

Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
	soil dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.	624	
2, 4	Yellowish brown (10YR5/6), moist, soft, silty CLAY with little sand.	622, 620	
6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.	618	
8	Gray (10YR5/1) with 50% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with sand.	616	
10	Yellowish brown (10YR5/6) with 10% Gray (10YR5/1) mottles, moist, soft, silty CLAY with sand.	614	
12	Yellowish brown (10YR5/8), very moist, soft, sandy CLAY with trace gravel.		
	Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist to very moist, clayey SILT with sand and trace gravel.	612	
14	Gray (10YR5/1), wet, soft, clayey very fine- to fine-grained SAND.		
	Gray (10YR5/1), wet, loose, fine- to very coarse-grained SAND with trace gravel.	610	
	Gray (10YR5/1), wet, dense, silty very fine- to fine-grained SAND.		
16	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		

End of Boring = 16.20 ft. BGS
See SB-09 for sample & testing details

NOTE(S): MW09S installed in blind-drilled borehole within 10 ft of SB-09.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/1/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-10
Well ID: MW10D
Surface Elev: 621 ft. MSL
Completion: 49 ft. BGS
Station: 878,245.1N
2,515,914.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.80 - While drilling
▼ = 4.91 - MW10S on 6/1/06
▽ = 47.48 - MW10D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil Dark gray (10YR3/1), moist, soft, clayey SILT with trace sand and trace gravel.			
1A	17/24 71%	ss	1-1 1-1 N=2	23		2.33 B	2	Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		620	
2A	24/24 100%	ss	1-1 2-2 N=3	25		2.47 BSh	4	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand.		618	
3A	24/24 100%	ss	1-2 1-2 N=3	24		2.33 B	▼			616	
4A	24/24 100%	ss	1-1 1-1 N=2	23		1.55 B	6	Gray (10YR5/1), moist, soft, clayey, very fine- to fine-grained SAND.		614	
4B							8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, moist, soft, silty CLAY with little sand and trace gravel.		612	
5A	17/24 71%	ss	1-1 1-2 N=2	23		2.06 B	10			610	
6A	24/24 100%	ss	0-1 1-1 N=2	17		1.16 B	▼ 12	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, clayey, very fine- to medium-grained SAND with trace gravel.		608	
7A	23/24 96%	ss	1-1 3-3 N=4	17		2.84 B	14	Grayish brown (10YR5/2), wet, loose, very fine- to medium-grained SAND with trace coarse- to very coarse-grained sand.		606	
7B				18				Yellowish brown (10YR5/6), moist, firm, silty CLAY with little sand and trace gravel.			
8A	24/24 100%	ss	3-5 9-9 N=14	10		7.64 BSP	16			604	
10A	12/33 36%	cs		16			18	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		602	
							20				

NOTE(S): MW10D installed in SB-10.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/1/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-10
Well ID: MW10D
Surface Elev: 621 ft. MSL
Completion: 49 ft. BGS
Station: 878,245.1N
2,515,914.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.80 - While drilling
▼ = 4.91 - MW10S on 6/1/06
▽ = 47.48 - MW10D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22			600	
							24	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		598	
11A				12							
	56/60 *93%*	cs					26			596	2" Gravel stringer
11B				13				Dark grayish brown (10YR4/2), very moist, soft, PEAT.		594	
11C				196			28				
										592	
							30				
	60/60 *100%*	cs								590	
12A				13			32				
								Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel.		588	
							34				
										586	
	60/60 *100%*	cs					36				
										584	
13A				12			38				
										582	
							40				

NOTE(S): MW10D installed in SB-10.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/1/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-10
Well ID: MW10D
Surface Elev: 621 ft. MSL
Completion: 49 ft. BGS
Station: 878,245.1N
2,515,914.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.80 - While drilling
▼ = 4.91 - MW10S on 6/1/06
▽ = 47.48 - MW10D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
14A	60/60 *100%*	cs		14			42	Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		580	
14B				23			44	Greenish gray (5G5/1), moist, firm, silty CLAY with little sand and sl. trace gravel.		578	1" Gravel stringer
15A	60/60 *100%*	cs		13			46	Greenish gray (5G5/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with little sand and sl. trace gravel.		576	
15B				25			▽ 48	Greenish gray (5G5/1), moist, firm, silty CLAY with little sand and sl. trace gravel.		574	

End of Boring = 48.75 ft.

NOTE(S): MW10D installed in SB-10.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/2/2006
Finish: 5/2/2006
WEATHER: Sunny, mild (mid-60's)

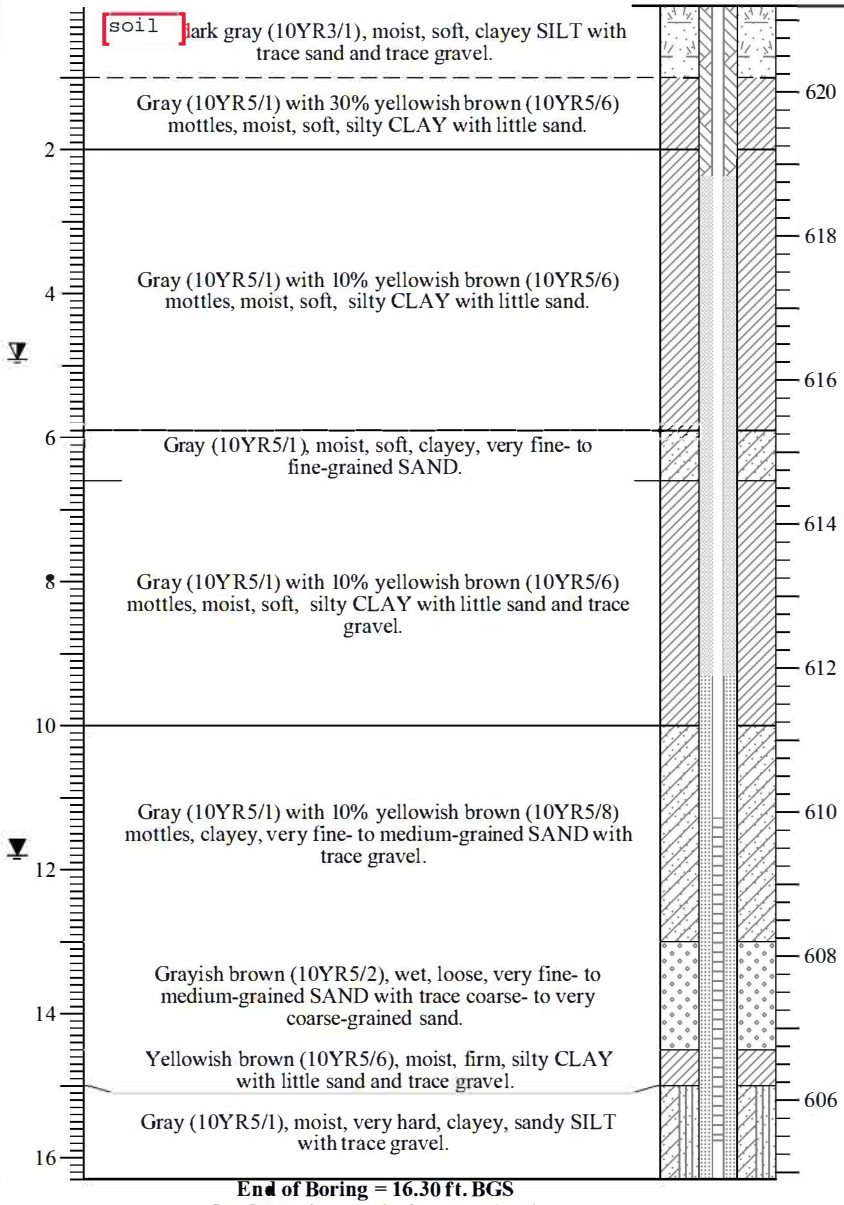
CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-10a
Well ID: MW10S
Surface Elev: 621 ft. MSL
Completion: 16 ft. BGS
Station: 878,250.5N
2,515,914.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.80 - While drilling
▼ = 4.91 - MW10S on 6/1/06
▽ = 47.48 - MW10D on 6/1/06



End of Boring = 16.30 ft. BGS
See SB-10 for sample & testing details

NOTE(S): MW10S installed in blind-drilled borehole within 10 ft of SB-10.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/27/2006
Finish: 4/28/2006
WEATHER: Partly cloudy, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-11
Well ID: MW11D
Surface Elev: 622 ft. MSL
Completion: 36 ft. BGS
Station: 876,749.6N
2,515,976.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 5.42 - MW11S on 6/1/06
▽ = 6.03 - MW11D on 6/1/06

Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	3-3 4-4 N=7	16				soil very dark grey (10YR3/1), moist, soft, clayey SILT.			
1B				34		1.09 B	2	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, moist , soft, silty CLAY.		620	
2A	24/24 100%	ss	4-7 14-21 N=21	27		2.13 BSh	4	Yellowish brown (10YR5/6) with 40% gray (10YR5/1) mottles, moist , soft, silty CLAY.		618	
3A	24/24 100%	ss	4-6 7-8 N=13	24		2.27 BSh		Gray (10YR5/1), moist, soft, clayey SILT.			
3B				19		2.33 B	6			616	
4A	24/24 100%	ss	7-8 13-14 N=21	21		2.13 None	8	Gray (10YR4/1), moist, firm, silty CLAY with little sand and trace gravel.		614	
5A	24/24 100%	ss	3-4 4-4 N=8	20		1.55 Sh	10			612	
6A	24/24 100%	ss	3-2 2-3 N=4	19		0.78 BSh					
6B				18			12	Gray (10YR4/1), wet, soft, sandy CLAY.		610	
7A	24/24 100%	ss	3-6 14-21 N=20	16				Yellowish brown (10YR5/6) with 50% gray (10YR5/1) mottles, wet, soft, sandy CLAY with trace gravel.			
7B				9		5.45 BSP	14	Gray (10YR5/1), moist, very hard, sandy, clayey SILT with gravel.		608	
8A	11/12 92%	ss	41-61/5"	7				Gray (10YR5/1), moist, hard, silty CLAY with little sand and trace gravel. Light gray (10YR7/1) with 10% yellowish brown (10YR5/8) mottles, moist, hard, silty CLAY with little sand and trace gravel.			
							16			606	
9A	48/54 89%	cs		8			18	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		604	
							20			602	

DRILLER NOTE: sampler recovered wet.

NOTE(S): MW11D installed in SB-11.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/27/2006
Finish: 4/28/2006
WEATHER: Partly cloudy, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-11
Well ID: MW11D
Surface Elev: 622 ft. MSL
Completion: 36 ft. BGS
Station: 876,749.6N
2,515,976.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 5.42 - MW11S on 6/1/06
▽ = 6.03 - MW11D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22			600	DRILLER NOTE: soft drilling 20.5' to 21.0'
10A	54/60 90%	cs		6							Wet, gravelly zone from 22.4' to 22.8'
							24	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		598	
							26			596	
11A	58/60 97%	cs		8			28			594	
							30			592	
12A	32/60 53%	cs		9				Gray (10YR5/1), wet, loose, clayey, very fine- to medium-grained SAND with little coarse-grained sand and trace gravel.			
							32			590	
12B				9			34	Gray (10YR6/1) with occasional black (10YR2/1) varves, dry, dense, SILT with trace sand.		588	
	22/22 100%	ss	7-19 41-50/4" N=60								
13B				14		4.85 BSh	36	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		586	

End of Boring = 36.33 ft.

NOTE(S): MW11D installed in SB-11.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/28/2006
Finish: 4/28/2006
WEATHER: Partly cloudy, mild (mid-60's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-11a
Well ID: MW11S
Surface Elev: 622 ft. MSL
Completion: 14 ft. BGS
Station: 876,749.4N
2,515,971.2E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 5.42 - MW11S on 6/1/06
▽ = 6.03 - MW11D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil very dark grey (10YR3/1), moist, soft, clayey SILT.			
							1.5	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, moist , soft, silty CLAY.			
							2			620	
							3	Yellowish brown (10YR5/6) with 40% gray (10YR5/1) mottles, moist , soft, silty CLAY.			
							4			618	
							4.5	Gray (10YR5/1), moist, soft, clayey SILT.			
							5.5	▼			
							6	▽		616	
							8	Gray (10YR4/1), moist, firm, silty CLAY with little sand and trace gravel.		614	
							10			612	
							11.5	▼			
							12	Gray (10YR4/1), wet, soft, sandy CLAY.		610	
							13	Yellowish brown (10YR5/6) with 50% gray (10YR5/1) mottles, wet, soft, sandy CLAY with trace gravel. Gray (10YR5/1), moist, very hard, sandy, clayey SILT with gravel.			
							14			608	

End of Boring = 14.08 ft. BGS
See SB-11 for sample & testing details

NOTE(S): MW11S installed in blind-drilled borehole within 10 ft of SB-11.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/10/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

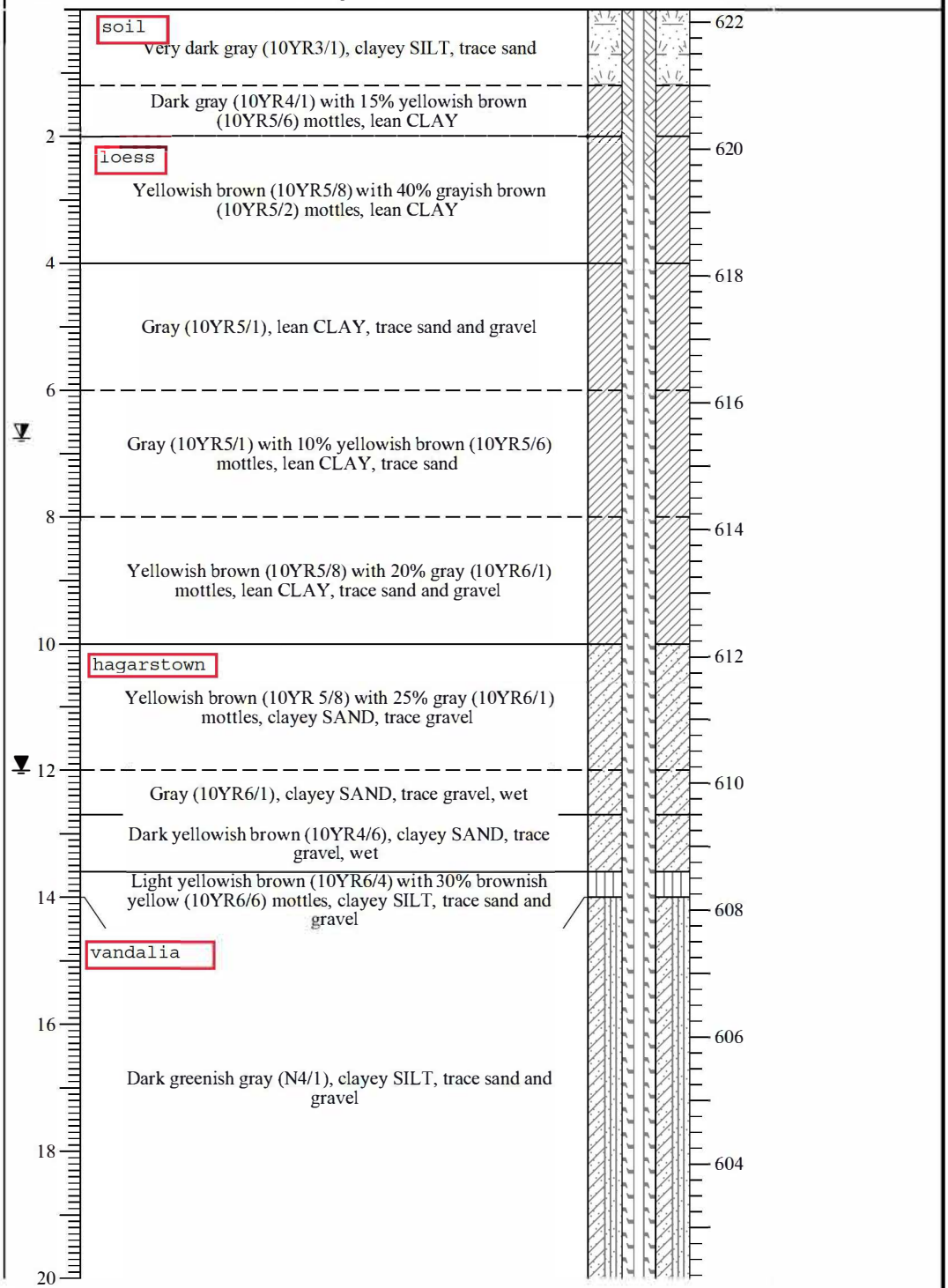
CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-12
Well ID: MW12D
Surface Elev: 622 ft. MSL
Completion: 50 ft. BGS
Station: 875,515.1N
2,515,900.6E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ = 6.76 - MW12S on 6/1/06
▽ = 46.90 - MW12D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	24"/24	ss	2-3 4-5 N=7	22		1.27 Sh
1B				27		2.33 B
2A	19"/24	ss	2-4 5-7 N=9	24		2.91 B
3A	20"/24	ss	2-2 3-4 N=5	21		2.13 B
4A	24/24 100%	ss	4-5 5-6 N=10	21		1.36 BSh
5A	24"/24	ss	1-2 2-5 N=4	20		1.47 BSh
6A	20"/24	ss	0-1 3-3 N=4	21		0.62 B
7A	21"/24	ss	2-2 3-5 N=5	22		0.19 B
7B				22		
7C				15		3.71 B
8A	24"/24	ss	4-13 18-29 N=31	9		5.15 BSh
9A	24"/24	ss	26-32 46-50 N=78	9		6.59 Sh
10A	24"/24	ss	21-31 63-71 N=94	11		6.39 Sh



NOTE(S): MW12D installed in SB-12.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/10/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-12
Well ID: MW12D
Surface Elev: 622 ft. MSL
Completion: 50 ft. BGS
Station: 875,515.1N
2,515,900.6E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ = 6.76 - MW12S on 6/1/06
▽ = 46.90 - MW12D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22	Dark greenish gray (N4/1), clayey SILT, trace sand and gravel *[Continued from previous page]*		602	
	60/60 *100%*	cs								600	
11A				6			24			598	
							26			596	
	60/60 *100%*	cs					28			594	
12A				7			30	Dark greenish gray (N4/1), sandy SILT, trace gravel		592	
							32			590	
	60/60 *100%*	cs									
13A				13			34			588	
								smithboro			
							36			586	
	60/60 *100%*	cs						Very dark gray (N3/1), clayey SILT, trace sand and gravel			
							38			584	
14A				16			40				

NOTE(S): MW12D installed in SB-12.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 5/10/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-12
Well ID: MW12D
Surface Elev: 622 ft. MSL
Completion: 50 ft. BGS
Station: 875,515.1N
2,515,900.6E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ = 6.76 - MW12S on 6/1/06
▽ = 46.90 - MW12D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							42	Very dark gray (N3/1), clayey SILT, trace sand and gravel *[Continued from previous page]*		582	
	60/60 *100%*	CS								580	
15A				14			44			578	
								Very dark gray (N3/1), PEAT			
							46			576	
	60/60 *100%*	CS						Gray (N5/1) with 30% yellowish brown (10YR5/6) mottles, lean CLAY			
							48			574	
16A				45							
							50	**End of Boring = 50.0 ft. BGS**			

NOTE(S): MW12D installed in SB-12.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/10/2006
Finish: 5/10/2006
WEATHER: Foggy to partly sunny, mild (hi-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA (blind drill)
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-12a
Well ID: MW12S
Surface Elev: 622 ft. MSL
Completion: 16 ft. BGS
Station: 875,520.1N
2,515,900.5E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Elevation ft. MSL
							0	soil Very dark gray (10YR3/1), clayey SILT, trace sand	622
							2	Dark gray (10YR4/1) with 15% yellowish brown (10YR5/6) mottles, lean CLAY	620
							4	Yellowish brown (10YR5/8) with 40% grayish brown (10YR5/2) mottles, lean CLAY	618
							6	Gray (10YR5/1), lean CLAY, trace sand and gravel	616
							8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand	614
							10	Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, lean CLAY, trace sand and gravel	612
							12	Yellowish brown (10YR 5/8) with 25% gray (10YR6/1) mottles, clayey SAND, trace gravel	610
							14	Gray (10YR6/1), clayey SAND, trace gravel, wet Dark yellowish brown (10YR4/6), clayey SAND, trace gravel, wet Light yellowish brown (10YR6/4) with 30% brownish yellow (10YR6/6) mottles, clayey SILT, trace sand and gravel Dark greenish gray (N4/1), clayey SILT, trace sand and gravel	608

End of Boring = 15.61 ft. BGS
See SB-12 for sample & testing details

NOTE(S): MW12S installed in blind-drilled borehole within 10 ft of SB-12.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/9/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-13
Well ID: MW13D
Surface Elev: 623 ft. MSL
Completion: 55 ft. BGS
Station: 874,694.3N
2,513,929.9E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.40 - While drilling
▼ = 8.24 - MW12S on 6/1/06
▽ = 56.03 - MW13D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	22/24 92%	ss	4-5 4-4 N=9	21			0	soil yish brown (10YR5/2), clayey SILT, trace sand		622	
1B				15				Light gray (10YR7/2), clayey SILT, trace sand			
1C				28		2.13 B	2	Light brownish gray (10YR6/2) with 15%yellowish brown (10YR5/6) mottles, lean CLAY, trace sand		620	
2A	21/24 88%	ss	3-4 5-8 N=9	25		2.13 BSh	4	Gray (10YR6/1) with 40% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand		618	
3A	24/24 100%	ss	4-5 6-8 N=11	22		2.84 Sh	6	Dark gray (10YR4/1), lean CLAY, trace sand and gravel		616	
3B				21		2.91 BSh					
4A	24/24 100%	ss	9-12 10-10 N=22	23		2.33 B	8 ▼	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand and gravel		614	
5A	24/24 100%	ss	3-4 6-7 N=10	21		2.72 Sh	10			612	
6A	19/24 79%	ss	1-3 6-8 N=9	23		1.94 Sh					
7A				18		1.94 Sh	12 ▼			610	
7B	21/24 88%	ss	6-8 10-12 N=18	13		1.55 BSh	14	Yellowish brown (10YR5/6), silty SAND, trace gravel, wet		608	
8A	22/24 92%	ss	7-21 29-30 N=50	11			16	Yellowish brown (10YR5/8) with 30% light brownish gray (10YR6/2) mottles, sandy SILT, trace gravel		606	
8B				9							
9A	23/24 96%	ss	25-28 28-45 N=56	9		9.16 Sh	18	Dark gray (10YR4/1), sandy SILT, trace gravel		604	
10A	24/24 100%	ss	18-27 31-36 N=58	8		12.00 Sh	20				

NOTE(S): MW13D installed in SB-13.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/9/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-13
Well ID: MW13D
Surface Elev: 623 ft. MSL
Completion: 55 ft. BGS
Station: 874,694.3N
2,513,929.9E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.40 - While drilling
▼ = 8.24 - MW12S on 6/1/06
▽ = 56.03 - MW13D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22			602	
	60/60 100%	cs									
							24			600	
11A				13							
							26			598	
	60/60 100%	cs					28	Dark gray (10YR4/1), sandy SILT, trace gravel *[Continued from previous page]*		596	
12A							30			594	
	60/60 100%	cs					32			592	
13A				15			34			590	
	60/60 100%	cs					36			588	
							38	Dark gray (10YR4/1), lean CLAY, trace sand and gravel		586	
14A				15			40			584	

NOTE(S): MW13D installed in SB-13.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/9/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler & 4¼" HSA overdrill

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-13
Well ID: MW13D
Surface Elev: 623 ft. MSL
Completion: 55 ft. BGS
Station: 874,694.3N
2,513,929.9E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.40 - While drilling
▼ = 8.24 - MW12S on 6/1/06
▽ = 56.03 - MW13D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							42			582	
	60/60 *100%*	CS									
							44			580	
15A				15							
							46			578	
								Dark gray (10YR4/1), lean CLAY, trace sand and gravel *[Continued from previous page]*			
	60/60 *100%*	CS					48			576	
16A				15							
							50			574	
							52			572	
17A				14				Gray (10YR4/1), silty, fine to medium SAND, wet			
17B	60/60 *100%*	CS		20				Gray (10YR4/1), sandy SILT		570	
17C				14							
							54	Dark greenish gray (5GY4/1) with 25% yellowish brown (10YR5/6) mottles, lean CLAY			
17D				22						568	

End of Boring = 55.0 ft. BGS

NOTE(S): MW13D installed in SB-13.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/9/2006
Finish: 5/9/2006
WEATHER: Overcast, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-13a
Well ID: MW13S
Surface Elev: 623 ft. MSL
Completion: 17 ft. BGS
Station: 874,695.7N
2,513,925.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ = 6.76 - MW13S on 6/1/06
▽ = 46.90 - MW12D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil yish brown (10YR5/2), clayey SILT, trace sand		622	
								Light gray (10YR7/2), clayey SILT, trace sand			
							1	Light brownish gray (10YR6/2) with 15%yellowish brown (10YR5/6) mottles, lean CLAY, trace sand			
							2			620	
							3	Gray (10YR6/1) with 40% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand			
							4			618	
							5	Dark gray (10YR4/1), lean CLAY, trace sand and gravel			
							6			616	
							7	▼			
							8	Gray (10YR5/1) with 25% yellowish brown (10YR5/6) mottles, lean CLAY, trace sand and gravel		614	
							9				
							10			612	
							11				
							12	▼			
							13	Yellowish brown (10YR5/6), silty SAND, trace gravel, wet		610	
							14				
							15	Yellowish brown (10YR5/8) with 30% light brownish gray (10YR6/2) mottles, sandy SILT, trace gravel		608	
							16	Dark gray (10YR4/1), sandy SILT, trace gravel			
								End of Boring = 16.62 ft. BGS			

See SB-13 for sample & testing details

NOTE(S): MW13S installed in blind-drilled borehole within 10 ft of SB-13.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/2/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-14
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 60 ft. BGS
Station: 875,740.0N
2,514,130.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 4.49 - MW14S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	TESTING Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	23/24 96%	ss	2-3 2-3 N=5	16		
1B				26		2.33 B
2A	24/24 100%	ss	3-4 5-7 N=9	23		3.10 B
3A	23/24 96%	ss	3-3 5-5 N=8	19		2.33 B
4A	24/24 100%	ss	5-6 5-7 N=11	23		2.68 BSh
5A	24/24 100%	ss	2-2 3-4 N=5	26		1.83 B
6A	19/24 79%	ss	2-2 3-5 N=5	17		2.18 B
7A	20/24 83%	ss	2-3 3-3 N=6	22		1.16 B
8A	24/24 100%	ss	5-14 14-20 N=28	16		1.36 B
8B				11		5.77 BSh
9A	12/24 50%	ss	57-65	10		
10A	24/24 100%	ss	6-8 16-18 N=24	12		5.04 BSh

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	soil Grayish brown (10YR5/2), clayey SILT, trace sand		624	
2	Gray (10YR6/1) with 30% yellowish brown (10YR6/8) mottles, lean CLAY, trace sand		622	
4	Light gray (10YR7/1) with 30% yellowish brown (10YR6/8) mottles, lean CLAY, trace sand		620	
6	Light gray (10YR7/1) with 15% yellowish brown (10YR6/8) mottles, lean CLAY, trace sand		618	
8			616	
10	Yellowish brown (10YR5/8) with 50% light gray (10YR7/1) mottles, sandy CLAY		614	
12			612	
14	Yellowish brown (10YR5/6), silty, fine SAND, trace medium sand and gravel, wet		610	
16	Yellowish brown (10YR5/6), sandy SILT, trace gravel		608	
18	Yellowsh brown (10YR5/6) with 40% gray (10YR6/1) mottles, sandy SILT, trace gravel		606	
20	Dark gray (10YR4/1), clayey SILT, trace sand and gravel			

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/2/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-14
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 60 ft. BGS
Station: 875,740.0N
2,514,130.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 4.49 - MW14S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 100%	ss	2-7 13-30 N=20	13		9.70 B	22			604	
12A	24/24 100%	ss	26-40 36-40 N=76	9		13.09 BSP	24			602	
13A	24/24 100%	ss	8-18 28-34 N=46	9		8.73 BSP	26			600	
14A	22/24 92%	ss	20-18 24-30 N=42	9		7.42 BSP	28	Dark gray (10YR4/1), clayey SILT, trace sand and gravel *[Continued from previous page]*		598	
15A	19/24 79%	ss	8-27 33-67 N=60	9			30			596	
16A	24/24 100%	ss	8-25 27-33 N=52	10		9.60 BSh	32			594	
17A	20/24 83%	ss	11-15 20-24 N=35	14		6.80 B	34			592	
18A	24/24 100%	ss	3-4 7-9 N=11	16		3.88 B	36			590	
19A	24/24 100%	ss	8-12 13-15 N=25	16		6.18 B	38	Dark gray (N4/1), lean CLAY, trace sand and gravel		588	
20A	24/24 100%	ss	3-7 10-13 N=17	14		3.10 B	40			586	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/1/2006
Finish: 5/2/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-14
Well ID: n/a
Surface Elev: 625 ft. MSL
Completion: 60 ft. BGS
Station: 875,740.0N
2,514,130.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 4.49 - MW14S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
21A	23/24 96%	ss	3-6 8-13 N=14	15		4.80 B	42			584	
22A	24/24 100%	ss	13-15 16-18 N=31	14		5.62 B	44	Dark gray (N4/1), lean CLAY, trace sand and gravel *[Continued from previous page]*		582	
23A	24/24 100%	ss	4-8 11-13 N=19	15		4.65 B	46			580	
24A	24/24 100%	ss	18-18 20-20 N=38	15		4.65 B	48			578	
25A	24/24 100%	ss	4-7 9-11 N=16	19		2.13 BSh	50	Dark gray (N4/1), clayey SILT, trace sand and gravel Gray (N4/1), wet, loose, fine- to medium-grained SAND Dark gray (N4/1), clayey SILT, trace sand and gravel		576	
26A	22/24 92%	ss	3-5 6-8 N=11	22		3.30 BSh	52	Greenish gray (5BG5/1), lean CLAY		574	
27A	24/24 100%	ss	3-5 5-7 N=10	25		2.89 BSh	54	Greenish gray (5BG5/1) with 15% yellowish brown (10YR5/6) mottles, lean CLAY		572	
28A	21/24 88% 0/24 0%	ss SH	4-6 7-8 N=13	22		3.71 BSh	56	Greenish gray (5BG5/1) with 25% yellowish brown (10YR5/6) mottles, lean CLAY		570	
29A	14/24 58%	ss	0-0 0-0 N=0	22		3.09 BSh	58	Greenish gray (5BG5/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY		568	
30A	22/24 92%	ss	5-6 8-12 N=14	19		4.46 BSh	60	Yellowish brown (10YR4/6) with 10% greenish gray (5BG5/1) mottles, lean CLAY **End of Boring = 60.0 ft. BGS**		566	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/2/2006
Finish: 5/2/2006
WEATHER: Sunny, mild (mid-60's)

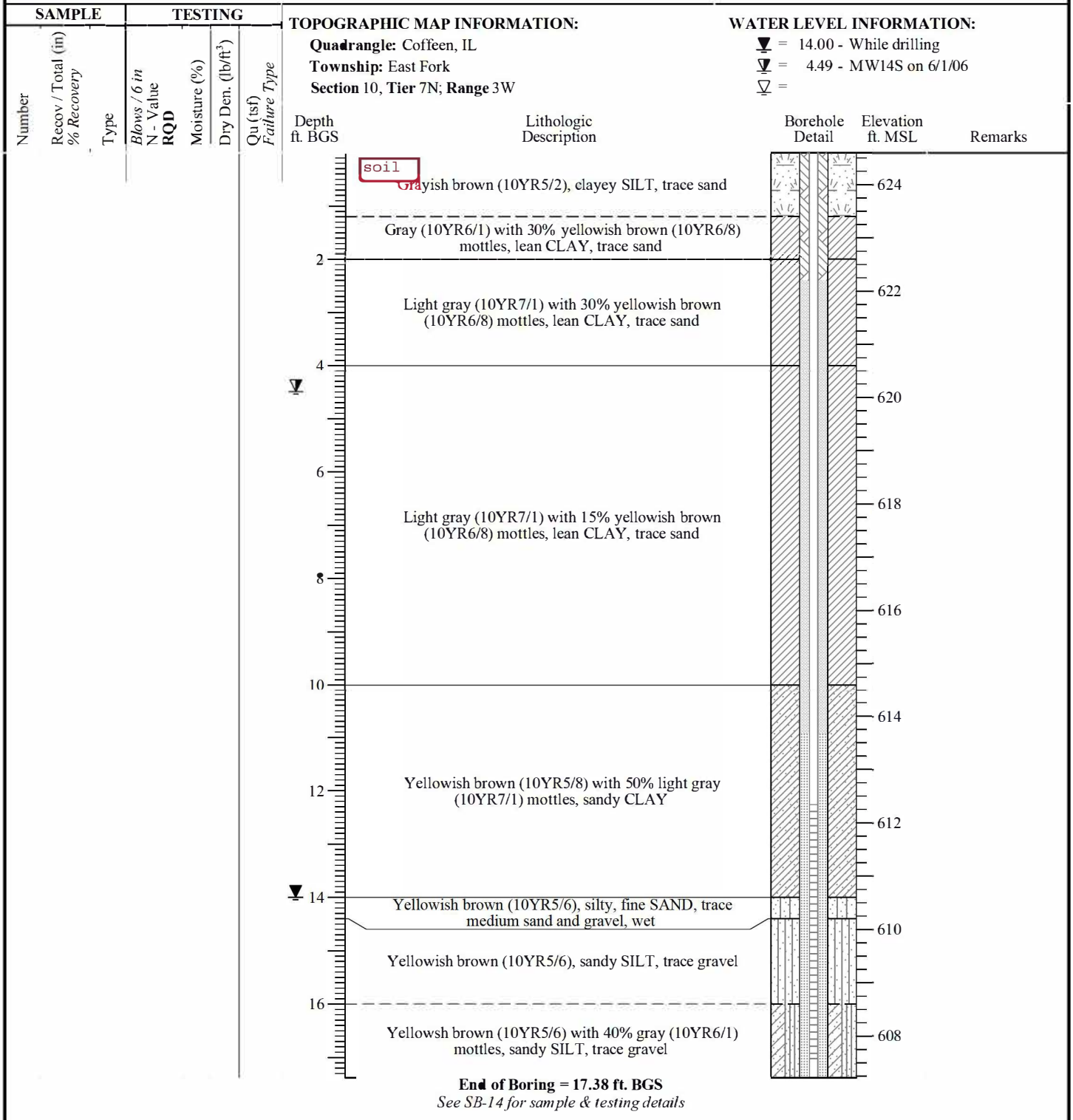
CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: Sb-14a
Well ID: MW14S
Surface Elev: 625 ft. MSL
Completion: 17 ft. BGS
Station: 875,737.8N
2,514,125.9E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - While drilling
▼ = 4.49 - MW14S on 6/1/06
▽ =



End of Boring = 17.38 ft. BGS
See SB-14 for sample & testing details

NOTE(S): MW14S installed in blind-drilled borehole within 10 ft of SB-14.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 84 ft. BGS
Station: 875,970.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	24/24 100%	ss	2-2 3-4 N=5	19		
1B				27		1.94 B
2A	24/24 100%	ss	2-2 4-6 N=6	25		3.10 B
3A	20/24 83%	ss	2-3 3-5 N=6	29		2.10 B
4A	24/24 100%	ss	4-6 5-5 N=11	24		1.75 B
5A	22/24 92%	ss	1-2 3-4 N=5	26		1.55 B
6A	22/24 92%	ss	2-3 3-4 N=6	22		1.85 B
	19/24 79%	SH				
7A	24/24 100%	ss	4-4 5-5 N=9	23		1.22 B
7B				17		
8A	21/24 88%	ss	2-6 15-19 N=21	11		3.22 BSP
9A	24/24 100%	ss	18-29 40-50 N=69	20		
9B				21		
9C				9		
10A	17/24 71%	ss	11-43 59/5"	7		7.42 B

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	soil — Dark brown (10YR3/3), clayey SILT			
	Dark grayish brown (10YR3/2), clayey SILT, trace sand			
2	Grayish brown (10YR5/2), with 50% very dark gray (10YR3/1) mottles, lean CLAY, trace sand		622	
	Gray (10YR6/1), lean CLAY, trace sand			
4	loess		620	
	Yellowish brown (10YR5/6) with 40% gray (10YR6/1) mottles, lean CLAY, trace sand			
6			618	
	Gray (10YR6/1), lean CLAY, trace sand			
8			616	
10	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand, trace gravel		614	
12			612	Shelby tube taken from shallow well borehole at indicated depth.
	hagarstown — R6/1) with 30% yellowish brown (10YR5/6) mottles, silty, fine to medium SAND, trace coarse sand and gravel, wet			
14	Pale brown (10YR6/3), clayey SILT, little sand, trace gravel		610	
16	Yellowish brown (10YR5/4), silty, fine to coarse SAND, wet		608	
	Yellowish brown (10YR5/4) silty fine SAND, wet			
18	Gray (10YR6/1), sandy SILT, trace medium to coarse sand and trace gravel		606	
	vandalia			
	Dark gray (10YR4/1), clayey SILT, little sand, trace gravel			
20			604	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 84 ft. BGS
Station: 875,970.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
11A	14/24 58%	ss	14-55 45/2"	8		
12A	8/24 33%	ss	100/8"	8		6.76 SP
13A	23/24 96%	ss	12-28 43-57/5" N=71	5		
14A	8/24 33%	ss	59-41/2"	6		7.95 BSh
15A	16/24 67%	ss	11-26 74/4"	12		4.74 BSh
16A	12/24 50%	ss	39-61	7		
17A	10/24 42%	ss	49-51/4"	9		5.43 B
18A	11/24 46%	ss	100-95	11		
19A	8/24 33%	ss	61-39/2"	10		
20A	24/24 100%	ss	21-41 21-24 N=62	12		16.00 None
20B				13		9.38

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
22			602	
24			600	
26			598	
28	Dark gray (10YR4/1), clayey SILT, little sand, trace gravel *[Continued from previous page]*		596	
30			594	
32			592	
34			590	
36	mulberry grove Dark gray (10YR4/1), silty, fine to medium SAND, trace coarse sand and gravel, wet		588	
38	Very dark gray (10YR3/1), clayey SILT, little sand, trace gravel		586	
40	Very dark gray (10YR3/1) with 20% dark grayish brown (10YR4/2) mottles, clayey SILT, trace sand and gravel		584	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 84 ft. BGS
Station: 875,970.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
						BSh		smithboro			
21A	22/24 92%	ss	3-7 11-18 N=18	19		6.11 BSh		Dark gray (10YR4/1), clayey SILT, trace sand and gravel			
							42			582	
22A	24/24 100%	ss	4-7 8-10 N=15	23		4.46 B		Dark greenish gray (5GY4/1) with 30% dark gray (N4/1) mottles, lean CLAY, trace sand			
							44			580	
23A				21							
23B	24/24 100%	ss	3-6 6-10 N=12	16		3.69 B					
							46			578	
24A	24/24 100%	ss	10-12 10-15 N=22	16		4.58 B					
							48	Dark gray (N4/1), lean CLAY, trace sand and gravel		576	
25A	24/24 100%	ss	2-4 7-9 N=11	16		4.65 B					
							50			574	
26A	19/24 79%	ss	3-5 7-13 N=12	21		3.88 B					
							52			572	
								yarmouth			
27A	24/24 100%	ss	8-10 8-13 N=18	25		3.49 BSh		Dark yellowish brown (10YR3/4) with 50% dark grayish brown (10YR4/2) mottles, lean CLAY, trace sand and gravel			
							54			570	
								lierle			
28A	24/24 100%	ss	4-5 8-12 N=13	22		3.49 BSh					
							56	Greenish gray (10YR5/1) with 20% dark yellowish brown (10YR4/4) mottles, lean CLAY, trace sand and gravel		568	
29A	24/24 100%	ss	5-9 15-18 N=24	20							
							58			566	
								banner			
30A	24/24 100%	ss	8-9 14-18 N=23	18		5.82 BSh		Olive (5Y4/3) with 15% greenish gray (10GY5/1) mottles, lean CLAY, trace sand and gravel			
							60			564	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 84 ft. BGS
Station: 875,970.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
31A	24/24 100%	ss	4-7 13-15 N=20	18		5.42 BSh	62	Olive (5Y4/3) with 15% greenish gray (10GY5/1) mottles, lean CLAY, trace sand and gravel *[Continued from previous page]*		562	
32A	24/24 100%	ss	10-15 11-16 N=26	20		4.74 BSh	64			560	
33A	24/24 100%	ss	6-10 11-13 N=21	16		6.98 BSh		Greenish gray (10Y5), lean CLAY, trace sand and gravel			
34A	24/24 100%	ss	11-14 18-31 N=32	18		6.98 BSh	66			558	
35A	23/24 96%	ss	9-18 27-40 N=45	15		11.95 BSh	68			556	
36A	24/24 100%	ss	4-12 18-24 N=30	16		7.15 BSh	70			554	
37A	24/24 100%	ss	17-29 36-47 N=65	17		8.24 BSh	72	Dark yellowish brown (10YR4/4), lean CLAY, trace sand and gravel		552	
38A	20/24 83%	ss	12-18 23-28 N=41	17		6.59 BSh	74			550	
39A	9/24 38%	ss	29-39 48-66 N=87	16			76			548	
40A	24/24 100%	ss	5-9 13-18 N=22	18		6.21 B	78			546	
							80			544	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS sampler

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 84 ft. BGS
Station: 875,970.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE			TESTING							
Number	Recov / Total (in) / % Recovery	Type	Blows / 6 in / N - Value / RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) / Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
41A	24/24 100%	ss	6-8 13-16 N=21	17		5.82 B	82	Dark yellowish brown (10YR4/4), lean CLAY, trace sand and gravel *[Continued from previous page]*		542	
42A	24/24 100%	ss	18-28 25-25 N=53	18		5.82 BSh	84	**End of Boring = 84.0 ft. BGS**		540	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/25/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15a
Well ID: MW15S
Surface Elev: 624 ft. MSL
Completion: 20 ft. BGS
Station: 875,971.1N
2,515,076.3E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE			TESTING							
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil — Dark brown (10YR3/3), clayey SILT			
								Dark grayish brown (10YR3/2), clayey SILT, trace sand			
							2	Grayish brown (10YR5/2), with 50% very dark gray (10YR3/1) mottles, lean CLAY, trace sand		622	
								Gray (10YR6/1), lean CLAY, trace sand			
							4			620	
								Yellowish brown (10YR5/6) with 40% gray (10YR6/1) mottles, lean CLAY, trace sand			
							6			618	
								Gray (10YR6/1), lean CLAY, trace sand			
							8			616	
							10	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand, trace gravel		614	
							12			612	
								Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, silty, fine to medium SAND, trace coarse sand and gravel, wet			
							14			610	
								Pale brown (10YR6/3), clayey SILT, little sand, trace gravel			
							16			608	
								Yellowish brown (10YR5/4), silty, fine to coarse SAND, wet			
								Yellowish brown (10YR5/4) silty fine SAND, wet			
								Gray (10YR6/1), sandy SILT, trace medium to coarse sand and trace gravel		606	
							18				
								Dark gray (10YR4/1), clayey SILT, little sand, trace gravel			
								See SB-15 for sample & testing details			
								End of Boring = 19.62 ft. BGS			

NOTE(S): MW15S installed in blind-drilled borehole within 10 ft of SB-15.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15b
Well ID: MW15D
Surface Elev: 624 ft. MSL
Completion: 39 ft. BGS
Station: 875,970.5N
2,515,080.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE			TESTING							
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil — Dark brown (10YR3/3), clayey SILT			
								Dark grayish brown (10YR3/2), clayey SILT, trace sand			
							2	Grayish brown (10YR5/2), with 50% very dark gray (10YR3/1) mottles, lean CLAY, trace sand		622	
								Gray (10YR6/1), lean CLAY, trace sand			
							4			620	
								Yellowish brown (10YR5/6) with 40% gray (10YR6/1) mottles, lean CLAY, trace sand			
							6			618	
								Gray (10YR6/1), lean CLAY, trace sand			
							8			616	
							10	Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, lean CLAY, little sand, trace gravel		614	
							12			612	
								Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, silty, fine to medium SAND, trace coarse sand and gravel, wet			
							14			610	
								Pale brown (10YR6/3), clayey SILT, little sand, trace gravel			
							16			608	
								Yellowish brown (10YR5/4), silty, fine to coarse SAND, wet			
								Yellowish brown (10YR5/4) silty fine SAND, wet			
								Gray (10YR6/1), sandy SILT, trace medium to coarse sand and trace gravel			
							18			606	
								Dark gray (10YR4/1), clayey SILT, little sand, trace gravel			
							20			604	

NOTE(S): MW15D installed in blind-drilled borehole within 10 ft of SB-15.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 4/24/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (lo-50's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-15b
Well ID: MW15D
Surface Elev: 624 ft. MSL
Completion: 39 ft. BGS
Station: 875,970.5N
2,515,080.7E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.40 - While drilling
▼ = 4.99 - MW15S on 6/1/06
▽ = 5.24 - MW15D on 6/1/06

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description
							22	
							24	
							26	
							28	Dark gray (10YR4/1), clayey SILT, little sand, trace gravel *[Continued from previous page]*
							30	
							32	
							34	
							36	Dark gray (10YR4/1), silty, fine to medium SAND, trace coarse sand and gravel, wet
							38	Very dark gray (10YR3/1), clayey SILT, little sand, trace gravel

End of Boring = 38.80 ft. BGS
See SB-15 for sample & testing details

Borehole Detail

Elevation ft. MSL: 602, 600, 598, 596, 594, 592, 590, 588, 586

Remarks

NOTE(S): MW15D installed in blind-drilled borehole within 10 ft of SB-15.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 92 ft. BGS
Station: 877,355.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								soil (10YR2/1), sl. moist, firm, clayey SILT with trace sand and trace gravel.		626	
1A	21/24 88%	ss	4-4 6-7 N=10	22							
1B				29		2.13 B	2	Brown (10YR4/3), sl. moist, firm, silty CLAY with trace sand.		624	
2A	24/24 100%	ss	4-6 7-9 N=13	25		2.13 B	4	Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, very soft, very silty CLAY with trace sand.		622	
3A	20/24 83%	ss	3-4 5-7 N=9	21		2.33 B	6			620	
4A	24/24 100%	ss	2-3 4-6 N=7	25		2.13 B		Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, very soft, very silty CLAY with trace sand.			
5A	24/24 100%	ss	3-4 5-5 N=9	24		2.33 B	8			618	
6A	24/24 100%	ss SH	2-4 4-5 N=8	24		1.75 B	10	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with some sand and trace gravel.		616	Shelby tube taken from shallow well borehole at indicated depth.
	24/24 100%										
7A	24/24 100%	ss	4-7 7-7 N=14	22		1.94 BSh	12			614	
7B				18				Dark yellowish brown (10YR4/6), wet, sl. dense, silty, very fine- to fine-grained SAND.			
							14	Dark yellowish brown (10YR4/6), moist, firm, silty CLAY with sand and trace gravel.		612	
	21/24 88%	ss	1-2 2-4 N=4					Dark yellowish brown (10YR4/6), wet, loose, silty, very fine- to fine-grained SAND.			
8A				20				Dark yellowish brown (10YR4/6), wet, soft, silty CLAY with sand and trace gravel.			
							16			610	
9A	18/24 75%	ss	4-3 4-10 N=7	14				Yellowish brown (10YR5/6), wet, loose, very fine- to very coarse-grained SAND.			
								Gray (10YR5/1), wet, loose, fine- to medium-grained SAND.			
9B				15			18	Gray (10YR5/1), moist, hard, clayey SILT with sand and trace gravel.		608	
10A				10							
10B	20/24 83%	ss	27-54 59-59 N=113	17				Gray (10YR5/1), wet, loose, very fine- to fine-grained SAND.			
								Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel.			
							20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 92 ft. BGS
Station: 877,355.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	10/24 *42%*	ss	*10-96*	8			22			606	
12A	14/24 *58%*	ss	*84-132*	10		3.10 *BSh*	24			604	
13A	20/24 *83%*	ss	*41-68* *82* N=150	10		7.56 *B*	26			602	
14A	12/24 *50%*	ss	*58-119*	10		9.89 *B*	28			600	Dusky red (7.5YR3/4) staining.
15A	24/24 *100%*	ss	*30-48* *70-71* N=118	9		5.62 *B*	30	Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		598	
16A	24/24 *100%*	ss	*50-54* *68-93* N=122	9			32			596	
17A	35/36 *97%*	cs		17			34			594	
18A	60/60 *100%*	cs		10			36			592	
							38			590	
							40			588	Wood fragments.

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 92 ft. BGS
Station: 877,355.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Gray (10YR5/1) with 50% black (10YR2/1) varves, very moist, soft SILT.		586	
19A				19			42	Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel.		584	
	60/60 100%	CS					44			582	
19B				11			46	Very dark greenish gray (10Y3/1), moist, hard, silty CLAY with sand and trace gravel.		580	
20A	60/60 100%	CS		13			48			578	
	24/24 100%	SS	6-14 18-22 N=32				50			576	
21A				19		1.94 B	▽ 52	Very dark bluish gray (5BG3/1), moist, firm, silty CLAY with trace sand and trace gravel.		574	Possible rock at end of auger.
	0/48 0%	CS					54			572	
	24/24 100%	SS	2-7 7-15 N=14				56			570	
22A				21		3.71 BSh		Greenish gray (5G6/1) with 40% yellowish brown (10YR5/6) mottles, moist, hard, silty CLAY with sl. trace sand.			
	24/24 100%	SS	4-8 11-13 N=19				58			568	
23A				26		2.13 BSh					
	0/12 0%	BD					60				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 92 ft. BGS
Station: 877,355.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/48 0%	RC					62	Greenish gray (5G6/1) with 40% yellowish brown (10YR5/6) mottles, moist, hard, silty CLAY with sl. trace sand. *[Continued from previous page]*		566	
										564	
26A	24/24 100%	SS	32-34 42-51 N=76	25		2.72 BSh	64			562	
	0/24 0%	RC					66	Yellowish brown (10YR5/6) with 20% greenish gray (5G6/1) mottles, moist, hard, silty CLAY with trace sand and trace coal fragments.		560	
	24/24 100%	SS	15-21 21-21 N=42				68			558	
28A				18		2.72 BSh					
	24/24 100%	SS	14-17 21-25 N=38				70			556	70' to 79.5' - possible oxidation rinds.
29A				20		2.91 BSh					
	24/24 100%	SS	12-21 34-35 N=55				72			554	
30A				18		5.04 BSh					
	24/24 100%	SS	16-21 27-35 N=48				74			552	
31A				16		8.15 BSh		Yellowish brown (10YR5/6) with zones of gray (10YR4/1) mottles, moist, hard, clayey SILT with some sand and trace gravel.			
							76			550	
	60/60 100%	CS					78			548	
32A				19							
							80				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 92 ft. BGS
Station: 877,355.0N
2,515,080.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							82	Yellowish brown (10YR5/6) with zones of gray (10YR4/1) mottles, moist, hard, clayey SILT with some sand and trace gravel. *[Continued from previous page]*		546	
	60/60 *100%*	cs								544	
33A				16			84	Yellow brown (10YR5/6), very moist, very soft, clayey, very fine-grained SAND and SILT.		542	
							86			540	
	0/60 *0%*	cs					88	Yellowish brown (10YR5/6), moist, hard, silty CLAY with sand and trace gravel.		538	Possible rock at end of auger.
							90			536	
35A	24/24 *100%*	ss	*9* *11-16* N=20			2.72 *BSh*		Dark gray (10YR3/1), moist, firm, silty CLAY with sand and trace gravel.			
							92	**End of Boring = 92.0 ft. BGS**			

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/25/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA (blind drill)

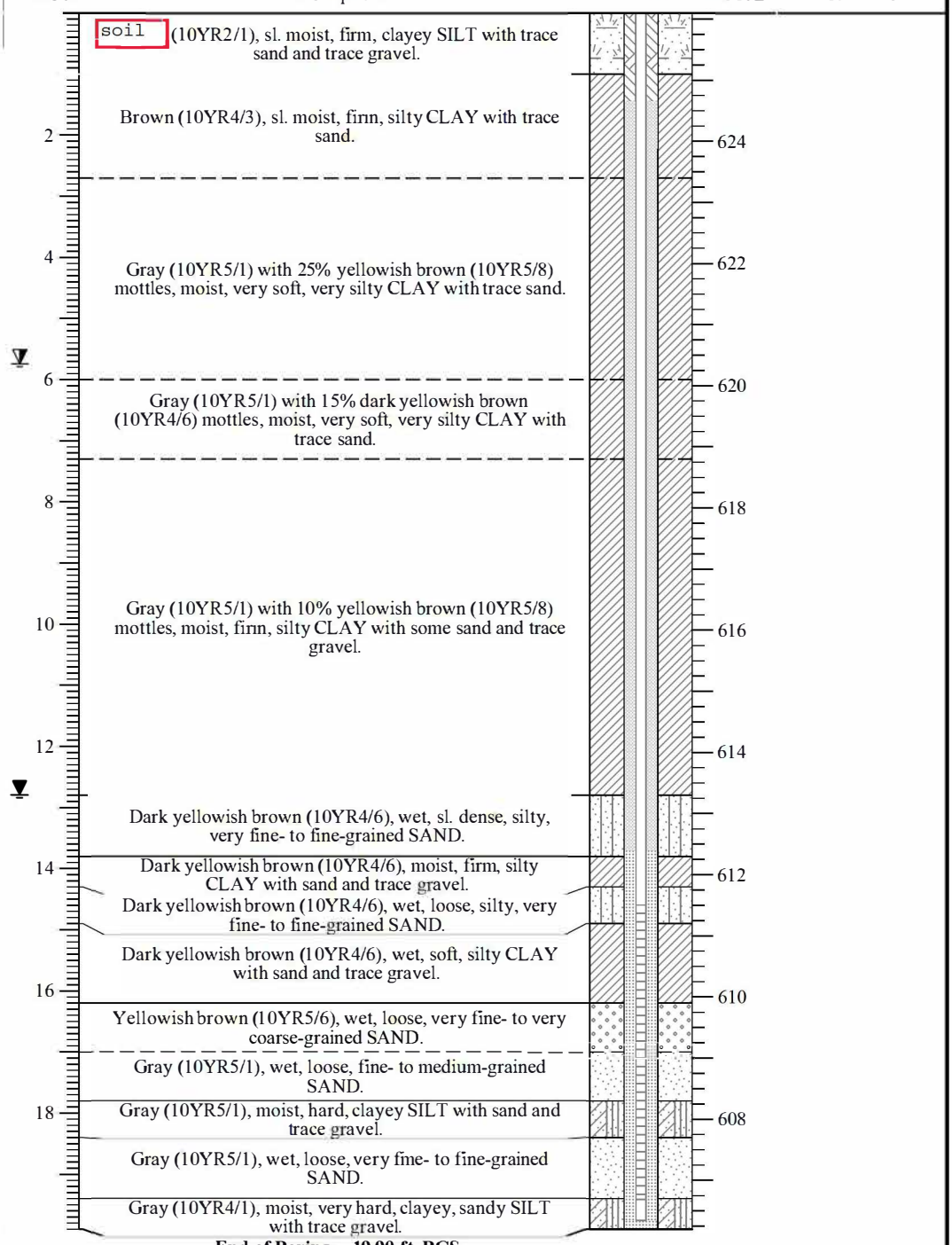
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16a
Well ID: MW16S
Surface Elev: 626 ft. MSL
Completion: 20 ft. BGS
Station: 877,355.1N
2,515,088.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE			TESTING							
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks



End of Boring = 19.90 ft. BGS
See SB-16 for sample & testing details

NOTE(S): MW16S installed in blind-drilled borehole within 10 ft of SB-16.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA (blind drill)
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16b
Well ID: MW16D
Surface Elev: 626 ft. MSL
Completion: 51 ft. BGS
Station: 877,354.9N
2,515,079.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil (10YR2/1), sl. moist, firm, clayey SILT with trace sand and trace gravel.		626	
							2	Brown (10YR4/3), sl. moist, firm, silty CLAY with trace sand.		624	
							4	Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, very soft, very silty CLAY with trace sand.		622	
							6	Gray (10YR5/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, very soft, very silty CLAY with trace sand.		620	
							8			618	
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with some sand and trace gravel.		616	
							12			614	
							13	Dark yellowish brown (10YR4/6), wet, sl. dense, silty, very fine- to fine-grained SAND.			
							14	Dark yellowish brown (10YR4/6), moist, firm, silty CLAY with sand and trace gravel.		612	
							15	Dark yellowish brown (10YR4/6), wet, loose, silty, very fine- to fine-grained SAND.			
							16	Dark yellowish brown (10YR4/6), wet, soft, silty CLAY with sand and trace gravel.		610	
							17	Yellowish brown (10YR5/6), wet, loose, very fine- to very coarse-grained SAND.			
							18	Gray (10YR5/1), wet, loose, fine- to medium-grained SAND.		608	
							19	Gray (10YR5/1), moist, hard, clayey SILT with sand and trace gravel.			
							20	Gray (10YR5/1), wet, loose, very fine- to fine-grained SAND.			
								Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel.			

NOTE(S): MW16D installed in blind-drilled borehole within 10 ft of SB-16.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16b
Well ID: MW16D
Surface Elev: 626 ft. MSL
Completion: 51 ft. BGS
Station: 877,354.9N
2,515,079.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Failure Type*	Depth ft. BGS	Lithologic Description
							22	
							24	
							26	
							28	
							30	Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*
							32	
							34	
							36	
							38	
							40	

Borehole Detail

Elevation ft. MSL: 606, 604, 602, 600, 598, 596, 594, 592, 590, 588

Remarks

NOTE(S): MW16D installed in blind-drilled borehole within 10 ft of SB-16.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 4/21/2006
Finish: 4/25/2006
WEATHER: Overcast, cool (mid-40's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-850 Track Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-16b
Well ID: MW16D
Surface Elev: 626 ft. MSL
Completion: 51 ft. BGS
Station: 877,354.9N
2,515,079.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.80 - While drilling
▼ = 5.74 - MW16S on 6/1/06
▽ = 51.37 - MW16D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								Gray (10YR5/1) with 50% black (10YR2/1) varves, very moist, soft SILT.		586	
							42	Gray (10YR4/1), moist, very hard, clayey, sandy SILT with trace gravel.		584	
							44			582	
							46	Very dark greenish gray (10Y3/1), moist, hard, silty CLAY with sand and trace gravel.		580	
							48			578	
							50	Very dark bluish gray (5BG3/1), moist, firm, silty CLAY with trace sand and trace gravel.		576	

End of Boring = 51.00 ft. BGS
See SB-16 for sample & testing details

NOTE(S): MW16D installed in blind-drilled borehole within 10 ft of SB-16.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-17
Well ID: MW17D
Surface Elev: 627 ft. MSL
Completion: 54 ft. BGS
Station: 878,659.0N
2,515,090.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 6.89 - MW17S on 6/1/06
▽ = 54.45 - MW17D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								soil grayish brown (10YR4/2), moist, soft, clayey SILT with trace sand and trace gravel.			
1A	20/24 83%	ss	1-1 1-1 N=2	29				Yellowish brown (10YR5/8), moist, soft, silty CLAY.		626	
							2				
2A	24/24 100%	ss	1-1 2-2 N=3	26		1.71 None		Gray (10YR5/1) with 40% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with little sand and trace gravel.		624	
							4				
3A	24/24 100%	ss	1-1 1-3 N=2	16		2.62 BSh		Yellowish brown (10YR5/6) with 10% gray (10YR5/1) mottles, moist, firm sandy, clayey SILT.		622	
							6				
4A	24/24 100%	ss	1-2 2-3 N=4	18		2.33 B	▼			620	
								Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist, firm sandy, clayey SILT.			
5A	24/24 100%	ss	1-1 2-3 N=3	18			8			618	
								Yellowish brown (10YR5/6), moist, soft, very sandy, clayey SILT.			
6A	24/24 100%	ss	1-1 1-1 N=2	21		0.58 B		Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, very moist, soft, very sandy, clayey SILT.		616	
6B				18			▼				
							12	Moderate yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND.			
7A	24/24 100%	ss	1-1 3-7 N=4	21				Yellowish brown (10YR5/6), wet, dense, silty, very fine- to fine-grained SAND.		614	
7B				19				Yellowish brown (10YR5/6), very moist, dense, silty, very fine-grained SAND.			
8A				15			14	Yellowish brown (10YR5/6) wet, dense, fine- to medium-grained SAND.			
8B	24/24 100%	ss	2-5 5-7 N=10	13				Moderate yellowish brown (10YR5/4), wet, dense, SILT and very fine-grained SAND.		612	
8C				13				Yellowish brown (10YR5/6), moist, clayey SILT and very fine-grained SAND with trace gravel.			
							16				
9A	24/24 100%	ss	0-6 6-6 N=12	17				Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND.		610	
							18				
								Yellowish brown (10YR5/6), wet, loose, very fine- to fine-grained SAND.			
10A	24/24 100%	ss	0-2 2-3 N=4	19				Yellowish brown (10YR5/6), wet, sl. dense, SILT with some very fine-grained SAND.		608	
10B				23			20	Gray (10YR5/1), wet, sl. dense, SILT with some very			

NOTE(S): CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

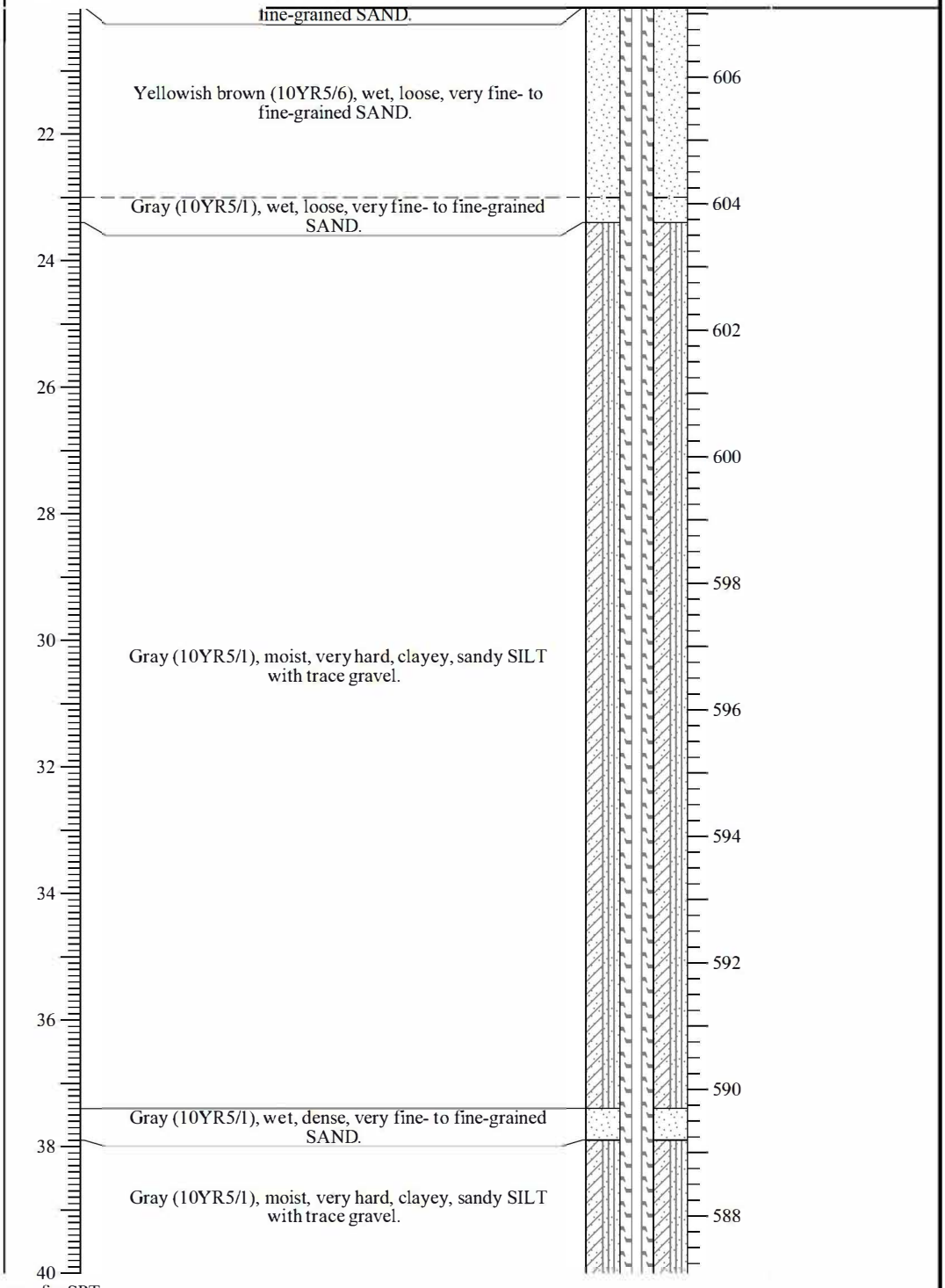
CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-17
Well ID: MW17D
Surface Elev: 627 ft. MSL
Completion: 54 ft. BGS
Station: 878,659.0N
2,515,090.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 6.89 - MW17S on 6/1/06
▽ = 54.45 - MW17D on 6/1/06

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
11A	12/24 50%	ss	0-1 1-2 N=2	21		
12A	24/24 100%	ss	2-2 5-7 N=7	18		
12B				9		4.65 BSh
	25/60 42%	cs				
13A						
	60/60 100%	cs				
14A				9		
	60/60 100%	cs				
15A				16		
15B				8		



NOTE(S): CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-17
Well ID: MW17D
Surface Elev: 627 ft. MSL
Completion: 54 ft. BGS
Station: 878,659.0N
2,515,090.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 6.89 - MW17S on 6/1/06
▽ = 54.45 - MW17D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	48/60 80%	cs					42			586	
16A				14							
16B				8			44			584	
								Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		582	
	60/60 100%	cs					46				
										580	
17A				13			48				
										578	
							50				
	60/60 100%	cs								576	
18A				22				Dark bluish gray (10BG4/1), moist, hard, silty CLAY with little sand.			
18B				16			52	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			
18C				11				Gray (10YR5/1), moist, firm, silty, very fine-grained to fine-grained SAND.		574	
								Dark bluish gray (10BG4/1), moist, hard, silty CLAY with little sand.			

End of Boring = 53.87 ft.

NOTE(S): CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-17a
Well ID: MW17S
Surface Elev: 627 ft. MSL
Completion: 24 ft. BGS
Station: 878,658.5N
2,515,084.8E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 6.89 - MW17S on 6/1/06
▽ = 54.45 - MW17D on 6/1/06

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil — grayish brown (10YR4/2), moist, soft, clayey SILT with trace sand and trace gravel.		626	
							2	Yellowish brown (10YR5/8), moist, soft, silty CLAY.			
							4	Gray (10YR5/1) with 40% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with little sand and trace gravel.		624	
							6	Yellowish brown (10YR5/6) with 10% gray (10YR5/1) mottles, moist, firm sandy, clayey SILT.		622	
							8	Yellowish brown (10YR5/6) with 30% gray (10YR5/1) mottles, moist, firm sandy, clayey SILT.		620	
							10	Yellowish brown (10YR5/6), moist, soft, very sandy, clayey SILT.		618	
							12	Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, very moist, soft, very sandy, clayey SILT.		616	
							14	Moderate yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND. Yellowish brown (10YR5/6), wet, dense, silty, very fine- to fine-grained SAND. Yellowish brown (10YR5/6), very moist, dense, silty, very fine-grained SAND. Yellowish brown (10YR5/6) wet, dense, fine- to medium-grained SAND.		614	
							16	Moderate yellowish brown (10YR5/4), wet, dense, SILT and very fine-grained SAND. Yellowish brown (10YR5/6), moist, clayey SILT and very fine-grained SAND with trace gravel.		612	
							18	Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND.		610	
							20	Yellowish brown (10YR5/6), wet, loose, very fine- to fine-grained SAND. Yellowish brown (10YR5/6), wet, sl. dense, SILT with some very fine-grained SAND. Gray (10YR5/1), wet, sl. dense, SILT with some very		608	

NOTE(S): MW17S installed in blind-drilled borehole within 10 ft of SB-17.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/4/2006
Finish: 5/4/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-17a
Well ID: MW17S
Surface Elev: 627 ft. MSL
Completion: 24 ft. BGS
Station: 878,658.5N
2,515,084.8E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 2, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 11.70 - While drilling
▼ = 6.89 - MW17S on 6/1/06
▽ = 54.45 - MW17D on 6/1/06

SAMPLE			TESTING						
Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail / Elevation ft. MSL	Remarks
								fine-grained SAND.		
								Yellowish brown (10YR5/6), wet, loose, very fine- to fine-grained SAND.	606	
							22	Gray (10YR5/1), wet, loose, very fine- to fine-grained SAND.	604	
							24	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		

End of Boring = 24.11 ft. BGS

See SB-17 for sample & testing details

NOTE(S): MW17S installed in blind-drilled borehole within 10 ft of SB-17.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-18
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 54 ft. BGS
Station: 878,605.0N
2,513,750.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.20 - While drilling
▼ = 6.87 - MW18S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type
1A	18/24 75%	ss	0-1 1-1 N=2	24		1.31 BSh
2A	24/24 100%	ss	1-2 2-2 N=4	28		1.78 Sh
3A	24/24 100%	ss	1-2 2-2 N=4	23		1.32 BSh
4A	24/24 100%	ss	1-1 1-2 N=2	24		1.09 B
5A	24/24 100%	ss	1-1 1-2 N=2	28		0.54 BSh
6A	24/24 100%	ss	0-0 1-2 N=1	21		0.39 B
7A	24/24 100%	ss	3-5 9-15 N=14	17		
7B				15		
8A				14		
8B	24/24 100%	ss	8-9 9-10 N=18	11		
8C				9		
9A	24/36 67%	cs				

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
0	soil			
	grayish brown (10YR4/2), moist, soft, clayey SILT with trace sand and trace gravel.			
	Yellowish brown (10YR5/6) with 50% gray (10YR4/1) mottles, moist, silty CLAY with little sand.		624	
2				
	Yellowish brown (10YR5/6) with 10% gray (10YR4/1) mottles, moist, silty CLAY with little sand.		622	
4				
			620	
6				
▼	Gray (10YR4/1)with 10% Yellowish brown (10YR5/6) mottles, moist, silty CLAY with little sand.		618	
8				
			616	
10				
	Light gray (10YR6/1) moist, soft, clayey, very fine- to fine-grained SAND.		614	
▼ 12				
	Light gray (10YR6/1) moist, soft, silty, very fine- to fine-grained SAND.			
	Yellowish brown (10YR5/6), very moist, soft, silty, very fine- to fine-grained, SAND with trace gravel.		612	
14				
	Yellowish brown (10YR5/6), wet, loose, fine- to medium-grained SAND.			
	Yellowish brown (10YR5/6), very moist, soft, sandy (very fine- to fine-grained) SILT.		610	
16				
			608	
	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			
18				
			606	
20				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-18
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 54 ft. BGS
Station: 878,605.0N
2,513,750.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.20 - While drilling
▼ = 6.87 - MW18S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
10A	60/60 100%	cs					22			604	
							24			602	
							26			600	
11A	60/60 100%	cs		5			28	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		598	
							30			596	
12A	60/60 100%	cs		11			32			594	Coal fragment seam
							34			592	
							36			590	
13A	60/60 100%	cs		10			38	Gray (10YR5/1), moist, dense, SILT.		588	
13B				12				Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.			
							40			586	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: K. Doetzel
Helper: S. McCartney
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-18
Well ID: n/a
Surface Elev: 626 ft. MSL
Completion: 54 ft. BGS
Station: 878,605.0N
2,513,750.0E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.20 - While drilling
▼ = 6.87 - MW18S on 6/1/06
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	60/60 100%	cs					42			584	Appears more clayey
14A				13			44			582	
	60/60 100%	cs					46	Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel. *[Continued from previous page]*		580	
15A				13			48			578	
							50			576	
16A				13							
	60/60 100%	cs					52			574	
16B				22				Greenish gray (10BG5/1), moist, firm, silty CLAY with little sand and trace gravel.			
							54	**End of Boring = 54.0 ft.**		572	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.
CME-1050 had 280# hammer for SPT.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/11/2006
Finish: 5/11/2006
WEATHER: Partly sunny, cool (mid-50's)

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-1050 ATV Rig
Drilling Method: 4¼" HSA (blind drill)

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-18a
Well ID: MW18S
Surface Elev: 626 ft. MSL
Completion: 16 ft. BGS
Station: 878,604.7N
2,513,745.2E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.20 - While drilling
▼ = 6.87 - MW18S on 6/1/06
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	soil grayish brown (10YR4/2), moist, soft, clayey SILT with trace sand and trace gravel.			
								Yellowish brown (10YR5/6) with 50% gray (10YR4/1) mottles, moist, silty CLAY with little sand.		624	
							2				
								Yellowish brown (10YR5/6) with 10% gray (10YR4/1) mottles, moist, silty CLAY with little sand.		622	
							4				
										620	
							6				
							▼				
								Gray (10YR4/1)with 10% Yellowish brown (10YR5/6) mottles, moist, silty CLAY with little sand.		618	
							8				
										616	
							10				
								Light gray (10YR6/1) moist, soft, clayey, very fine- to fine-grained SAND.		614	
							▼ 12				
								Light gray (10YR6/1) moist, soft, silty, very fine- to fine-grained SAND.			
								Yellowish brown (10YR5/6), very moist, soft, silty, very fine- to fine-grained, SAND with trace gravel.		612	
							14				
								Yellowish brown (10YR5/6), wet, loose, fine- to medium-grained SAND.			
								Yellowish brown (10YR5/6), very moist, soft, sandy (very fine- to fine-grained) SILT.			
								Gray (10YR5/1), moist, very hard, clayey, sandy SILT with trace gravel.		610	
							16				

End of Boring = 16.40 ft. BGS
See SB-18 for sample & testing details

NOTE(S): MW18S installed in blind-drilled borehole within 10 ft of SB-18.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/17/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-19
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 60 ft. BGS
Station: 875,415.4N
2,513,226.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
								soil Dark grayish brown (10YR4/2), clayey SILT, trace sand			
1A	20/24 83%	ss	2-2 3-4 N=5	21				Pale brown (10YR6/3) with 50% brown (10YR5/3) mottles, clayey SILT			
1B				22			2			622	
2A	22/24 92%	ss	2-2 5-6 N=7	23	2.89 B			Pale brown (10YR6/3) with 40% yellowish brown (10YR5/6) mottles, lean CLAY			
3A	23/24 96%	ss	2-3 5-6 N=8	17	1.82 B		4			620	
4A	24/24 100%	ss	6-8 10-8 N=18	19	2.52 B			Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, clayey SILT, trace sand			
5A	24/24 100%	ss	3-4 6-8 N=10	18	2.52 B		6			618	
6A	24/24 100%	ss	2-3 4-5 N=7	16	1.24 None			Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, sandy CLAY			
							8			616	
								Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, clayey SAND			
							10			614	
							▼ 12	Brownish yellow (10YR6/6), silty, fine to medium SAND, wet			
7A	24/24 100%	ss	4-8 10-10 N=18	25				Yellowish brown (10YR5/6), sandy SILT, trace gravel			
7B				13			14			612	
8A	22/24 92%	ss	3-5 18-25 N=23	18				Yellowish brown (10YR5/8), silty, fine SAND, wet			
							16			610	
9A	24/24 100%	ss	20-40 59-68 N=99	12	4.26 BSh			Light gray (10YR7/1), silty, fine SAND, trace gravel			
							18			608	
10A	24/24 100%	ss	29-38 56-79 N=94	9				Dark gray (10YR4/1), sandy SILT, trace gravel			
							20			606	
										604	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/17/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-19
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 60 ft. BGS
Station: 875,415.4N
2,513,226.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	60/60 100%	cs					22	Dark gray (10YR4/1), sandy SILT, trace gravel *[Continued from previous page]*		602	
11A				8			24			600	
							26			598	
12A				10				Dark gray (10YR4/1), medium to coarse SAND, trace gravel			
	60/60 100%	cs					28			596	
12B				6			30	Dark gray (10YR4/1), sandy SILT, trace gravel, trace sandstone fragments		594	
							32			592	
	60/60 100%	cs						Dary grayish brown (10YR4/2), SILT		590	
13A				11			34				
13B				10				Dark gray (10YR4/1), sandy SILT, trace gravel		588	
14A				10			36	Gray (10YR5/1), silty, fine SAND, trace medium to coarse sand and gravel			
14B				10				Dark gray (10YR4/1), sandy SILT, trace gravel			
14C	60/60 100%	cs		8				Gray (10YR5/1), silty, fine SAND, trace medium to coarse sand and gravel		586	
							38	Dark gray (10YR4/1), sandy SILT, trace gravel			
14D				21				Gray (10YR5/1), silty, fine SAND, trace medium to coarse sand and gravel		584	
							40				

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: Start: 5/17/2006
Finish: 5/17/2006
WEATHER: Sunny, mild (mid-60's)

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: Driller: B. Williamson
Helper: R. Keedy
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB-19
Well ID: n/a
Surface Elev: 624 ft. MSL
Completion: 60 ft. BGS
Station: 875,415.4N
2,513,226.4E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 3, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 12.00 - While drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
15A				24				Dark greenish gray (5G4/1) with 20% yellowish brown (10YR5/6) mottles, lean CLAY *[Continued from previous page]*			
	60/60 *100%*	CS					42			582	
							44			580	
15B				14							
							46	Dark gray (10YR4/1), clayey SILT, trace sand and gravel		578	
	60/60 *100%*	CS					48			576	
16A				15							
							50			574	
	60/60 *100%*	CS					52	Dark gray (10YR4/1), sandy SILT, some gravel		572	
17A				10			54			570	
17B				14				Dark gray (10YR4/1), clayey SILT, trace sand and gravel			
							56			568	
	60/60 *100%*	CS						Dark greenish gray (10BG4/1) with 30% yellowish brown (10YR5/6) mottles, lean CLAY			
							58			566	
18A											
							60	**End of Boring = 60.0 ft. BGS**		564	

NOTE(S): Borehole abandoned using bentonite grout pumped from bottom of borehole.

APPENDIX 3-A-4
Well Completion Reports

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW1D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-01

State Plane Coordinate: X 874,972.6 Y 2,513,478.0 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/3/2006 Date Finished: 5/3/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 21 min.

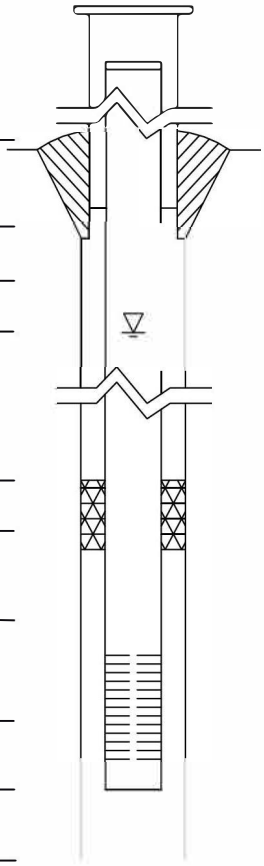
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
609.29	-1.89	Top of Protective Casing
609.01	-1.61	Top of Riser Pipe
607.40	0.00	Ground Surface
604.80	2.60	Top of Annular Sealant
571.12	36.28	Static Water Level (After Completion) 6/1/2006
578.90	28.50	Top of Seal
575.82	31.58	Top of Sand Pack
574.11	33.29	Top of Screen
569.35	38.05	Bottom of Screen
568.99	38.41	Bottom of Well
567.40	40.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	35.17
Bottom of Screen to End Cap	(feet)	0.36
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	40.29
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW2S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-02a

State Plane Coordinate: X 876,408.9 Y 2,513,210.0 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/5/2006 Date Finished: 5/5/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

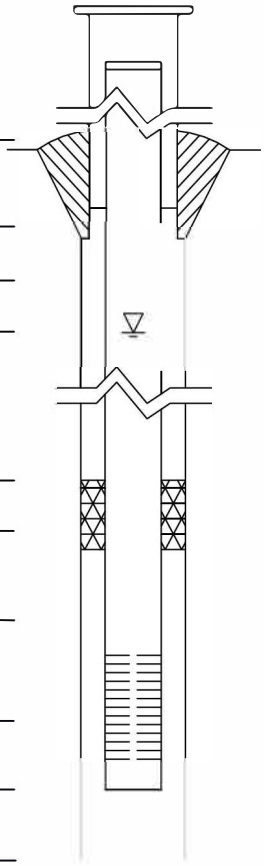
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.55	-3.45	Top of Protective Casing
627.07	-2.97	Top of Riser Pipe
624.10	0.00	Ground Surface
619.72	4.38	Top of Annular Sealant
616.68	7.42	Static Water Level (After Completion) 6/1/2006
619.72	4.38	Top of Seal
614.60	9.50	Top of Sand Pack
613.76	10.34	Top of Screen
608.98	15.12	Bottom of Screen
608.59	15.51	Bottom of Well
608.59	15.51	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.31
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.78
Total Length of Casing	(feet)	18.48
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW2D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-02b

State Plane Coordinate: X 876,414.0 Y 2,513,209.7 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/5/2006 Date Finished: 5/5/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 20 min.

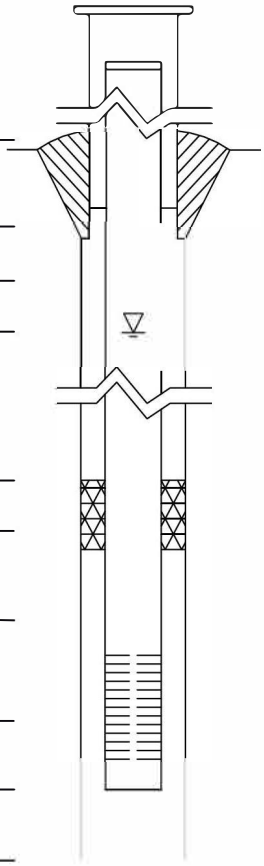
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: Re-drill borehole



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.52	-3.42	Top of Protective Casing
627.07	-2.97	Top of Riser Pipe
624.10	0.00	Ground Surface
621.00	3.10	Top of Annular Sealant
616.74	7.36	Static Water Level (After Completion) 6/1/2006
606.00	18.10	Top of Seal
603.92	20.18	Top of Sand Pack
602.07	22.03	Top of Screen
597.27	26.83	Bottom of Screen
596.88	27.22	Bottom of Well
596.88	27.22	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	25.00
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	30.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW3D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-03

State Plane Coordinate: X 876,554.5 Y 2,514,535.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 4/27/2006 Date Finished: 4/27/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 25 min.

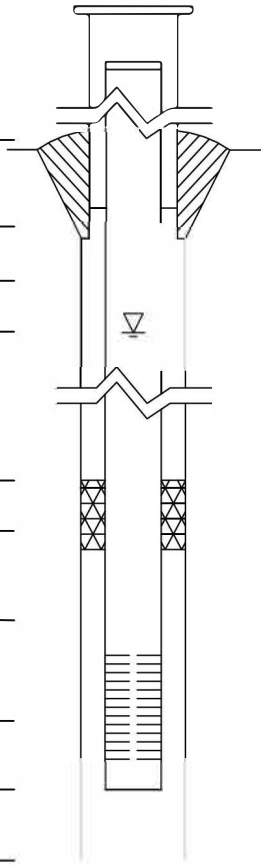
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Cuttings (if applicable)

Installation Method: Over-drill borehole



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
629.37	-3.67	Top of Protective Casing
628.94	-3.24	Top of Riser Pipe
625.70	0.00	Ground Surface
623.00	2.70	Top of Annular Sealant
570.30	55.40	Static Water Level (After Completion) 6/1/2006
576.70	49.00	Top of Seal
575.60	50.10	Top of Sand Pack
573.41	52.29	Top of Screen
568.64	57.06	Bottom of Screen
568.30	57.40	Bottom of Well
567.70	58.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	55.51
Bottom of Screen to End Cap	(feet)	0.36
Screen Length (1st slot to last slot)	(feet)	4.77
Total Length of Casing	(feet)	60.64
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW3S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-03a

State Plane Coordinate: X 876,554.8 Y 2,514,531.5 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 4/28/2006 Date Finished: 4/28/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

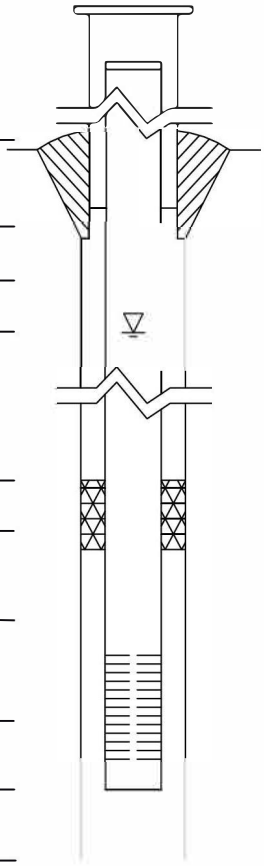
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
629.45	-3.75	Top of Protective Casing
628.96	-3.26	Top of Riser Pipe
625.70	0.00	Ground Surface
623.70	2.00	Top of Annular Sealant
618.67	7.03	Static Water Level (After Completion) 6/1/2006
623.70	2.00	Top of Seal
616.20	9.50	Top of Sand Pack
613.68	12.02	Top of Screen
608.92	16.78	Bottom of Screen
608.55	17.15	Bottom of Well
608.55	17.15	Bottom o f Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.28
Bottom of Screen to End Cap	(feet)	0.37
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	20.41
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW4S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-04a

State Plane Coordinate: X 877,999.7 Y 2,514,450.6 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/11/2006 Date Finished: 5/11/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

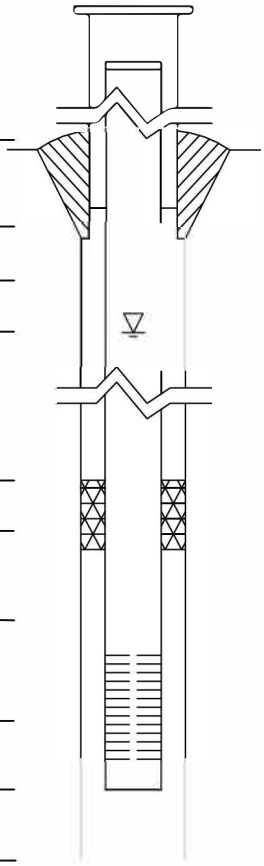
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.07	-3.67	Top of Protective Casing
625.60	-3.20	Top of Riser Pipe
622.40	0.00	Ground Surface
619.57	2.83	Top of Annular Sealant
616.73	5.67	Static Water Level (After Completion) 6/1/2006
619.57	2.83	Top of Seal
614.15	8.25	Top of Sand Pack
612.57	9.83	Top of Screen
608.14	14.26	Bottom of Screen
607.63	14.77	Bottom of Well
607.63	14.77	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.25
Bottom of Screen to End Cap	(feet)	0.51
Screen Length (1st slot to last slot)	(feet)	4.43
Total Length of Casing	(feet)	19.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW5D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-05

State Plane Coordinate: X 878,174.8 Y 2,513,290.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/12/2006 Date Finished: 5/17/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: 18 min.

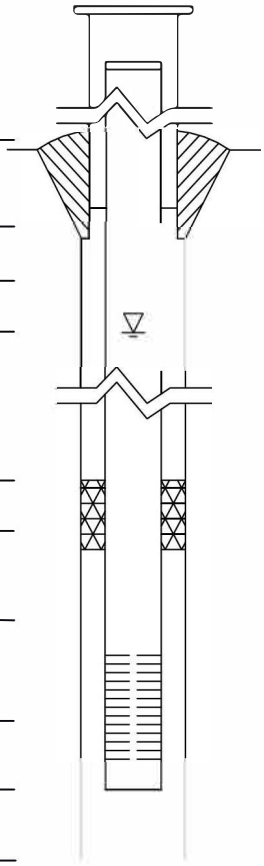
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.21	-3.61	Top of Protective Casing
625.78	-3.18	Top of Riser Pipe
622.60	0.00	Ground Surface
620.77	1.83	Top of Annular Sealant
572.16	50.44	Static Water Level (After Completion) 6/1/2006
582.29	40.31	Top of Seal
579.14	43.46	Top of Sand Pack
577.03	45.57	Top of Screen
572.27	50.33	Bottom of Screen
571.88	50.72	Bottom of Well
568.60	54.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	48.74
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	53.89
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW5S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-05a

State Plane Coordinate: X 878,175.6 Y 2,513,285.5 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/17/2006 Date Finished: 5/17/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

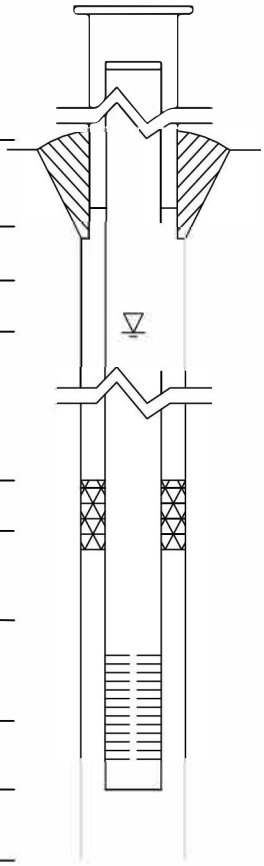
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Cuttings (if applicable)

Installation Method: Over-drill borehole



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	626.14	-3.54	Top of Protective Casing
	625.73	-3.13	Top of Riser Pipe
	622.60	0.00	Ground Surface
	620.49	2.11	Top of Annular Sealant
	615.86	6.74	Static Water Level (After Completion) 6/1/2006
	620.49	2.11	Top of Seal
	611.06	11.54	Top of Sand Pack
	609.94	12.66	Top of Screen
	605.19	17.41	Bottom of Screen
	604.89	17.71	Bottom of Well
	604.89	17.71	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.69
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.75
Total Length of Casing	(feet)	20.84
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW6S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-06a

State Plane Coordinate: X 879,021.2 Y 2,513,189.4 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Testing Services Corp. Date Started: 5/4/2006 Date Finished: 5/4/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

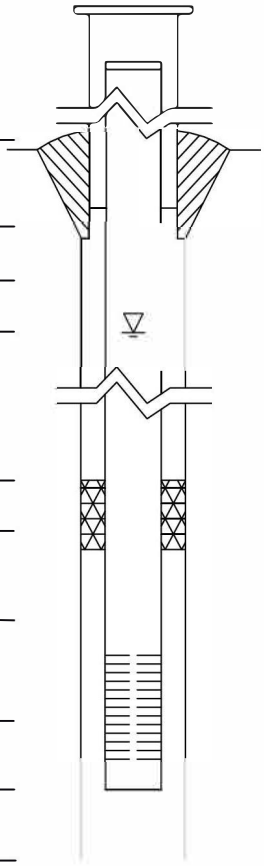
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.67	-3.57	Top of Protective Casing
626.21	-3.11	Top of Riser Pipe
623.10	0.00	Ground Surface
620.10	3.00	Top of Annular Sealant
616.89	6.21	Static Water Level (After Completion) 6/1/2006
620.10	3.00	Top of Seal
613.34	9.76	Top of Sand Pack
612.06	11.04	Top of Screen
607.48	15.62	Bottom of Screen
607.02	16.08	Bottom of Well
607.02	16.08	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.15
Bottom of Screen to End Cap	(feet)	0.46
Screen Length (1st slot to last slot)	(feet)	4.58
Total Length of Casing	(feet)	19.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW7S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-07a

State Plane Coordinate: X 879,181.1 Y 2,514,397.5 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: P. McIntire

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Rhonald W Hasenyager Date Started: 5/9/2006 Date Finished: 5/9/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

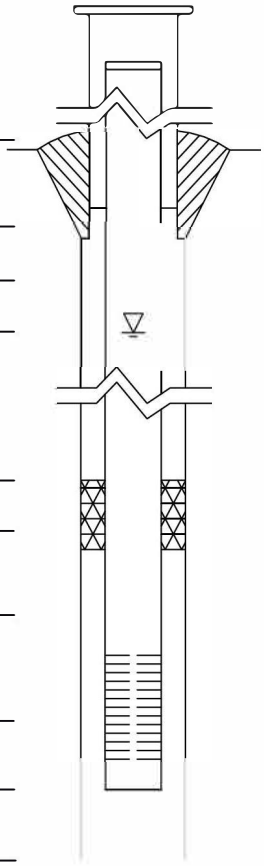
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.71	-3.21	Top of Protective Casing
627.56	-3.06	Top of Riser Pipe
624.50	0.00	Ground Surface
621.70	2.80	Top of Annular Sealant
619.60	4.90	Static Water Level (After Completion) 6/1/2006
621.70	2.80	Top of Seal
616.23	8.27	Top of Sand Pack
614.59	9.91	Top of Screen
610.71	13.79	Bottom of Screen
610.11	14.39	Bottom of Well
610.11	14.39	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	12.37
Bottom of Screen to End Cap	(feet)	0.60
Screen Length (1st slot to last slot)	(feet)	4.48
Total Length of Casing	(feet)	17.45
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW8S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-08a

State Plane Coordinate: X 879,776.6 Y 2,514,478.8 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/10/2006 Date Finished: 5/10/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

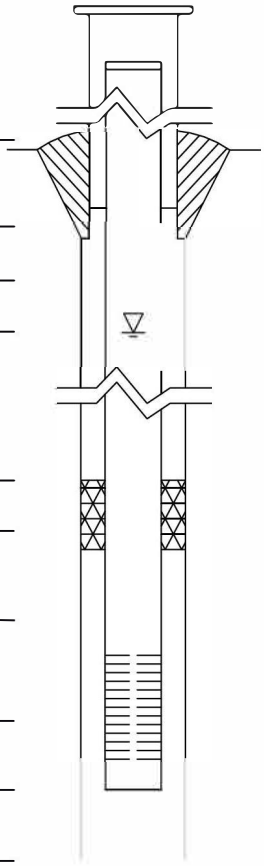
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
628.26	-3.56	Top of Protective Casing
627.92	-3.22	Top of Riser Pipe
624.70	0.00	Ground Surface
622.20	2.50	Top of Annular Sealant
619.37	5.33	Static Water Level (After Completion) 6/1/2006
622.20	2.50	Top of Seal
614.72	9.98	Top of Sand Pack
613.19	11.51	Top of Screen
608.70	16.00	Bottom of Screen
608.10	16.60	Bottom of Well
607.62	17.08	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.73
Bottom of Screen to End Cap	(feet)	0.60
Screen Length (1st slot to last slot)	(feet)	4.49
Total Length of Casing	(feet)	19.82
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW9D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-09

State Plane Coordinate: X 879,679.7 Y 2,515,666.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/3/2006 Date Finished: 5/3/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 min.

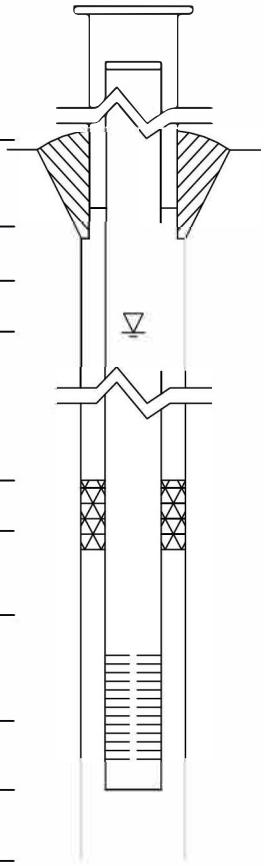
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.84	-3.24	Top of Protective Casing
627.52	-2.92	Top of Riser Pipe
624.60	0.00	Ground Surface
621.70	2.90	Top of Annular Sealant
572.14	52.46	Static Water Level (After Completion) 6/1/2006
582.60	42.00	Top of Seal
580.80	43.80	Top of Sand Pack
578.79	45.81	Top of Screen
574.03	50.57	Bottom of Screen
573.60	51.00	Bottom of Well
570.60	54.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	52.25
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	57.44
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW9S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-09a

State Plane Coordinate: X 879,684.9 Y 2,515,666.2 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/3/2006 Date Finished: 5/3/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

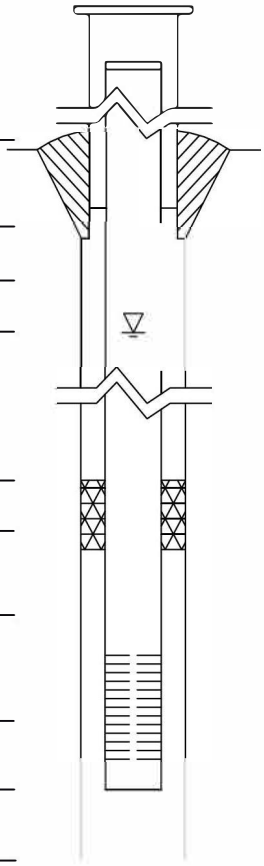
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.84	-3.24	Top of Protective Casing
627.51	-2.91	Top of Riser Pipe
624.60	0.00	Ground Surface
621.35	3.25	Top of Annular Sealant
619.37	5.23	Static Water Level (After Completion) 6/1/2006
621.35	3.25	Top of Seal
615.49	9.11	Top of Sand Pack
613.39	11.21	Top of Screen
608.98	15.62	Bottom of Screen
608.40	16.20	Bottom of Well
608.40	16.20	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.12
Bottom of Screen to End Cap	(feet)	0.58
Screen Length (1st slot to last slot)	(feet)	4.41
Total Length of Casing	(feet)	19.11
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW10D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-10

State Plane Coordinate: X 878,245.1 Y 2,515,914.0 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/1/2006 Date Finished: 5/1/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- Granular Pellet [Slurry] (choose one)

Installation Method: Tremie

Setting Time: 22 min.

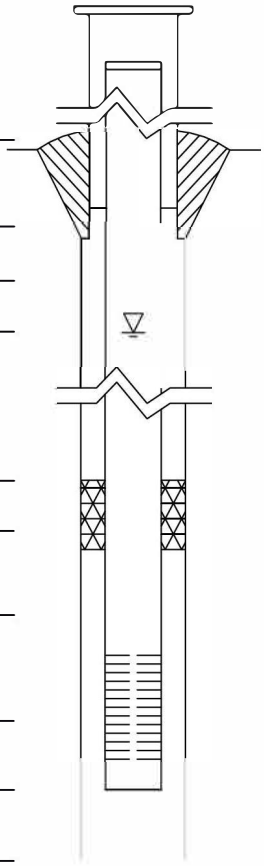
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.72	-3.52	Top of Protective Casing
624.42	-3.22	Top of Riser Pipe
621.20	0.00	Ground Surface
619.77	1.43	Top of Annular Sealant
573.72	47.48	Static Water Level (After Completion) 6/1/2006
619.77	1.43	Top of Seal
581.65	39.55	Top of Sand Pack
579.46	41.74	Top of Screen
574.63	46.57	Bottom of Screen
574.18	47.02	Bottom of Well
572.45	48.75	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	45.06
Bottom of Screen to End Cap	(feet)	0.45
Screen Length (1st slot to last slot)	(feet)	4.73
Total Length of Casing	(feet)	50.24
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW10S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-10a

State Plane Coordinate: X 878,250.5 Y 2,515,914.4 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/2/2006 Date Finished: 5/2/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

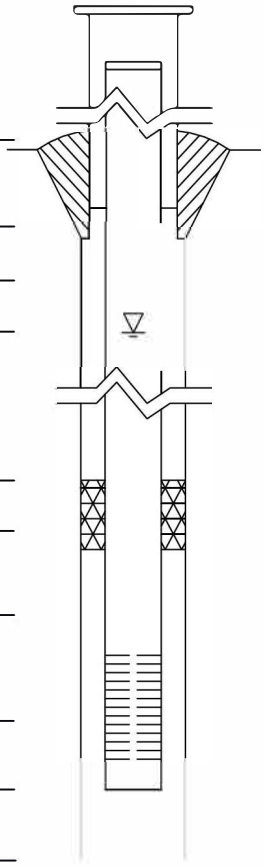
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
624.55	-3.35	Top of Protective Casing
624.24	-3.04	Top of Riser Pipe
621.20	0.00	Ground Surface
618.83	2.37	Top of Annular Sealant
616.29	4.91	Static Water Level (After Completion) 6/1/2006
618.83	2.37	Top of Seal
611.90	9.30	Top of Sand Pack
609.92	11.28	Top of Screen
605.44	15.76	Bottom of Screen
604.90	16.30	Bottom of Well
604.90	16.30	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.32
Bottom of Screen to End Cap	(feet)	0.54
Screen Length (1st slot to last slot)	(feet)	4.48
Total Length of Casing	(feet)	19.34
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW11D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-11

State Plane Coordinate: X 876,749.6 Y 2,515,976.7 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 4/27/2006 Date Finished: 4/28/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 18 min.

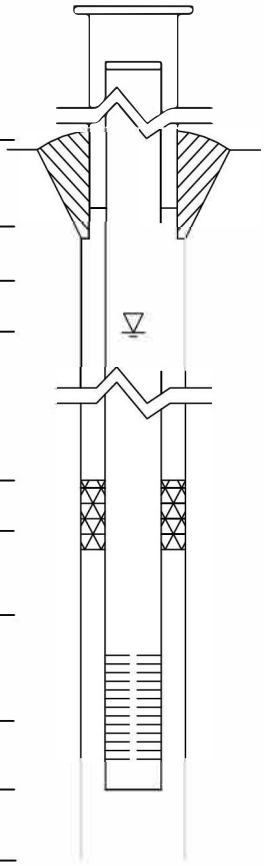
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	625.70	-3.70	Top of Protective Casing
	625.36	-3.36	Top of Riser Pipe
	622.00	0.00	Ground Surface
	618.89	3.11	Top of Annular Sealant
	615.97	6.03	Static Water Level (After Completion) 6/1/2006
	597.20	24.80	Top of Seal
	595.59	26.41	Top of Sand Pack
	593.69	28.31	Top of Screen
	588.96	33.04	Bottom of Screen
	588.50	33.50	Bottom of Well
	585.67	36.33	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	31.67
Bottom of Screen to End Cap	(feet)	0.46
Screen Length (1st slot to last slot)	(feet)	4.73
Total Length of Casing	(feet)	36.86
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW11S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-11a

State Plane Coordinate: X 876,749.4 Y 2,515,971.2 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 4/28/2006 Date Finished: 4/28/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 26 min.

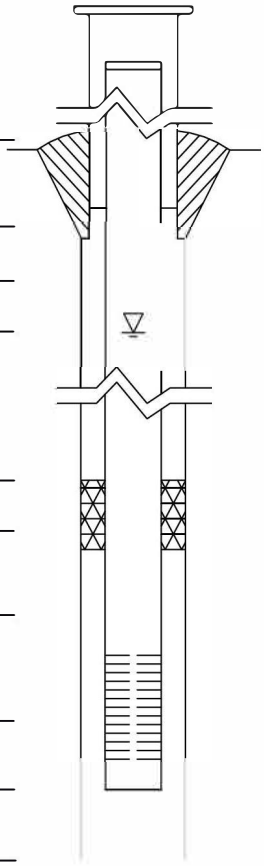
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.47	-3.47	Top of Protective Casing
625.16	-3.16	Top of Riser Pipe
622.00	0.00	Ground Surface
620.00	2.00	Top of Annular Sealant
616.58	5.42	Static Water Level (After Completion) 6/1/2006
620.00	2.00	Top of Seal
615.25	6.75	Top of Sand Pack
613.11	8.89	Top of Screen
608.37	13.63	Bottom of Screen
607.92	14.08	Bottom of Well
607.92	14.08	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	12.04
Bottom of Screen to End Cap	(feet)	0.46
Screen Length (1st slot to last slot)	(feet)	4.74
Total Length of Casing	(feet)	17.24
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW12D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-12

State Plane Coordinate: X 875,515.1 Y 2,515,900.6 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/10/2006 Date Finished: 5/10/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

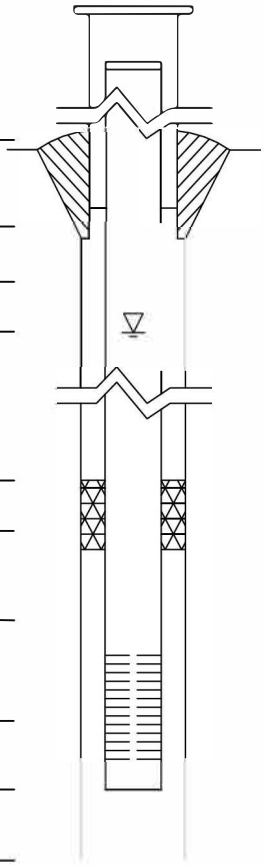
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: Over-drill borehole



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.49	-3.29	Top of Protective Casing
625.03	-2.83	Top of Riser Pipe
622.20	0.00	Ground Surface
619.43	2.77	Top of Annular Sealant
575.30	46.90	Static Water Level (After Completion) 6/1/2006
585.50	36.70	Top of Seal
581.69	40.51	Top of Sand Pack
579.74	42.46	Top of Screen
575.21	46.99	Bottom of Screen
574.73	47.47	Bottom of Well
572.20	50.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	45.29
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	4.53
Total Length of Casing	(feet)	50.30
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW12S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-12a

State Plane Coordinate: X 875,520.1 Y 2,515,900.5 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/10/2006 Date Finished: 5/10/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 18 min.

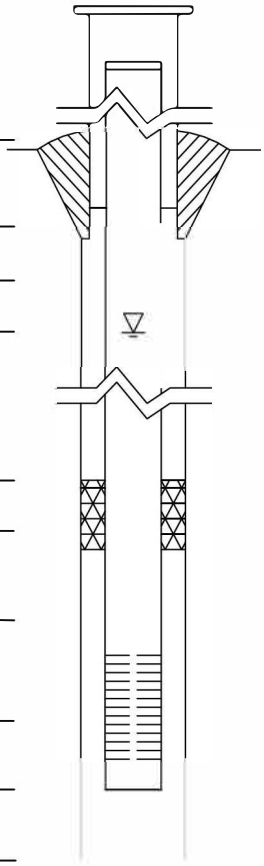
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.58	-3.38	Top of Protective Casing
625.10	-2.90	Top of Riser Pipe
622.20	0.00	Ground Surface
619.20	3.00	Top of Annular Sealant
615.44	6.76	Static Water Level (After Completion) 6/1/2006
619.20	3.00	Top of Seal
613.95	8.25	Top of Sand Pack
611.59	10.61	Top of Screen
607.02	15.18	Bottom of Screen
606.59	15.61	Bottom of Well
606.59	15.61	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	13.51
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.57
Total Length of Casing	(feet)	18.51
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW13D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-13

State Plane Coordinate: X 874,694.3 Y 2,513,929.9 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/9/2006 Date Finished: 5/9/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

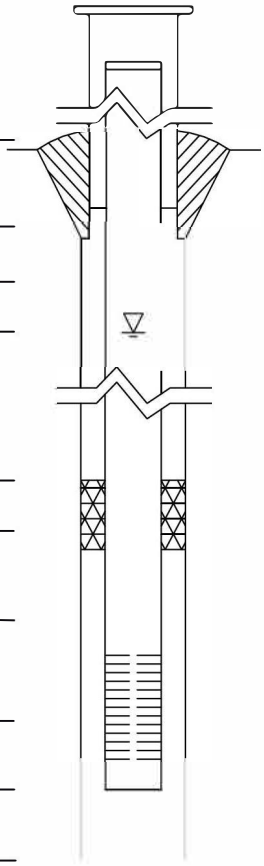
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	626.33	-3.63	Top of Protective Casing
	625.87	-3.17	Top of Riser Pipe
	622.70	0.00	Ground Surface
	619.64	3.06	Top of Annular Sealant
	566.67	56.03	Static Water Level (After Completion) 6/1/2006
	577.48	45.22	Top of Seal
	574.76	47.94	Top of Sand Pack
	572.89	49.81	Top of Screen
	568.10	54.60	Bottom of Screen
	567.70	55.00	Bottom of Well
	567.70	55.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	52.98
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	58.17
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW13S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-13a

State Plane Coordinate: X 874,695.7 Y 2,513,925.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/9/2006 Date Finished: 5/9/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 21 min.

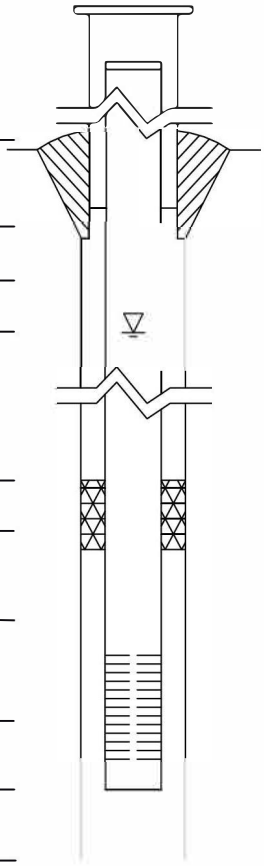
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.42	-3.72	Top of Protective Casing
625.92	-3.22	Top of Riser Pipe
622.70	0.00	Ground Surface
619.35	3.35	Top of Annular Sealant
614.46	8.24	Static Water Level (After Completion) 6/1/2006
619.35	3.35	Top of Seal
612.65	10.05	Top of Sand Pack
611.27	11.43	Top of Screen
606.47	16.23	Bottom of Screen
606.08	16.62	Bottom of Well
606.08	16.62	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	7.3
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.65
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	19.84
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW14S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: Sb-14a

State Plane Coordinate: X 875,737.8 Y 2,514,125.9 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/2/2006 Date Finished: 5/2/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 23 min.

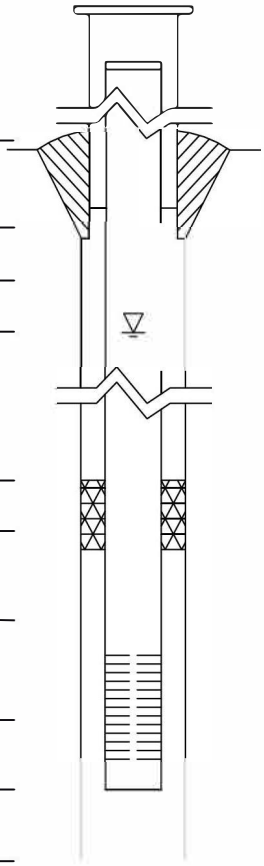
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.23	-2.63	Top of Protective Casing
626.82	-2.22	Top of Riser Pipe
624.60	0.00	Ground Surface
622.20	2.40	Top of Annular Sealant
620.11	4.49	Static Water Level (After Completion) 6/1/2006
622.20	2.40	Top of Seal
613.67	10.93	Top of Sand Pack
612.34	12.26	Top of Screen
607.58	17.02	Bottom of Screen
607.22	17.38	Bottom of Well
607.22	17.38	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.48
Bottom of Screen to End Cap	(feet)	0.36
Screen Length (1st slot to last slot)	(feet)	4.76
Total Length of Casing	(feet)	19.60
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW15S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-15a

State Plane Coordinate: X 875,971.1 Y 2,515,076.3 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 4/25/2006 Date Finished: 4/25/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 20 min.

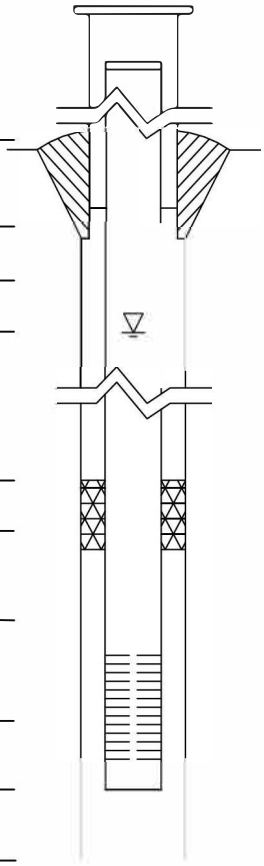
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
627.06	-3.26	Top of Protective Casing
626.60	-2.80	Top of Riser Pipe
623.80	0.00	Ground Surface
623.30	0.50	Top of Annular Sealant
618.81	4.99	Static Water Level (After Completion) 6/1/2006
614.30	9.50	Top of Seal
611.60	12.20	Top of Sand Pack
609.39	14.41	Top of Screen
604.64	19.16	Bottom of Screen
604.18	19.62	Bottom of Well
604.18	19.62	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.28
Bottom of Screen to End Cap	(feet)	19.62
Screen Length (1st slot to last slot)	(feet)	4.77
Total Length of Casing	(feet)	41.67
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW15D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-15b

State Plane Coordinate: X 875,970.5 Y 2,515,080.7 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 4/24/2006 Date Finished: 4/25/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry
(choose one)

Installation Method: Gravity

Setting Time: +24 hr.

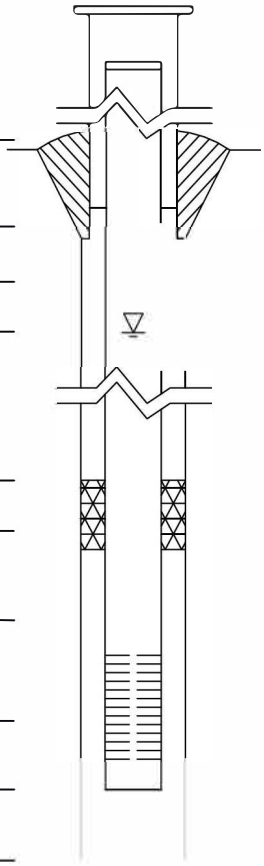
Type of Sand Pack: Quartz sand

Grain Size: #5 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: Re-drill borehole



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
626.93	-3.13	Top of Protective Casing
626.45	-2.65	Top of Riser Pipe
623.80	0.00	Ground Surface
620.55	3.25	Top of Annular Sealant
618.56	5.24	Static Water Level (After Completion) 6/1/2006
594.80	29.00	Top of Seal
591.80	32.00	Top of Sand Pack
590.12	33.68	Top of Screen
585.35	38.45	Bottom of Screen
585.00	38.80	Bottom of Well
585.00	38.80	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	36.32
Bottom of Screen to End Cap	(feet)	0.36
Screen Length (1st slot to last slot)	(feet)	4.77
Total Length of Casing	(feet)	41.45
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW16S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-16a

State Plane Coordinate: X 877,355.1 Y 2,515,088.0 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Rhonald W Hasenyager Date Started: 4/25/2006 Date Finished: 4/25/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 17 min.

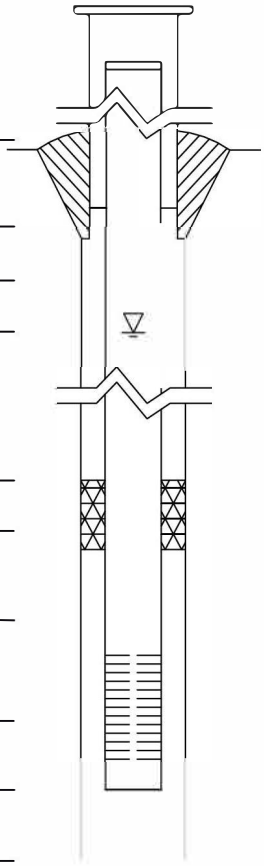
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
629.62	-3.52	Top of Protective Casing
629.28	-3.18	Top of Riser Pipe
626.10	0.00	Ground Surface
624.66	1.44	Top of Annular Sealant
620.36	5.74	Static Water Level (After Completion) 6/1/2006
624.66	1.44	Top of Seal
612.40	13.70	Top of Sand Pack
611.51	14.59	Top of Screen
606.69	19.41	Bottom of Screen
606.34	19.76	Bottom of Well
606.20	19.90	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.74
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.82
Total Length of Casing	(feet)	22.94
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW16D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-16b

State Plane Coordinate: X 877,354.9 Y 2,515,079.4 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Rhonald W Hasenyager Date Started: 4/21/2006 Date Finished: 4/25/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

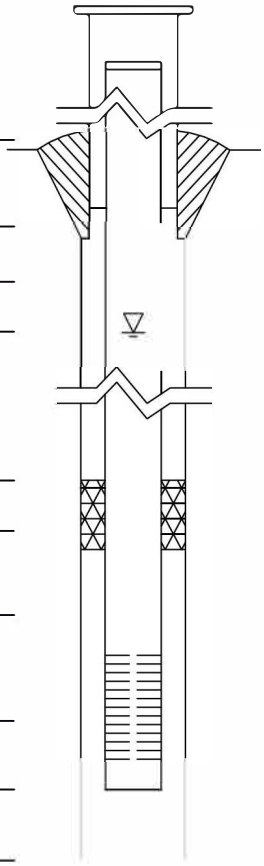
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: Re-drill borehole



	Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
	629.68	-3.58	Top of Protective Casing
	629.33	-3.23	Top of Riser Pipe
	626.10	0.00	Ground Surface
	623.77	2.33	Top of Annular Sealant
	574.73	51.37	Static Water Level (After Completion) 6/1/2006
	584.65	41.45	Top of Seal
	582.65	43.45	Top of Sand Pack
	580.20	45.90	Top of Screen
	575.76	50.34	Bottom of Screen
	575.32	50.78	Bottom of Well
	575.10	51.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	48.83
Bottom of Screen to End Cap	(feet)	0.44
Screen Length (1st slot to last slot)	(feet)	4.74
Total Length of Casing	(feet)	54.01
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW17D

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-17

State Plane Coordinate: X 878,659.0 Y 2,515,090.4 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/4/2006 Date Finished: 5/4/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite grout

Installation Method: Tremie

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: +24 hr.

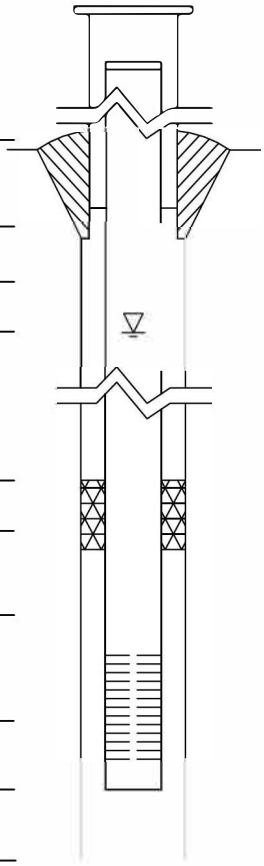
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
630.62	-3.52	Top of Protective Casing
630.29	-3.19	Top of Riser Pipe
627.10	0.00	Ground Surface
624.92	2.18	Top of Annular Sealant
572.65	54.45	Static Water Level (After Completion) 6/1/2006
581.55	45.55	Top of Seal
580.25	46.85	Top of Sand Pack
578.28	48.82	Top of Screen
573.78	53.32	Bottom of Screen
573.23	53.87	Bottom of Well
573.23	53.87	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	52.01
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	4.50
Total Length of Casing	(feet)	57.06
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW17S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-17a

State Plane Coordinate: X 878,658.5 Y 2,515,084.8 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: K. Doetzel

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/4/2006 Date Finished: 5/4/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 22 min.

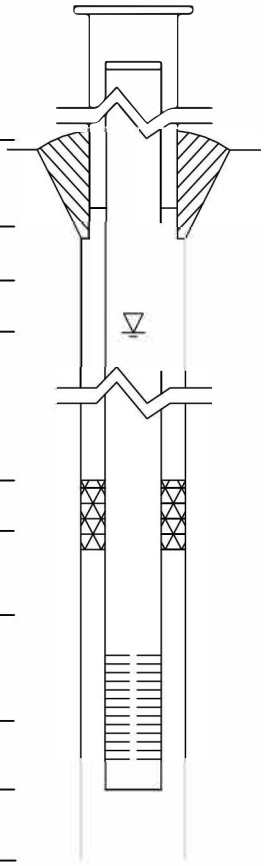
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
630.68	-3.58	Top of Protective Casing
630.34	-3.24	Top of Riser Pipe
627.10	0.00	Ground Surface
626.40	0.70	Top of Annular Sealant
620.21	6.89	Static Water Level (After Completion) 6/1/2006
617.33	9.77	Top of Seal
614.80	12.30	Top of Sand Pack
613.08	14.02	Top of Screen
603.54	23.56	Bottom of Screen
602.99	24.11	Bottom of Well
602.99	24.11	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.26
Bottom of Screen to End Cap	(feet)	0.55
Screen Length (1st slot to last slot)	(feet)	9.54
Total Length of Casing	(feet)	27.35
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: MW18S

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: SB-18a

State Plane Coordinate: X 878,604.7 Y 2,513,745.2 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): Potable water

Logged By: Reynolds Drilling Corp. Date Started: 5/11/2006 Date Finished: 5/11/2006

Report Form Completed By: Rhonald W Hasenyager Date: 6/7/2006

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: +24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 25 min.

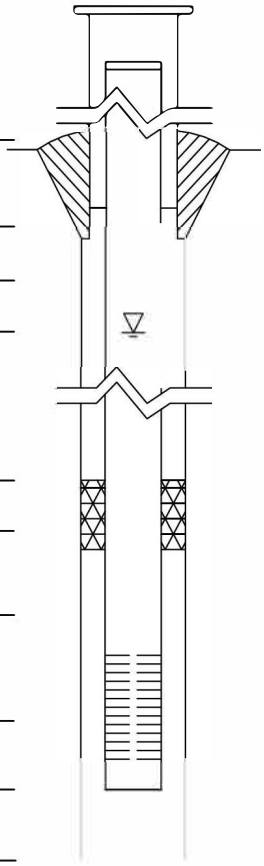
Type of Sand Pack: Quartz sand

Grain Size: #JC50FS (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
629.02	-3.42	Top of Protective Casing
628.71	-3.11	Top of Riser Pipe
625.60	0.00	Ground Surface
622.13	3.47	Top of Annular Sealant
618.73	6.87	Static Water Level (After Completion) 6/1/2006
622.13	3.47	Top of Seal
615.79	9.81	Top of Sand Pack
614.29	11.31	Top of Screen
609.81	15.79	Bottom of Screen
609.20	16.40	Bottom of Well
609.20	16.40	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	14.42
Bottom of Screen to End Cap	(feet)	0.61
Screen Length (1st slot to last slot)	(feet)	4.48
Total Length of Casing	(feet)	19.51
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX A8

AECOM BORING LOGS AND PIEZOMETER CONSTRUCTION DOCUMENTATION

Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B001

Sheet 1 of 2

Date(s) Drilled	08/07/2015 8:40 AM to 08/07/2015 4:10 PM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	35.0 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	634.8 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout (Installed COF-P000 5 ft South of COF-B001)	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 871595.4 E 2516695.5 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
	0							634.8	0.0								
		S1		3 4 6	67		Stiff, moist, brown and gray, silty and sandy CLAY, trace fine gravel, topsoil upper 2 inches, (CL) (EMBANKMENT FILL).			12.9				3.5			
630	5	S2		2 4 6	61		Stiff, moist, brown and gray, medium plasticity, silty and sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			20.3		31	17	2.5			
		S3		2 5 7	72		Stiff, very moist, brown and gray, medium plastic, silty and sandy CLAY, trace gravel (CL) (EMBANKMENT FILL).			15.4				1.75			
625	10	S4		2 4 5	83		Stiff, moist, brown and gray, sandy CLAY, trace fine gravel, with gray silt seams, (CL) (EMBANKMENT FILL).			16.1				1.5			
620	15	S5			92		Very stiff, very moist, dark grayish brown with yellowish brown and dark gray, medium plastic, CLAY, with sand, (CL) (EMBANKMENT FILL).			14.7	129.4	35	20	2.5			
		S6		1 2 2	83		Very stiff to 19'	615.8	19.0	23.2							
615	20						Soft, wet, brown and gray, silty CLAY, trace fine sand and decayed organic matter, organic odor, (CL) (NATIVE).	613.8	21.0								
		S7			92		Gray with yellowish brown, very plastic, CLAY, with sand, (CH).	611.8	23.0	23.4	125.7	66	44				
610	25	S8		1 4 5	100		Stiff, very moist, brown and gray, high plasticity, sandy CLAY, trace fine gravel, (CL).			19.6		41	26	1.5			
		S9		1 3 3	100			605.3	29.5	16.8				< 0.25			
605	30																

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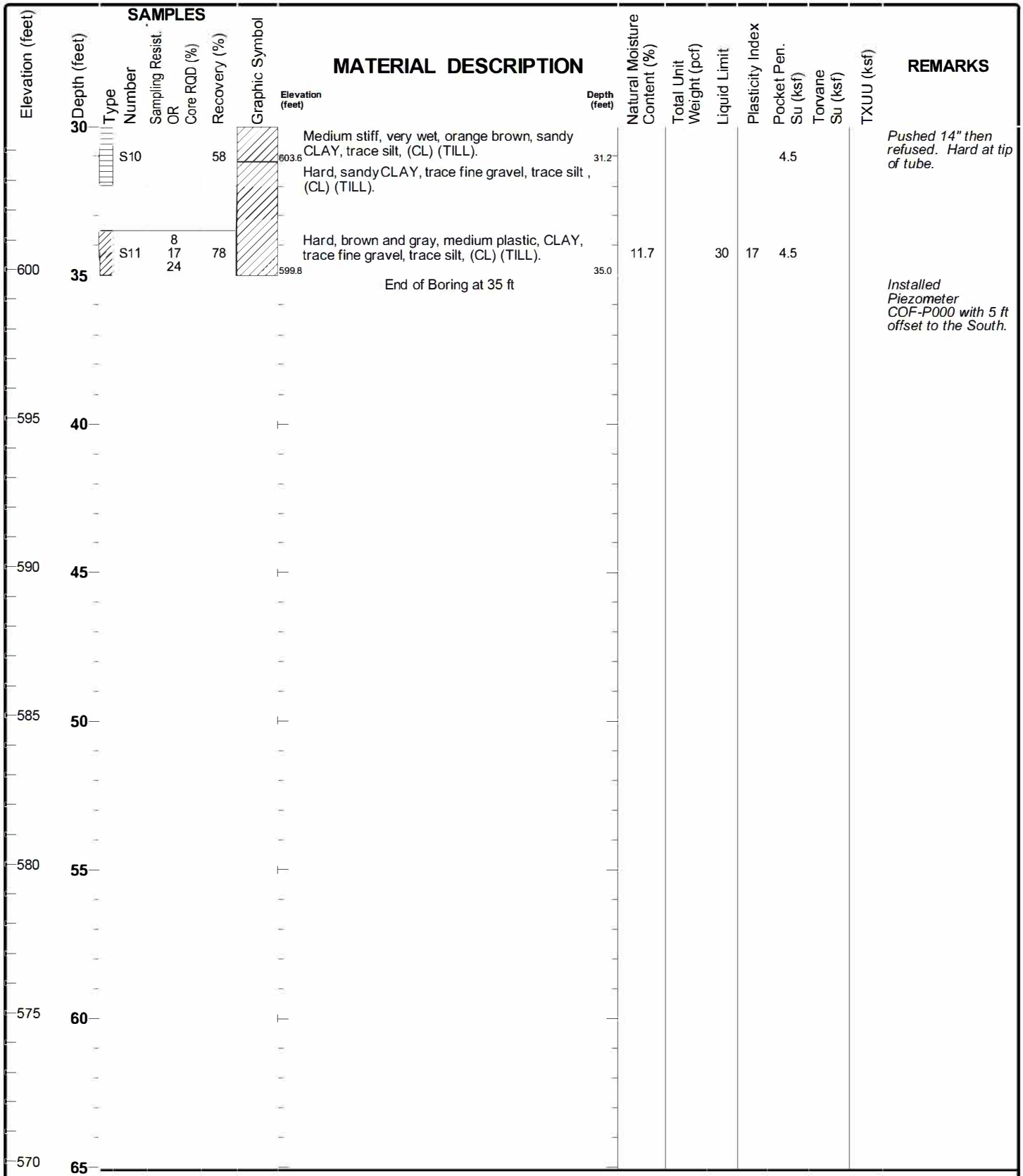
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B001

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B002

Sheet 1 of 2

Date(s) Drilled	08/06/2015 9:30 AM to 08/06/2015 3:00 PM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	35.5 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	635.4 ft NAVD88
Borehole Backfill	Piezometer COF-P002	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 871459.5 E 2516041.9 (ft NAD83)	Groundwater Level(s)	28 ft on 8/6/2015 1:00:00 PM		

Elevation (feet)	Depth (feet)	Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
								635.4	0.0								
635	0																
			S1	1 2 4	78		Medium stiff, very moist, brown and gray, CLAY, trace organics, (CL) (EMBANKMENT FILL).			25.4				2.0			
			S2	2 3 5	89		Stiff, very moist, brown and gray, medium plastic, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			25.9		35	18	1.0			
630	5		S3	1 3 5	83		Medium stiff, very moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			25.9				1.25			
			S4		100		Very stiff, very moist, gray with yellowish brown, high plasticity, CLAY, with sand, (CL) (EMBANKMENT FILL).			17.8	134.5	40	25	3.5			
625	10																
			S5	1 1 2	78		Soft, moist to wet, brown and gray, CLAY, with fine sand, trace fine gravel, (CL) (EMBANKMENT FILL).			23.3				0.75			
620	15		S6		100		Soft, very moist, gray with brown, low plasticity, silty CLAY, (CL) (EMBANKMENT FILL).	618.4	17.0	26.7	120.2	25	7	0.75			
			S7	2 3 5	94		Medium stiff, very moist, brown and gray, high plasticity, CLAY, trace fine sand, with brown silt seams, (CL) (NATIVE).			25.4		47	29	1.5			
615	20																
			S8	2 3 4	100					18.9				0.75			
610	25																
			S9	1 2 4			Loose, very wet, brown fine to coarse clayey SAND, trace gravel, (SP-SC) (NATIVE).	607.4	28.0	13.6							
	30																

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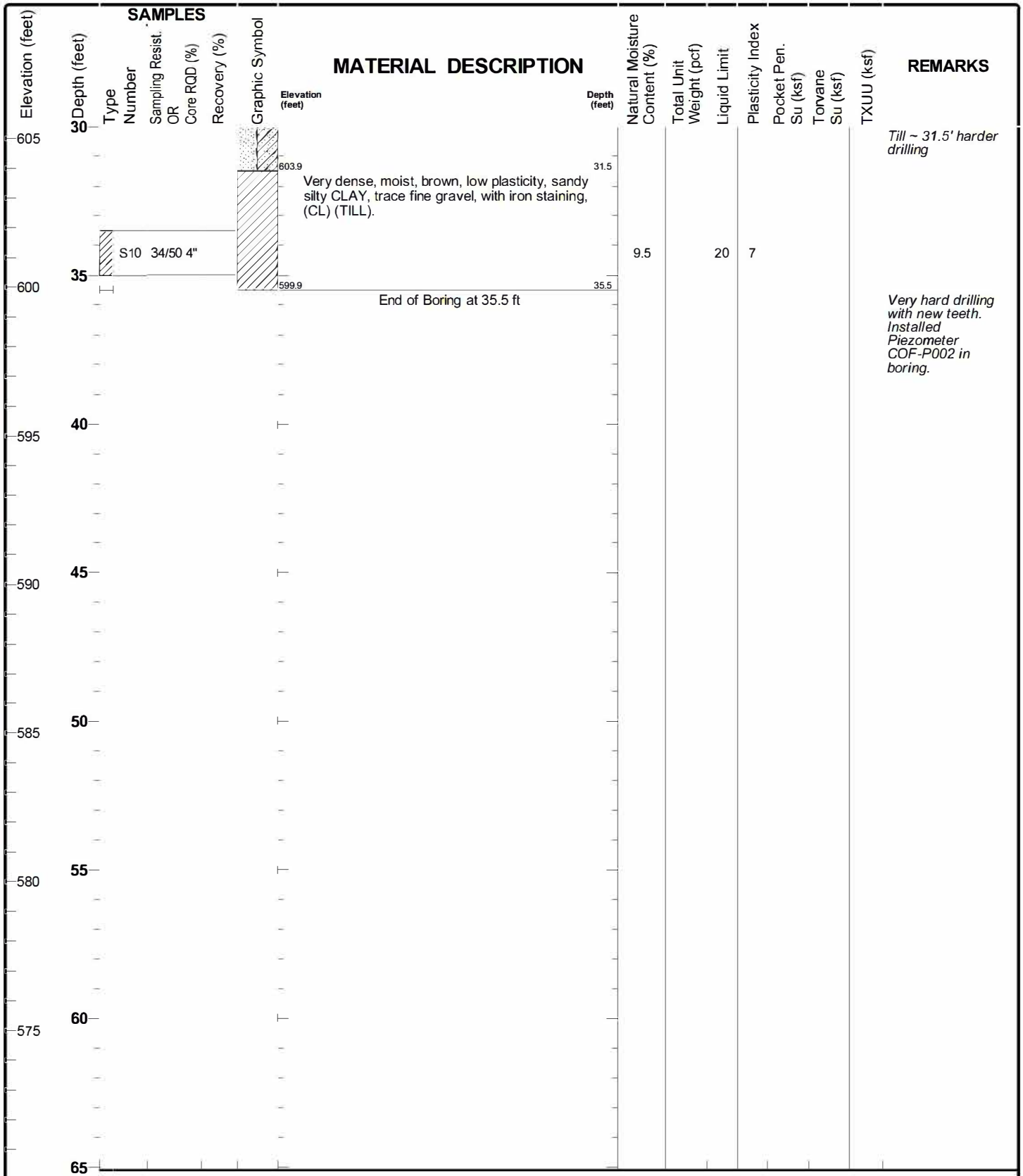
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B002

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B003

Sheet 1 of 2

Date(s) Drilled	08/05/2015 11:30 AM to 08/05/2015 5:30 PM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	45.0 ft
Drill Rig Type	CME 550X (Rubber Tire ATV)	Drilling Contractor	Geotechnology	Surface Elevation	635.7 ft NAVD88
Borehole Backfill	Piezometer COF-P003	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 871786.2 E 2515149.7 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
	0							635.7	0.0								
635			S1	3 5 4	50		Stiff, dry, brown and gray, sandy CLAY, trace fine gravel, trace coarse ash, (CL) (EMBANKMENT FILL).			14.2				4.5			
			S2	2 3 4	67		Medium stiff, moist, brown and gray, high plasticity, sandy CLAY, trace fine gravel, trash coarse ash, (CL) (EMBANKMENT FILL).			18.1		42	26	1.25			
	5																
630			S3	2 2 5	67		Medium stiff, moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			15.0				2.5			
			S4	2 4 8			Stiff, very moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			17.4				1.5			
	10																
625								621.7	14.0								
			S5		92		Stiff, very moist, dark gray trace yellowish brown, high plasticity, CLAY, (CH).			21.8	127.5	54	36	1.75			
	15																
620			S6	2 3 4	83		Medium stiff, very moist, brown and gray, medium plasticity, CLAY, trace fine sand, (CH).			26.0				1.75			
	20																
615																	
			S7	WOH 2 3	100		Medium stiff, very moist, brown and gray, high plasticity, CLAY, with sand, with iron stained seams, (CH).			20.8		50	34	1.75			
	25																
610																	
			S8	2 1 9	100		Stiff, very moist, brown, low plasticity, sandy silty CLAY, trace fine gravel, (CL) (TILL).	606.7	29.0	12.5		21	6	3.5			
	30																

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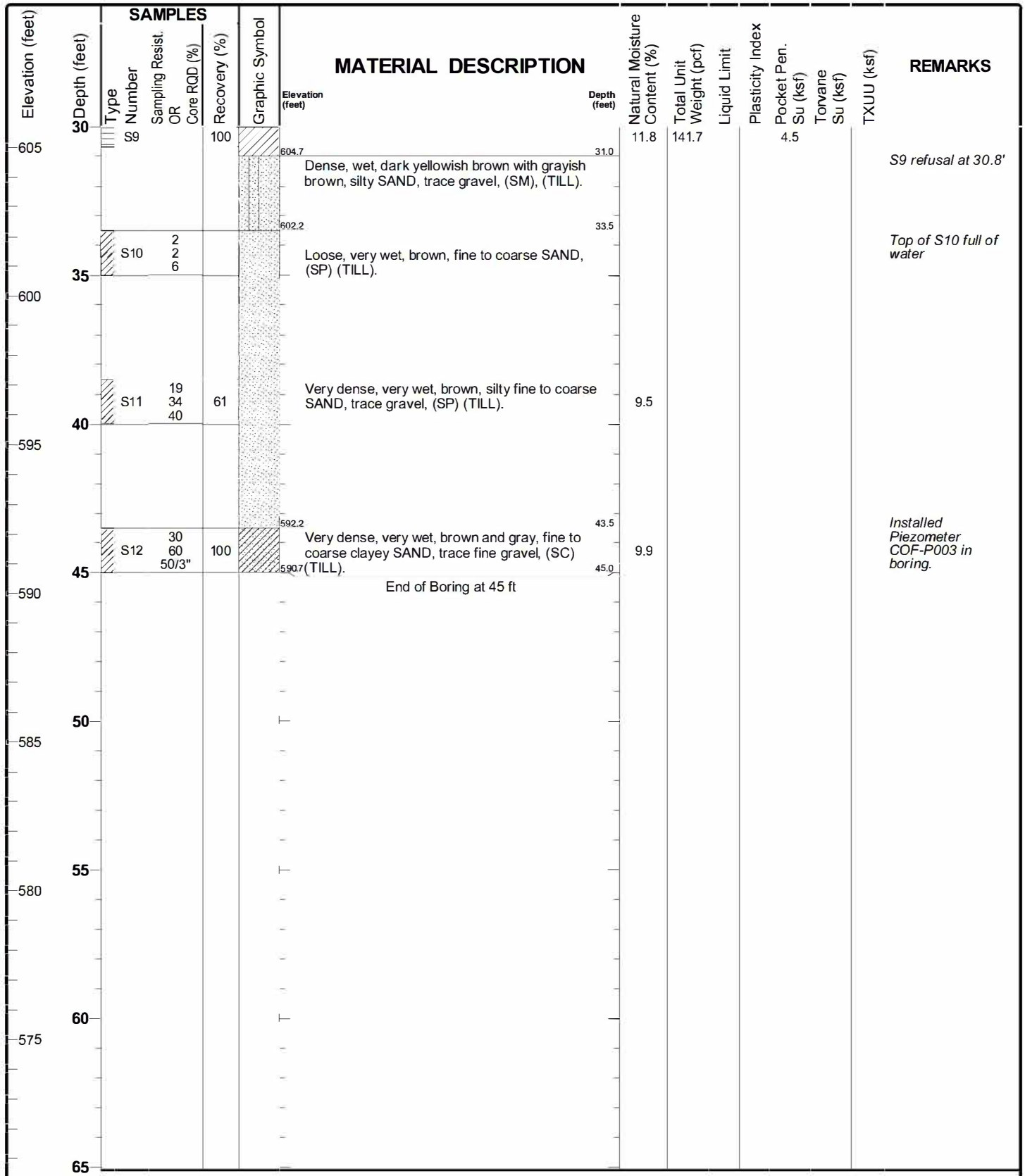
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B003

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B004

Sheet 1 of 2

Date(s) Drilled	08/04/2015 10:20 AM to 08/05/2015 11:00 AM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	45.0 ft
Drill Rig Type	CME 550X (Rubber Tire ATV)	Drilling Contractor	Geotechnology	Surface Elevation	635.0 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout (Installed COF-P005 5 ft West of COF-B004)	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 872197.6 E 2516082 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
635	0						Elevation (feet) 635.0 / Depth (feet) 0.0								
		S1		2 3 5	67		Medium stiff, moist, brown, CLAY, with fine sand, trace fine gravel, (CL) (EMBANKMENT FILL).	18.0				1.75			
		S2		3 4 5	67		Stiff, moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).	10.9				3.5			
630	5														
		S3		2 4 4	72		Medium stiff, moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).	11.0				2.25			
		S4			79		Medium stiff, moist, yellowish brown with gray, high plasticity, CLAY, with sand, (CL) (EMBANKMENT FILL).	12.8	136.6	39	24	2.25			
625	10														
		S5		3 5 6	94		Stiff, moist, brown and gray, medium plastic, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).	13.1		26	12	4.0			
620	15														
							Elevation (feet) 617.0 / Depth (feet) 18.0								
		S6		2 3 7	83		Stiff, very moist, brown and gray, sandy CLAY, trace fine gravel, with gray silt seams, (CL) (NATIVE).	21.8				1.75			
615	20														
		S7			92		Very stiff, very moist, reddish brown, high plasticity, silty CLAY, trace fine sand, with dark gray silt seams, (CL).	20.6	129.5	51	34	2.75			
610	25														
		S8		1 4 5	100		Stiff, very moist, brown and gray silt seams, high plasticity, CLAY, with fine to medium sand, (CL).	24.2		43	27	1.75			
605	30														

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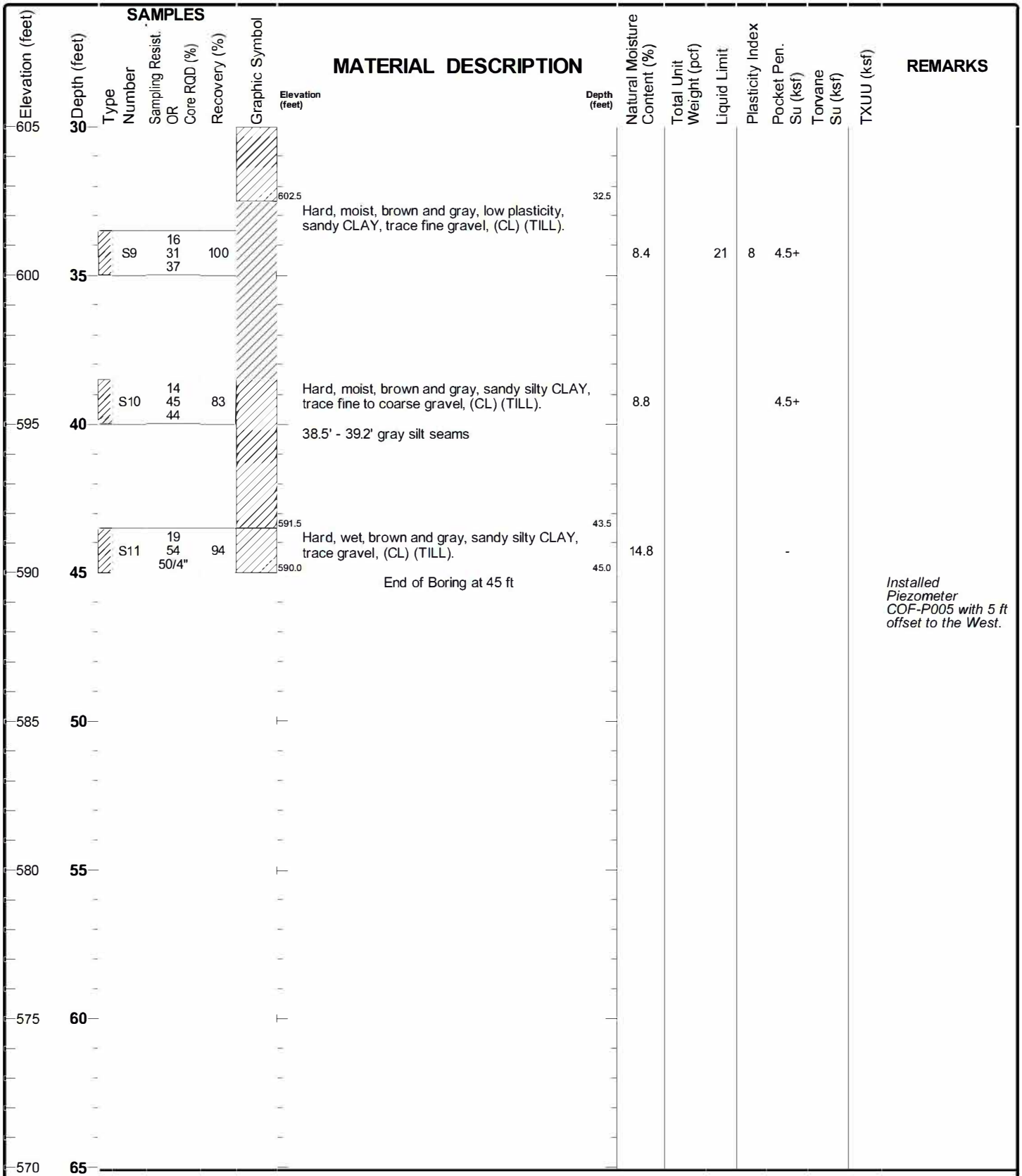
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B004

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B005

Sheet 1 of 2

Date(s) Drilled	08/08/2015 7:45 AM to 08/08/2015 12:00 PM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	60.0 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	635.1 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout (Installed COF-P006 5 ft South of COF-B005)	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 872109.6 E 2516693.3 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	Sample Type	Sample Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
								635.1	0.0								
635	0	S1		2 3 4	83		Medium stiff, moist, brown and gray, CLAY, (CL) (EMBANKMENT FILL).			21.1				1.5			
630	5	S2			54		Stiff, moist, brown, low plasticity, sandy CLAY, (CL) (EMBANKMENT FILL).			8.0	136.6	22	9	3.0			
		S3		1 3 4	72		Medium stiff, moist, brown, sandy CLAY, (CL) (EMBANKMENT FILL).			13.1				0.75			
625	10	S4		2 7 6	89		Stiff, moist, brown, low plasticity, sandy silty CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			9.9		20	6	3.0			*Shale in tip*
620	15	S5		2 6 6	78		Stiff, moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			10.3				2.0			
615	20	S6		WOH 2 3	67		Medium stiff, moist, brown and gray, sandy CLAY, trace fine gravel, (CL) (EMBANKMENT FILL).			9.4				1.0			
								612.1	23.0								
610	25	S7			92		Stiff to very stiff, gray with grayish brown, medium plastic, CLAY, with sand, with organics, (CL) (NATIVE).			18.7	131.4	37	20	1.5			
								606.6	28.5								
	30	S8		1 4 6	89		Stiff, brown and gray, medium plastic, CLAY, trace fine sand, trace organics, (CH).			21.9				2.0			

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:24 PM

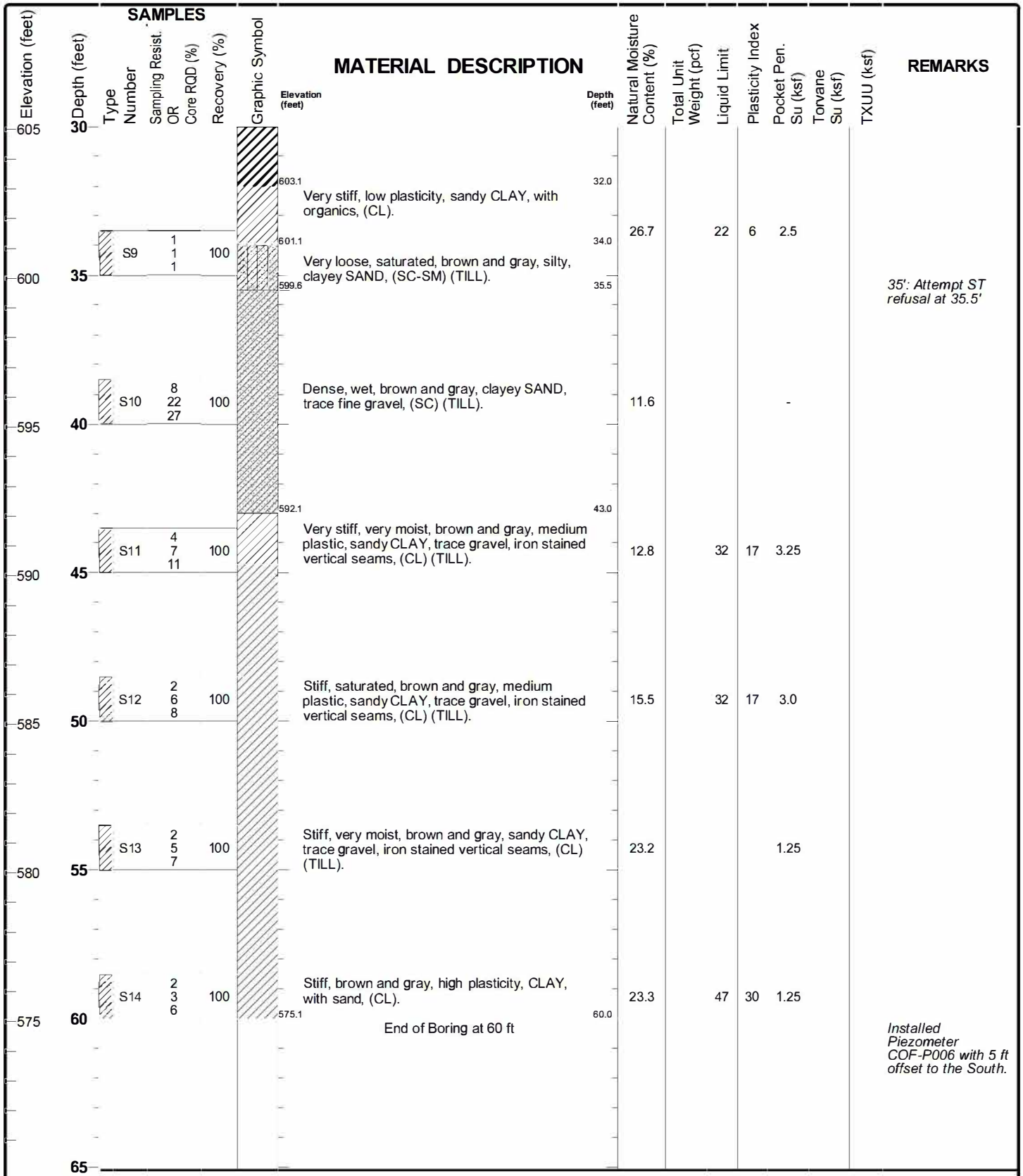
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B005

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B006

Sheet 1 of 2

Date(s) Drilled	08/06/2015 4:00 PM to 08/07/2015 7:30 AM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	33.5 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	631.9 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 871654.5 E 2515234.7 (ft NAD83)	Groundwater Level(s)	4 ft on 8/6/2015 5:00:00 PM		

Elevation (feet)	Depth (feet)	Sample Type	Sample Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
	0							631.9	0.0								
630			S1	5 13 15	78		Medium dense, moist, black CINDERS, well-graded sand, with silt, trace fine gravel, (ASH).			6.6							
	5		S2	2 2 2	100		Very loose, wet, black CINDERS, with clay, (ASH).			48.3							
625			S3		17					22.2							
	10		S4	3 4 6	100		Loose, wet, black CINDERS, well-graded sand, with clay, (FILL).			16.7							
620								617.9	14.0								
			S5	WOH 2 3			Medium stiff, very moist, brown and gray, high plasticity CLAY, trace fine sand, (CH) (NATIVE).			24.4		57	37	1.75			
	15																
615																	
	20		S6	1 3 4	67					21.9				1.25			
610								608.9	23.0								
			S7	1 1 1	100		Very soft, very wet, brown, low plasticity, sandy CLAY, (CL) (TILL).			19.8		23	9	0.5			
	25							605.9	26.0								
605																	
			S8	20 50/4"			Hard, very wet, brown and gray, sandy CLAY, (CL) (TILL).			16.1							
	30																

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:32 PM

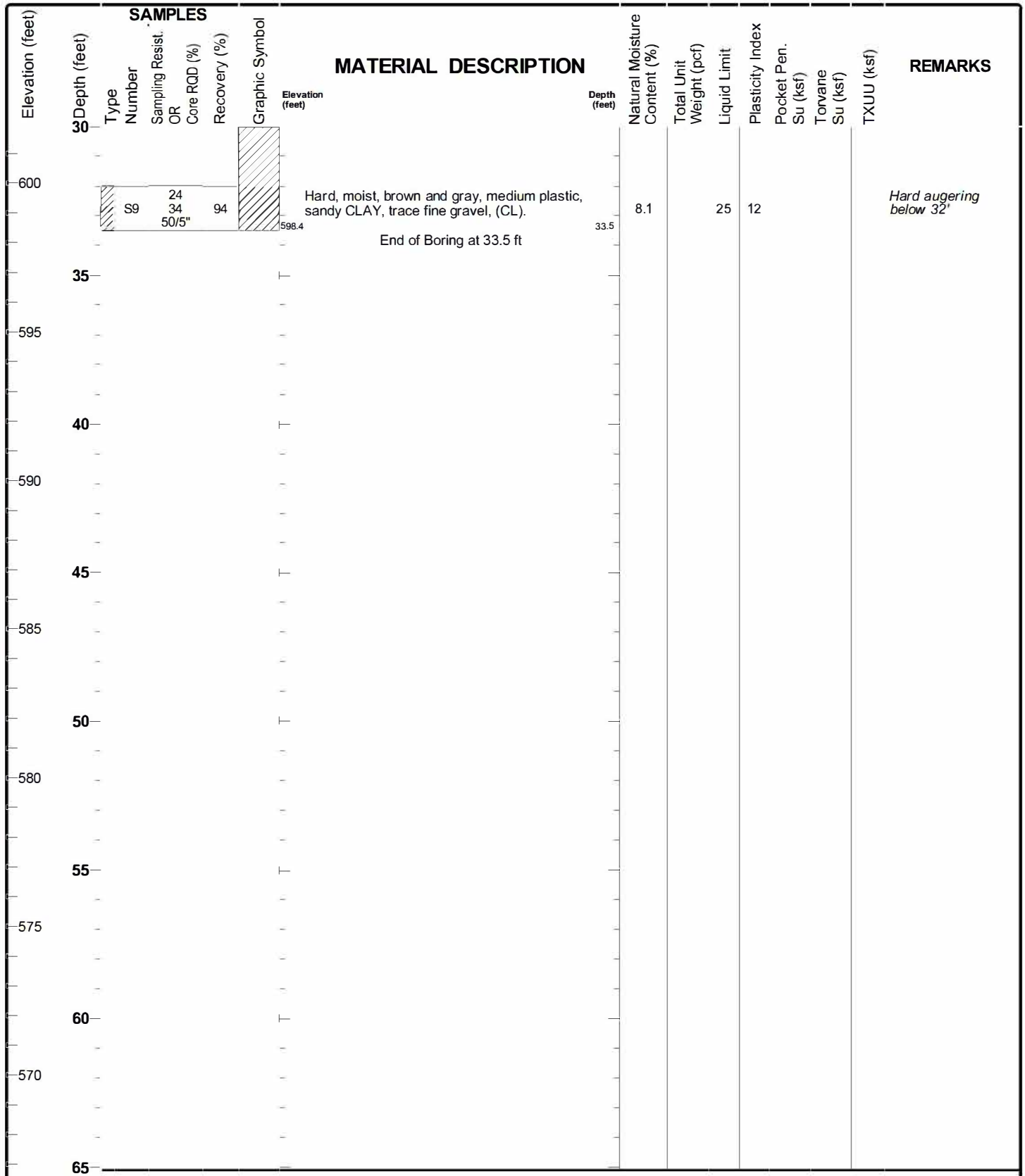
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B006

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B006A

Sheet 1 of 1

Date(s) Drilled	08/19/2015 7:15 AM to 08/19/2015 10:15 AM	Logged By	A. Grossman	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	25.5 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	632 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout	Sampling Method(s)	Piston	Hammer Data	-
Boring Location	N 871649.5 E 2515234.7 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
632.0	0.0													
630	0	PS-1	75			Loose, moist, black, medium to coarse grained , CINDERS, (ASH).								
625	5	PS-2	20											
619.5	12.5					Stiff, light grayish brown, silty CLAY, some ash, (CL).								
620	10	PS-3	70								1.25			
615	15	PS-4	83								1.25			
615	15	PS-5	73								1.25			
610	20	PS-6	93			Stiff to very stiff, grayish brown CLAY, (CL).					2.0			
606.5	25.5					End of Boring at 25.5 ft								*Auger refusal at 25.5' bgs.*
605	25													
	30													

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:39 PM

Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B007

Sheet 1 of 2

Date(s) Drilled	08/11/2015 12:00 AM to	Logged By	A. Grossman	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	37.5 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	638.0 ft NAVD88
Borehole Backfill	Piezometer COF-P009	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 873894 E 2515111.2 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
							Elevation (feet) 638.0 / Depth (feet) 0.0								
635	0		S1	6 9 12	89		Very stiff, slightly moist, brown, silty and sandy CLAY, some fine to coarse gravel, trace silt, (CL) (EMBANKMENT FILL).	21.4							
	5		S2		83		Very stiff, moist, gray, high plasticity, silty CLAY, well sorted, (CL) (EMBANKMENT FILL).	23.2	126.8	46	27				
630			S3		100		Medium stiff to stiff, moist, gray trace yellowish brown, medium plastic, CLAY, well sorted, with sand, (CL) (EMBANKMENT FILL).	21.7							
	10		S4	2 5 7	78		Stiff, moist, brown and gray, medium plastic, CLAY, trace fine sand, well sorted, (CL) (EMBANKMENT FILL).	25.3							
625			S5	2 7 9	83		Very stiff, moist, brown and gray, high plasticity, CLAY, trace fine sand and gravel, (CL) (EMBANKMENT FILL).	21.6		47	28				
	15						Elevation (feet) 621.0 / Depth (feet) 17.0								
620			S6	2 2 4	94		Medium stiff, moist, brown and gray, high plasticity, CLAY, trace fine to coarse sand, (CH).	24.5							
	20		S7		92		Firm, moist, yellowish brown with dark gray, high plasticity, CLAY, with sand, trace gravel, (CH).	22.5	127.0	52	35				
615			S8		100			18.3	128.5	43	27				
	25														
610															
							Elevation (feet) 609.0 / Depth (feet) 29.0								
	30		S9	1	72		Soft, wet to saturated, brown and gray, sandy CLAY (CL).	20.3							

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:42 PM

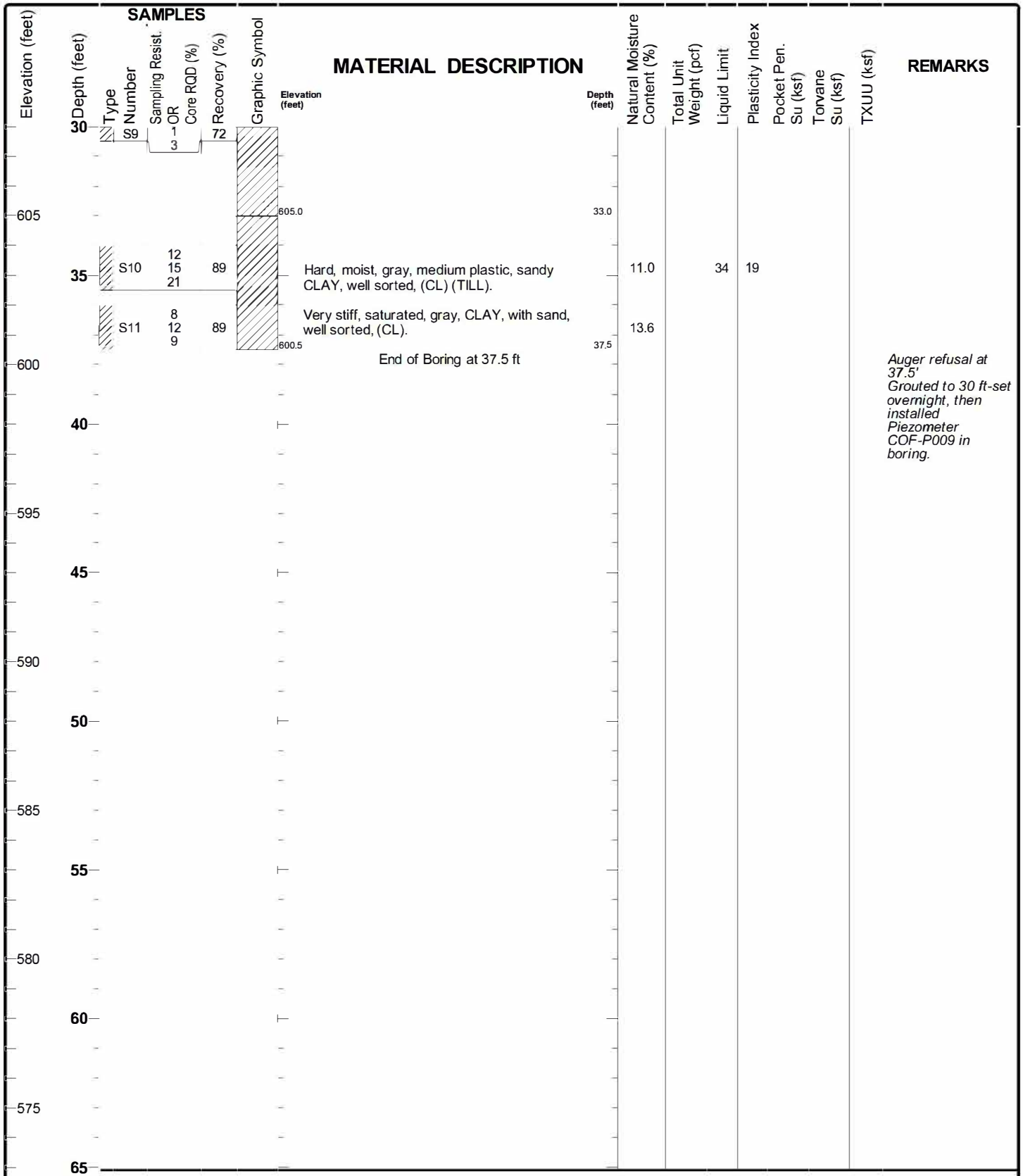
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B007

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B008

Sheet 1 of 2

Date(s) Drilled	08/13/2015 8:00 AM to 08/14/2015 9:30 AM	Logged By	A. Grossman	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	38.5 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	635.7 ft NAVD88
Borehole Backfill	Cement-Bentonite Grout	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 873886.6 E 2516222.7 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	Sample Type	Sample Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
	0							635.7	0.0								
635							Stiff, moist, brown and gray, CLAY, trace sand, with roots, (CL) (EMBANKMENT FILL).										
		SS	S1	2 4 5	89					19.7							
		SS	S2	2 1 2	67		Soft, moist, brown, high plasticity, CLAY, with roots, (CL) (EMBANKMENT FILL).			16.3		46	29				
	5							628.7	7.0								
630		SS	S3	1 3 6	78		Stiff, moist, brown and gray, medium plastic, CLAY, trace sand, with roots, (CH) (EMBANKMENT FILL).			21.7				3.25			
	10	SS	S4	2 4 8	78			624.7	11.0	21.6		54	36	2.25			
625		SS	S5		83		Very stiff to hard, moist to wet, dark gray with trace grayish brown, high plasticity, CLAY, with sand, with roots, (CL) (EMBANKMENT FILL).			16.6	131.5	43	27	> 4.5			
		SS	S6		100		Stiff, wet, light yellowish brown with light gray, medium plastic, CLAY, with sand, with roots, (CL) (EMBANKMENT FILL).			13.9	137.2	35	20	2.25			
	15																
620																	
	20							615.7	20.0								
615		SS	S7	2 3 6	83		Stiff, moist, brown and gray, medium plastic, CLAY, trace sand, (CH) (NATIVE).			20.5				2.0			
	25																
610		SS	S8	2 6 7	78		Stiff, moist, brown and gray , medium plastic, CLAY, with sand, (CH).			16.4				3.25			
								607.7	28.0								
		SS	S9		96		Soft, moist to wet, grayish brown, medium plastic, CLAY, some silt, (CL) (NATIVE).			19.1	128.4			0.5			
	30																

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:50 PM

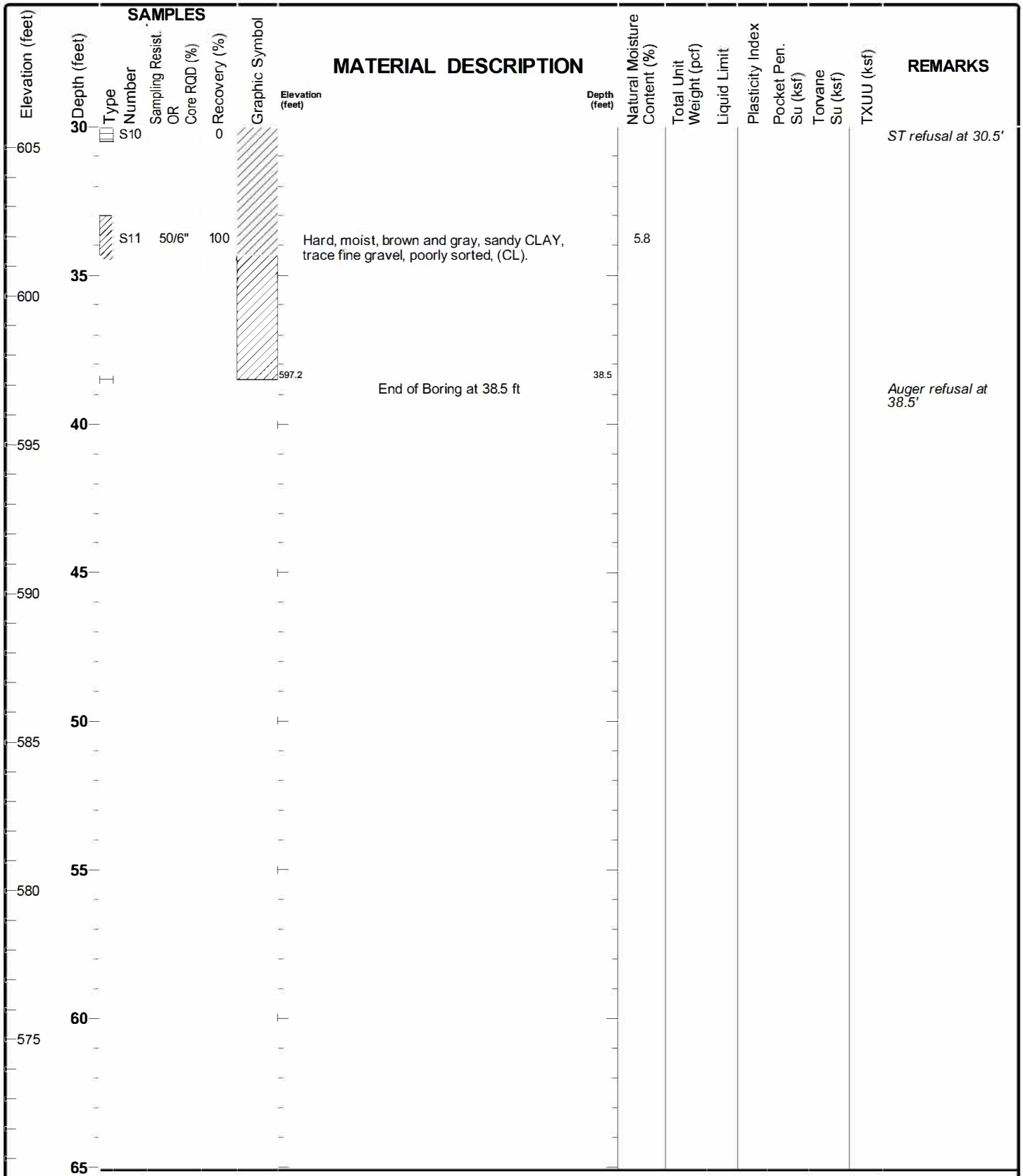
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B008

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B009

Sheet 1 of 2

Date(s) Drilled	08/13/2015 9:00 AM to 08/13/2015 12:15 PM	Logged By	E. Drumright/A.Grossman	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	40.0 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	635.2 ft NAVD88
Borehole Backfill	Piezometer COF-B010	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 873505 E 2516620.8 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	Sample Type	Sample Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
								635.2	0.0								
635	0	S1		3 4 6	83		Medium dense, moist, 2" sandy clay layer over 12" black, fine to coarse CINDERS, (ASH).			2.6							
								631.7	3.5								
		S2		1 2 3	44		Medium stiff, very moist, 2" ash layer over brown and gray, silty CLAY, trace sand, (CH) (EMBANKMENT FILL).			26.1			1.25			
630	5	S3		2 4 5	83		Stiff, very moist, dark grayish brown, high plasticity, CLAY, (CH) (EMBANKMENT FILL).			17.1		58	40	2.0			
		S4		2 5 6	61		Stiff, very moist, brown and gray, CLAY, trace sand, (CH) (EMBANKMENT FILL).			22.4				2.0			
625	10																
		S5			79		Very stiff, very moist, olive gray and grayish brown, high plasticity, CLAY, with sand, (CH) (EMBANKMENT FILL).			18.4	131.5	50	35	2.25			
620	15							619.7	15.5								
		S6			75		Stiff, very moist, brown and gray, CLAY, (CL-CH) (EMBANKMENT FILL).			23.3	128.5			1.75			
		S7		1 3 6	100					29.3				1.75			
615	20																
		S8		1 3 5	89		Medium stiff, very moist, brown and gray, high plasticity, CLAY, trace sand, (CL) (EMBANKMENT FILL).			23.1		48	30	1.75			
610	25							608.2	27.0								
		S9			92		Very stiff, brown and gray, high plasticity, CLAY, (CH) (NATIVE).			24.9	124.9	62	40	2.25			
	30																

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:43:57 PM

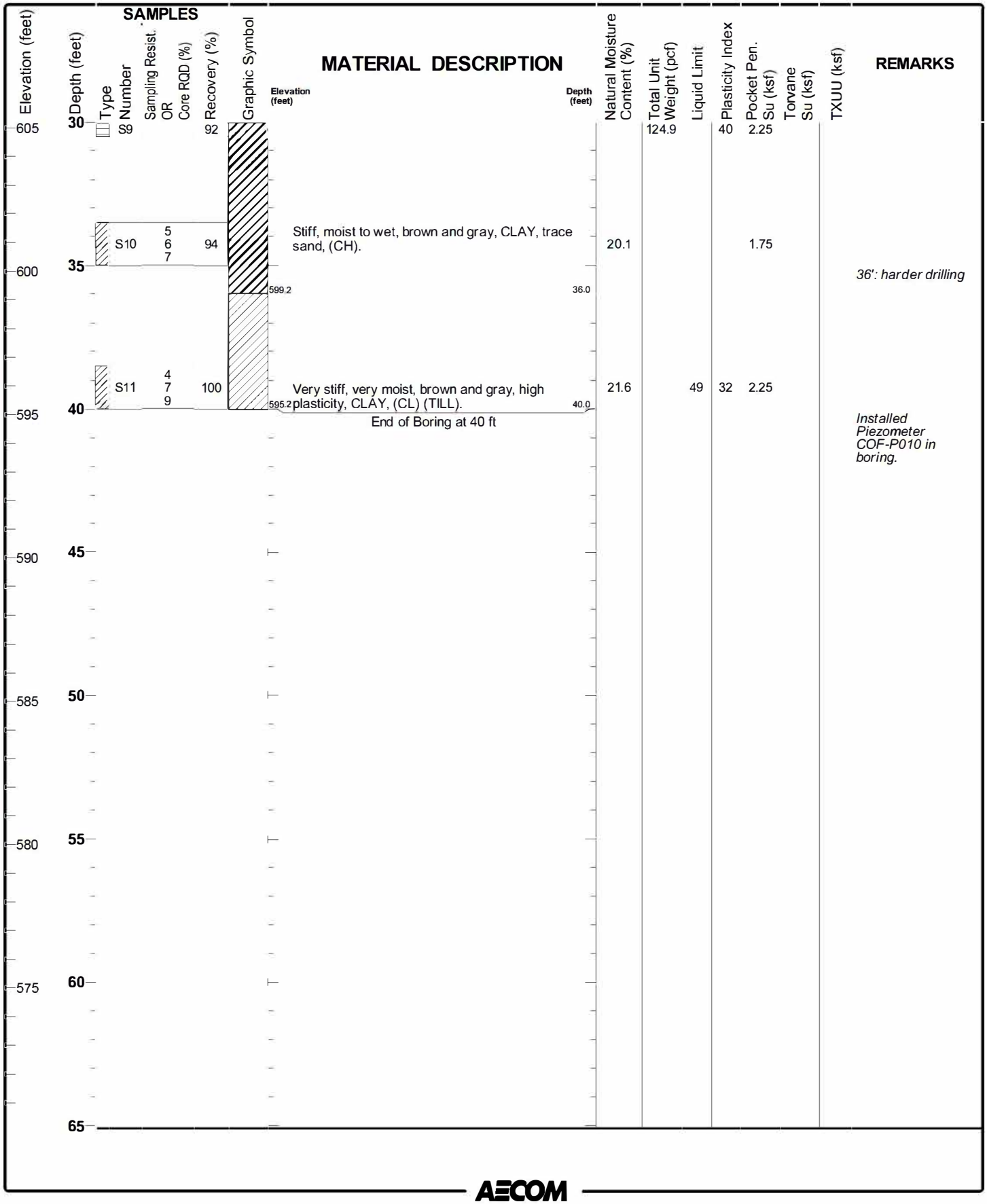
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B009

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B010

Sheet 1 of 2

Date(s) Drilled	08/10/2015 3:00 PM to 08/11/2015 10:00 AM	Logged By	E. Drumright/A.Grossman	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	HSA	Borehole Depth	44.0 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	642.2 ft NAVD88
Borehole Backfill	Piezometer COF-P012	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 872690.8 E 2515090.7 (ft NAD83)	Groundwater Level(s)	10 ft on 8/10/2015 3:30:00 PM		

Elevation (feet)	Depth (feet)	Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
	0							642.2	0.0								
640		S1		3 6 7	89		Stiff, moist, brown and gray, CLAY, trace fine gravel and ash, with orange-brown seams, (CL) (FILL).			15.1				4.5		
								638.5	3.7								
	5	S2		3 7 7	72		Medium dense, moist, 2" layer of well-graded SAND, over medium to coarse grained CINDERS (ASH).			5.8						
635		S3		8 14 16	72		Dense, moist, black medium to coarse grained CINDERS (ASH).			3.8						
	10	S4		3 9 13	72		Medium dense, moist to wet, black medium to coarse grained, CINDERS (ASH).			9.6						
630																	
	15	S5		2 7 12	89		Medium dense, wet, black medium to coarse grained CINDERS, (ASH).			14.2						
625																	
	20	S6		4 6 6	67		Medium dense, black, non-plastic, CINDERS, (ASH).			14.8		NP	NP			
620																	
								618.2	24.0								
	25	S7		3 3 5	100		Medium stiff, wet, brown and gray, CLAY, trace fine sand, (CH) (NATIVE).			3.9/24.1						
615																	
								613.7	28.5								
	30	S8		3 3 5	100		Medium stiff, brown and gray, high plasticity, sandy CLAY, (CL).			21.9		48	31			

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:44:04 PM

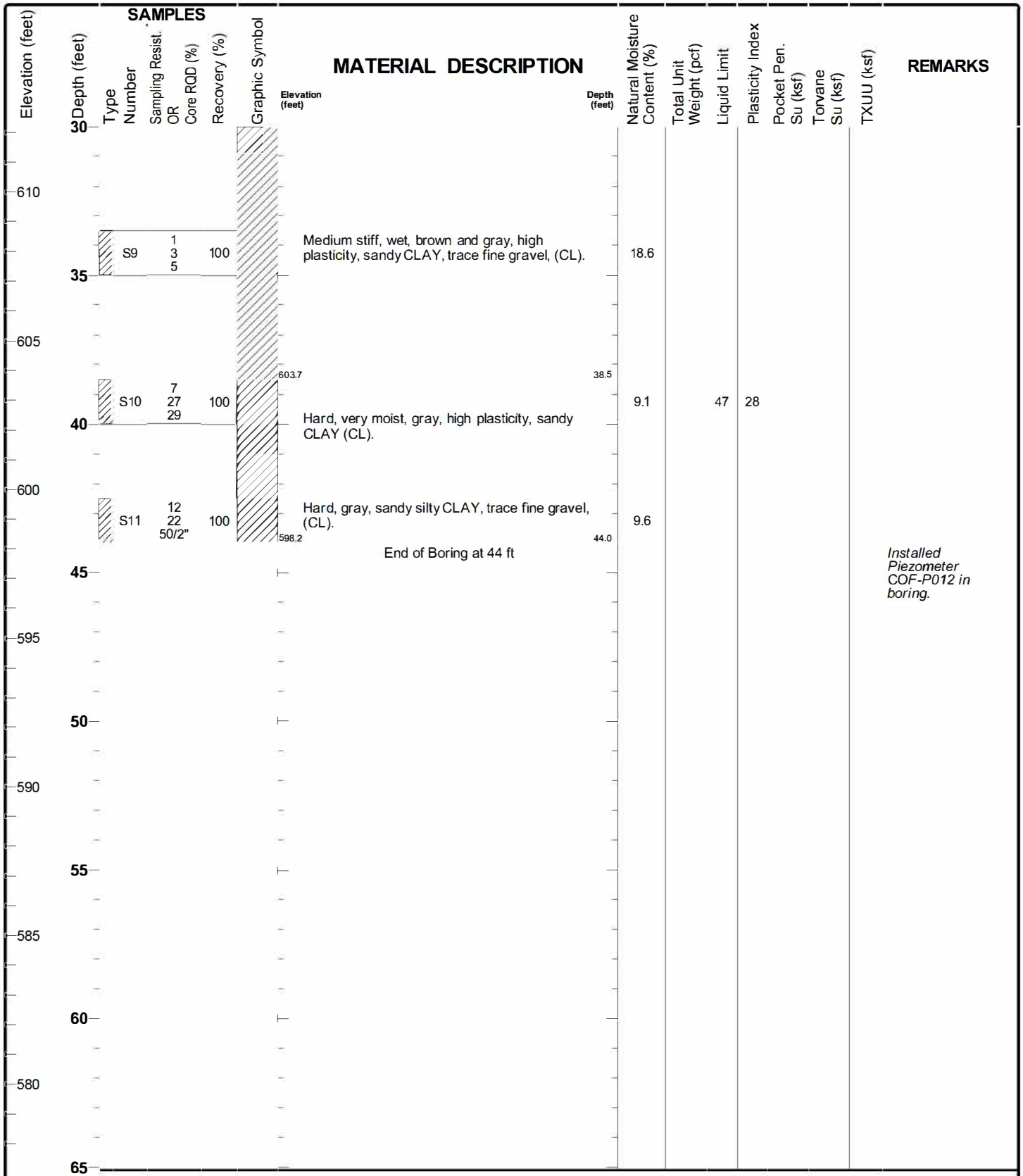
Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B010

Sheet 2 of 2



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Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B011

Sheet 1 of 2

Date(s) Drilled	08/11/2015 9:45 AM to 08/11/2015 1:15 PM	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hollow Stem Auger	Drill Bit Size/Type	7.5 inch O.D. HSA	Borehole Depth	40.0 ft
Drill Rig Type	CME 550X	Drilling Contractor	Geotechnology	Surface Elevation	635.1 ft NAVD88
Borehole Backfill	Piezometer COF-P014	Sampling Method(s)	SS / ST	Hammer Data	Automatic
Boring Location	N 872538.3 E 2515411.6 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
							Elevation (feet) / Depth (feet)								
635	0						635.1 / 0.0								
			S1	2 3 6	67		Stiff, moist, brown and gray, CLAY, with fine to medium sand, with roots, (CL-CH) (EMBANKMENT FILL).	23.9				2.5			
							631.6 / 3.5								
			S2	2 4 5	94		Stiff, moist, brown and gray, very plastic, CLAY, with roots, one ash seam, (CH)	23.5		67	47	1.75			
630	5						630.1 (EMBANKMENT FILL). / 5.0								
			S3	2 4 6	89		Stiff, moist, brown and gray, CLAY, trace fine sand, with roots, (CL) (EMBANKMENT FILL).	26.1				2.0			
			S4	30/3"	17			21.8							*S4: Concrete or boulder chips in tip of spoon. Drill through to continue.*
			S5	4 8 8	83		Very stiff, very moist, brown and gray, medium plastic, sandy CLAY, trace fine gravel, limestone rock in middle of sample, (CL) (EMBANKMENT FILL).	10.9		32	18	4.0			
625	10														
			S6		58		Very stiff, yellowish brown with grayish brown, medium plastic, sandy CLAY, (CL) (EMBANKMENT FILL).	11.5	139.4	34	20	4.0			
620	15														*Gravel in tip. Bent tip of tube.*
			S7		54		Hard, very moist, yellowish brown trace gray, medium plastic, sandy CLAY, trace gravel, (CL) (EMBANKMENT FILL).	12.0	134.1	30	16	4.5+			
							617.1 / 18.0								
			S8	2 3 6	83		Stiff, very moist, brown and gray, CLAY, with orange-brown silt seams, (CL-CH) (NATIVE).	27.3				1.75			
615	20														
			S9	2 4 5	100		Stiff, brown and gray, CLAY, trace fine to medium sand, (CL).	19.4				1.5			
610	25														
			S10	1 2 3	100		Medium stiff, brown and gray, medium plastic, sandy CLAY, trace fine gravel, (CL).	17.3		32	17	0.25			
							605.6 / 29.5								
	30														

SAMPLES

AECOM

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:44:11 PM

Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-B011

Sheet 2 of 2

Elevation (feet)	Depth (feet)	SAMPLES Type Number	SAMPLES Sampling Resist OR Core RQD (%)	SAMPLES Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
605	30	S11		100		Soft to stiff, wet, with orange brown, sandy CLAY TILL, trace fine sand, with orange-brown silt seams, (CL).	603.1	32.0	9.9	144.5						
		S12				Brown and gray, sand CLAY, trace fine gravel, (CL).	602.1	33.0	8.9							
600	35	S13	16 32 41	94		Very dense, very moist, gray, silty clayey SAND, trace gravel, with orange-brown silt seams, (SC-SM) (TILL).	596.6	38.5	9.3				4.5+			
		S14	20 46 50/4"	83		Hard, wet, gray, sandy silty CLAY, trace fine grave, (CL) (TILL).	595.1	40.0	9.8				4.5+			
595	40					End of Boring at 40 ft										*Installed Piezometer COF-P014 in boring.*
590	45															
585	50															
580	55															
575	60															
	65															

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:44:11 PM

Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-HA1

Sheet 1 of 1

Date(s) Drilled	08/30/2015 12:00 AM to	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hand Auger	Drill Bit Size/Type	2.25" O.D Hand Auger	Borehole Depth	8.0 ft
Drill Rig Type		Drilling Contractor	AECOM	Surface Elevation	610.5 ft NAVD88
Borehole Backfill	Drill Cuttings	Sampling Method(s)	Bag	Hammer Data	None
Boring Location	N 872484.5 E 2516572.3 (ft NAD83)	Groundwater Level(s)	7.3' ft on 8/30/2015		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
610	0		S1				Very stiff to stiff, moist to very moist, brown to brown and gray, medium plastic, CLAY (CL-CH), (FILL).	610.5	0.0	12.9							
			S2							13.3		35	14				
			S3							21.7							
			S4				Stiff to very stiff, very moist, brown and gray, CLAY, trace sand to with sand, (CL-CH).	607.5	3.0	19.0							
	5		S5							18.1							
605			S6							18.0							
			S7				Stiff, very wet, brown and gray, high plasticity, sandy CLAY, (CL) (TILL).	604.5	6.0	16.0		35	21				
			S8							22.9							
								602.5	8.0								
							End of Boring at 8 ft										
	10																
600																	
	15																
595																	
	20																
590																	
	25																
585																	
	30																

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:44:18 PM

Project: Dynegy

Project Location: Coffeen Power Station, IL

Project Number: 60440742

Log of Boring COF-HA2

Sheet 1 of 1

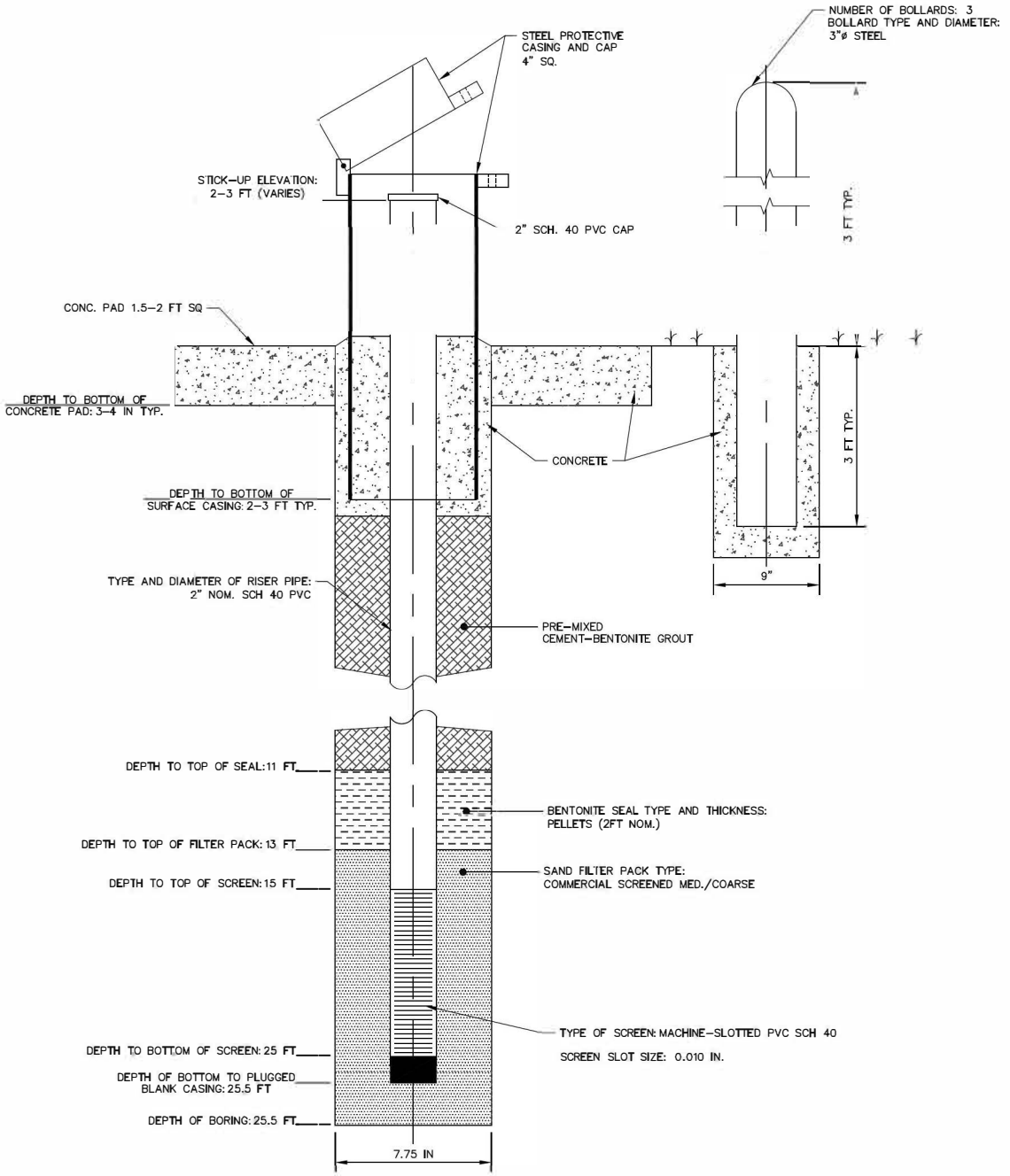
Date(s) Drilled	08/30/2015 12:00 AM to	Logged By	E. Drumright	Checked By	D. Swanson
Drilling Method	Hand Auger	Drill Bit Size/Type	2.25" O.D Hand Auger	Borehole Depth	5.5 ft
Drill Rig Type		Drilling Contractor	AECOM	Surface Elevation	594.6 ft NAVD88
Borehole Backfill	Drill Cuttings	Sampling Method(s)	Bag	Hammer Data	None
Boring Location	N 873496.7 E 2516761.2 (ft NAD83)	Groundwater Level(s)	Not Encountered		

Elevation (feet)	Depth (feet)	SAMPLES Type	Number	Sampling Resist. OR Core RQD (%)	Recovery (%)	Graphic Symbol	MATERIAL DESCRIPTION	Elevation (feet)	Depth (feet)	Natural Moisture Content (%)	Total Unit Weight (pcf)	Liquid Limit	Plasticity Index	Pocket Pen. Su (ksf)	Torvane Su (ksf)	TXUU (ksf)	REMARKS
								594.6	0.0								
	0		S1				Dark brown, high plasticity, CLAY, with sand, cinders and organics, (CH) (TOPSOIL).	593.9	0.7	18.6		51	25				
			S2				Very stiff, very moist, brown, CLAY, (CL).			20.9		47	27				
			S3							22.8							
								591.6	3.0								
			S4				Stiff to very stiff, very moist, brown, high plasticity, CLAY, trace sand to sandy, none to trace fine gravel, (CL) (TILL).			15.8							
590	5		S5							13.4		43	27				
			S6					589.1	5.5	11.4							
							End of Boring at 5.5 ft										
585	10																
580	15																
575	20																
570	25																
565	30																

Report: GEO_SOIL; File N:\PROJECTS\60428794_DYNEGY_CCR_RULEASMT\SUB_00\10.0_CALCULATIONS_ANALYSIS_DATA\SITE INVESTIGATION\COFFEEN\BORINGS\GINT TEMPLATE\DYNEGY_COFFEEN_2015.GPJ; 12/29/2015 5:44:22 PM

Project: Dynegy Project Location: COFFEEN POWER STATION, ILLINOIS Project Number: 60440742	Log of Piezometer Sheet 1 of 1

Piezometer Location	COF-P000	Date Installed	8/7/2015	Time	
Installed By		Observed By	AECOM	Total Depth	25 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	
Screened Interval	15-25 FT	Completion Zone	EMBANKMENT/FOUNDATION		
Remarks	OFFSET 5 FT SOUTH FROM COF-B001	Groundwater Level(s)	17.9 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

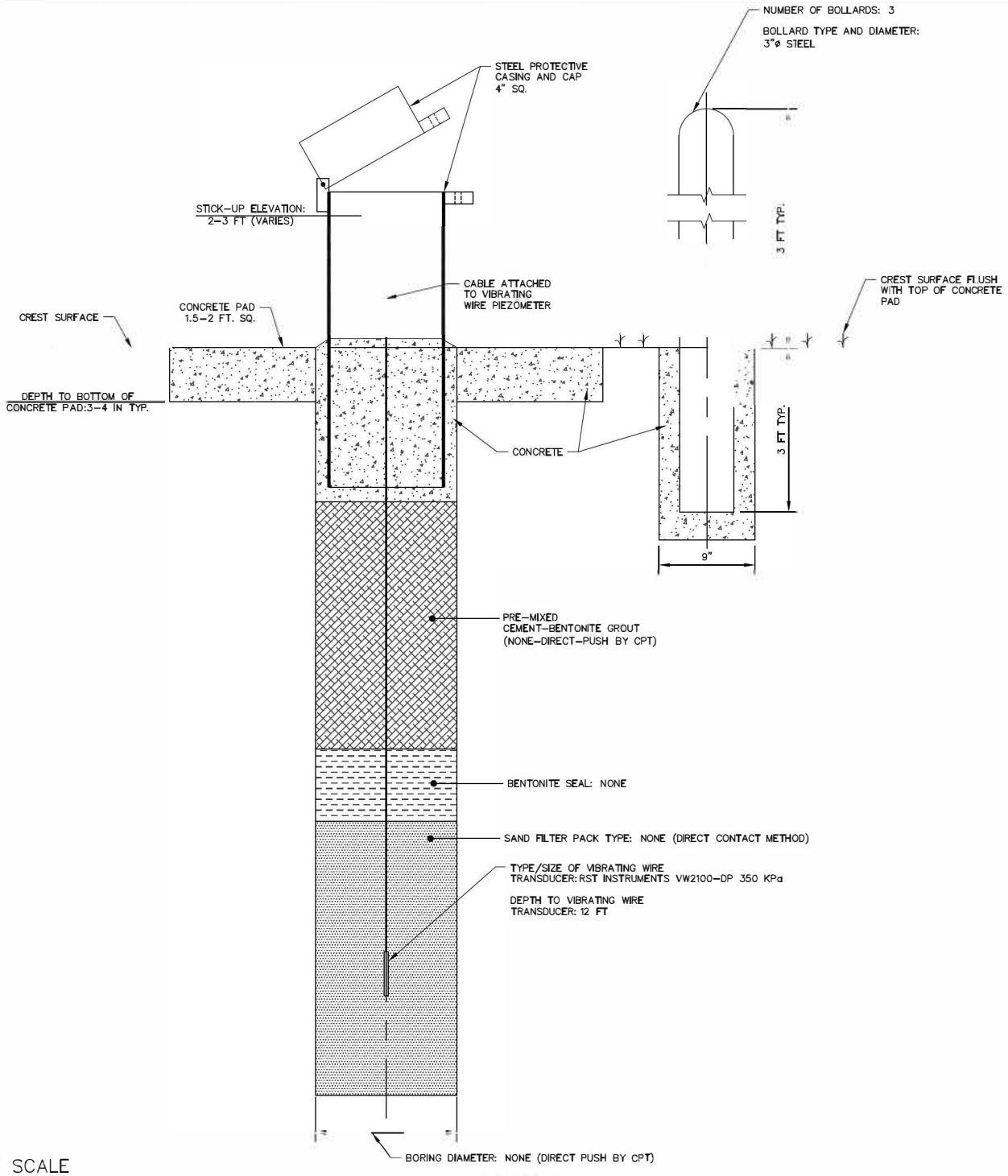
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P001	Date Installed	8/12/2015	Time	
Installed By		Observed By	AECOM	Total Depth	12 FT
Method of Installation	CPT - DIRECT PUSH	Drilling Contractor	CONETEC, INC.	Surface Elevation	615.6 FT
Screened Interval	N/A	Completion Zone	POND #1 FOUNDATION		
Remarks		Groundwater Level(s)	1.3 FT ON 8/29/2015		



NOT TO SCALE

NOT TO SCALE

Project: Dynegy

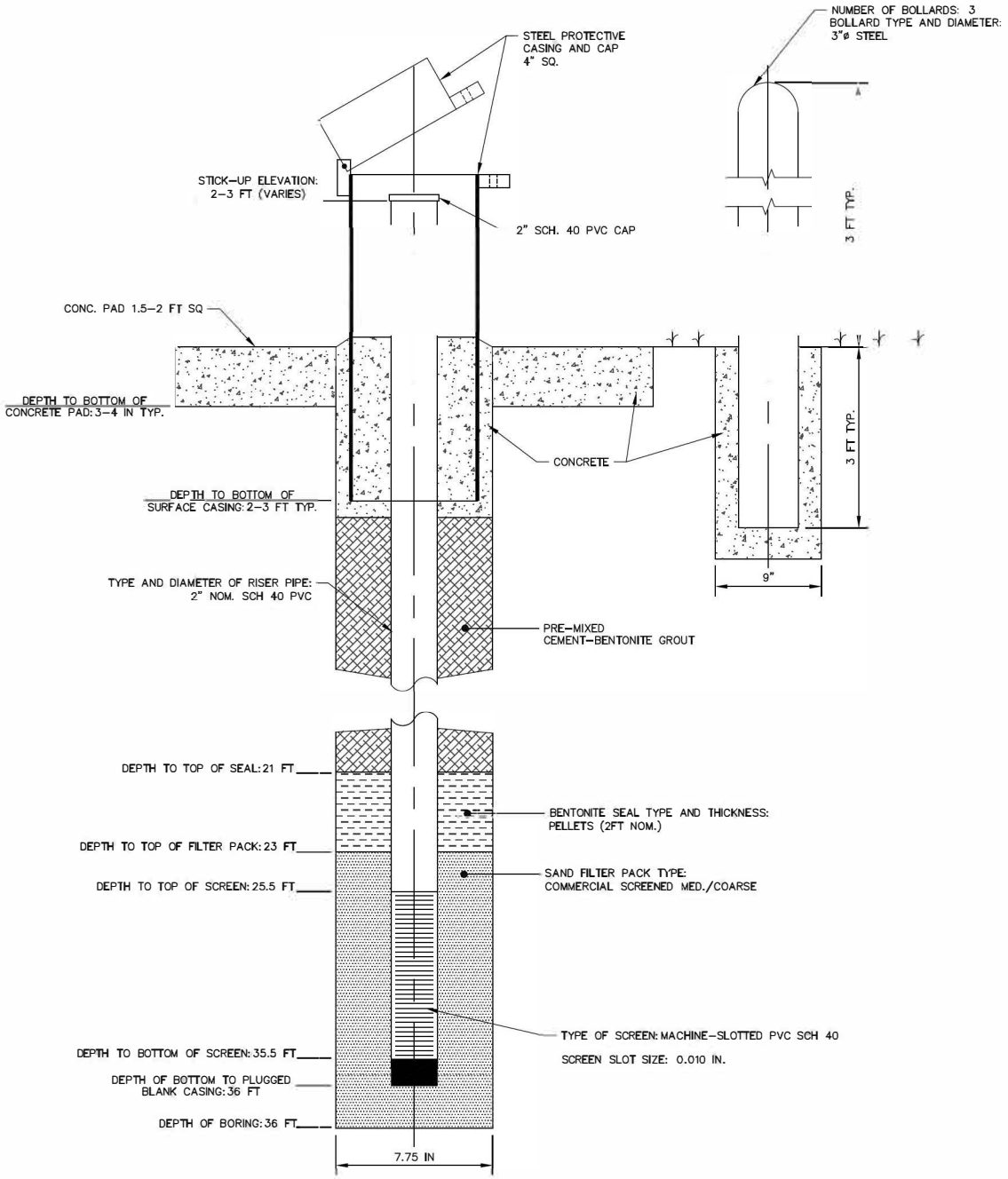
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P002	Date Installed	8/6/2015	Time	
Installed By		Observed By	AECOM	Total Depth	35.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.4 FT
Screened Interval	25.5-35.5 FT	Completion Zone	POND #1 FOUNDATION		
Remarks	INSTALL IN COF-B002	Groundwater Level(s)	10.5 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

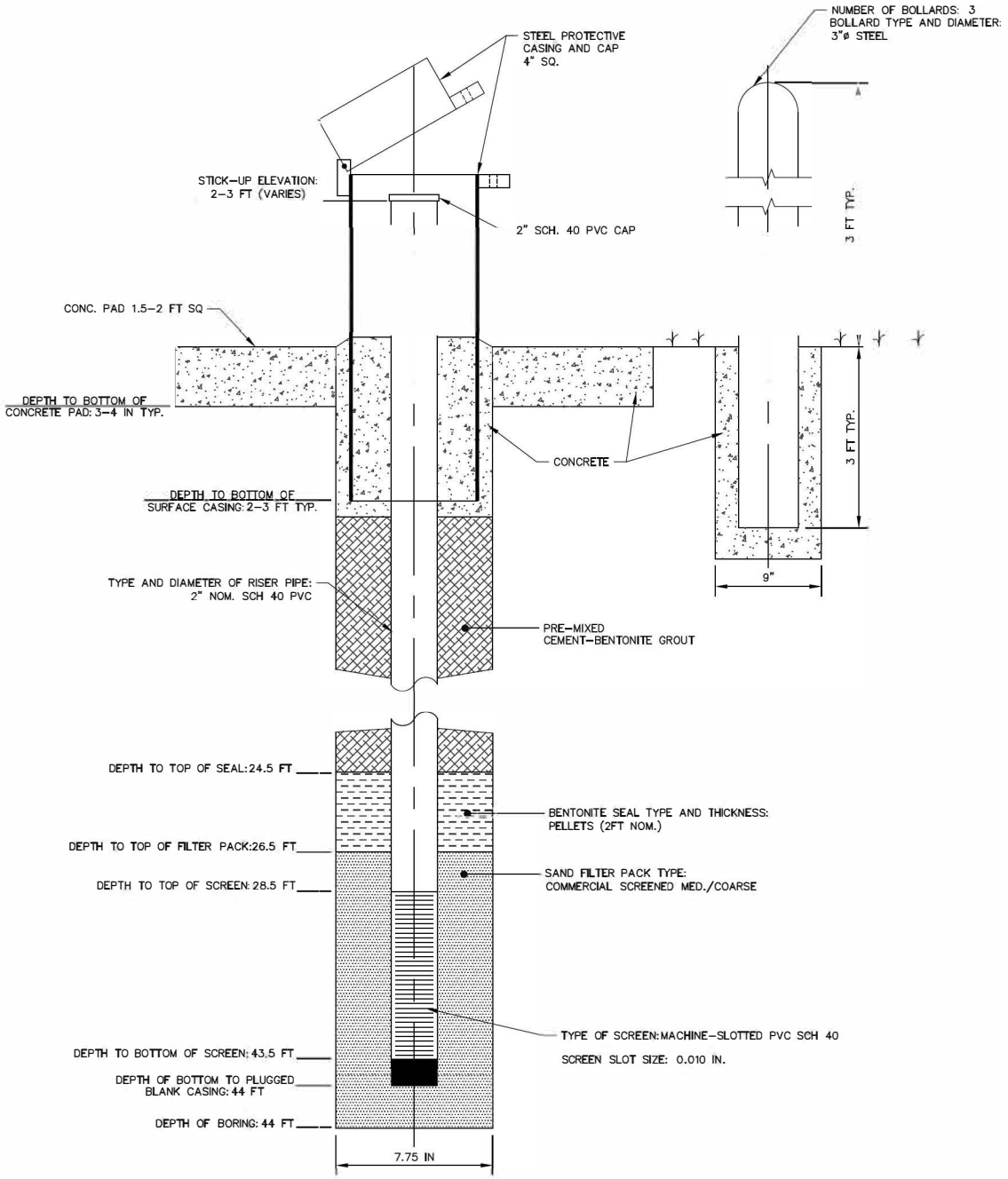
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P003	Date Installed	8/5/2015	Time	
Installed By		Observed By	AECOM	Total Depth	43.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.7 FT
Screened Interval	28.5-43.5 FT	Completion Zone	POND #1 FOUNDATION		
Remarks	INSTALL IN COF-B003	Groundwater Level(s)	15.3 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

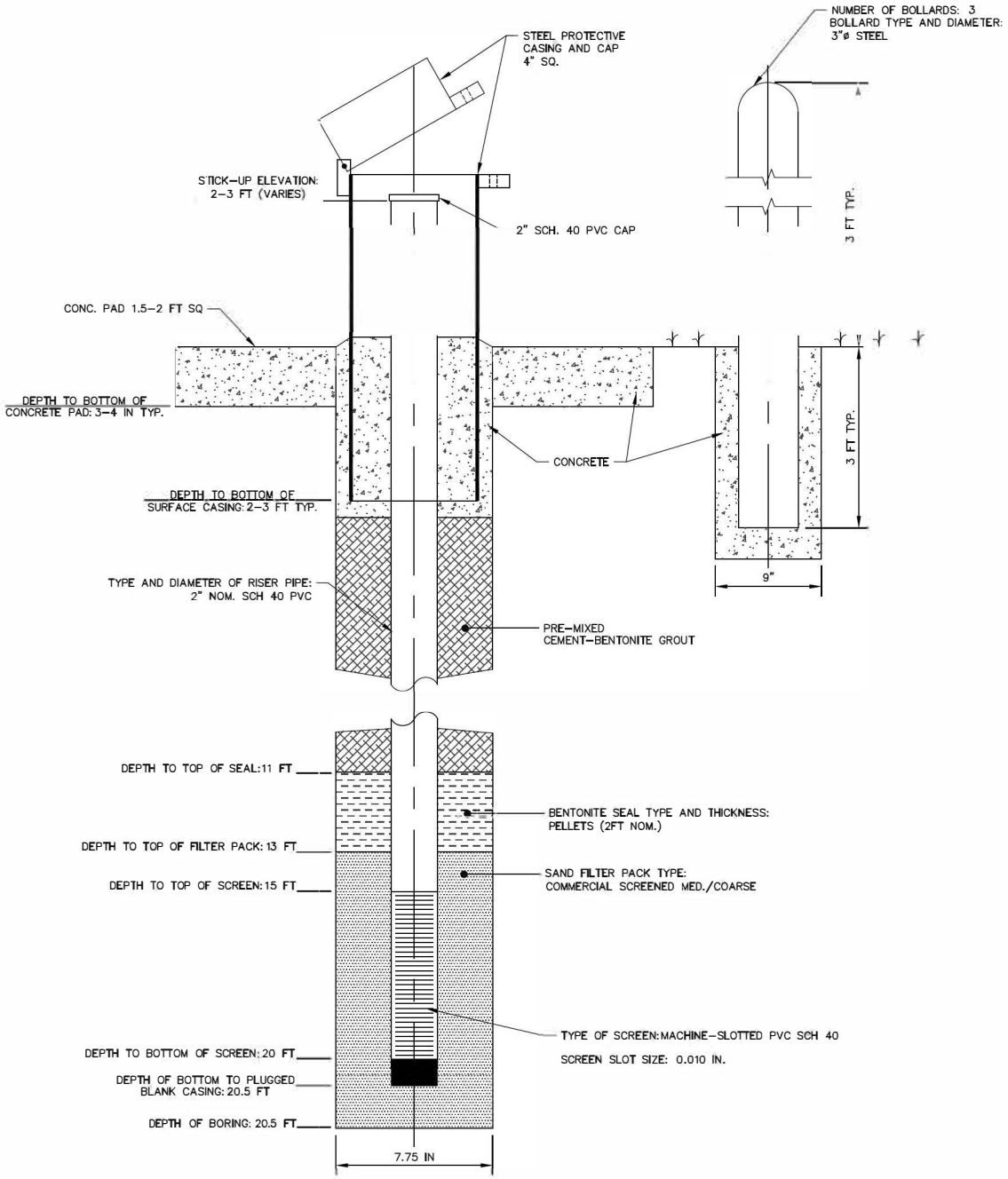
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P005	Date Installed	8/5/2015	Time	
Installed By		Observed By	AECOM	Total Depth	20 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.0 FT
Screened Interval	15-20 FT	Completion Zone	EMBANKMENT		
Remarks	OFFSET 5' WEST OF COF-B004	Groundwater Level(s)	14.4 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

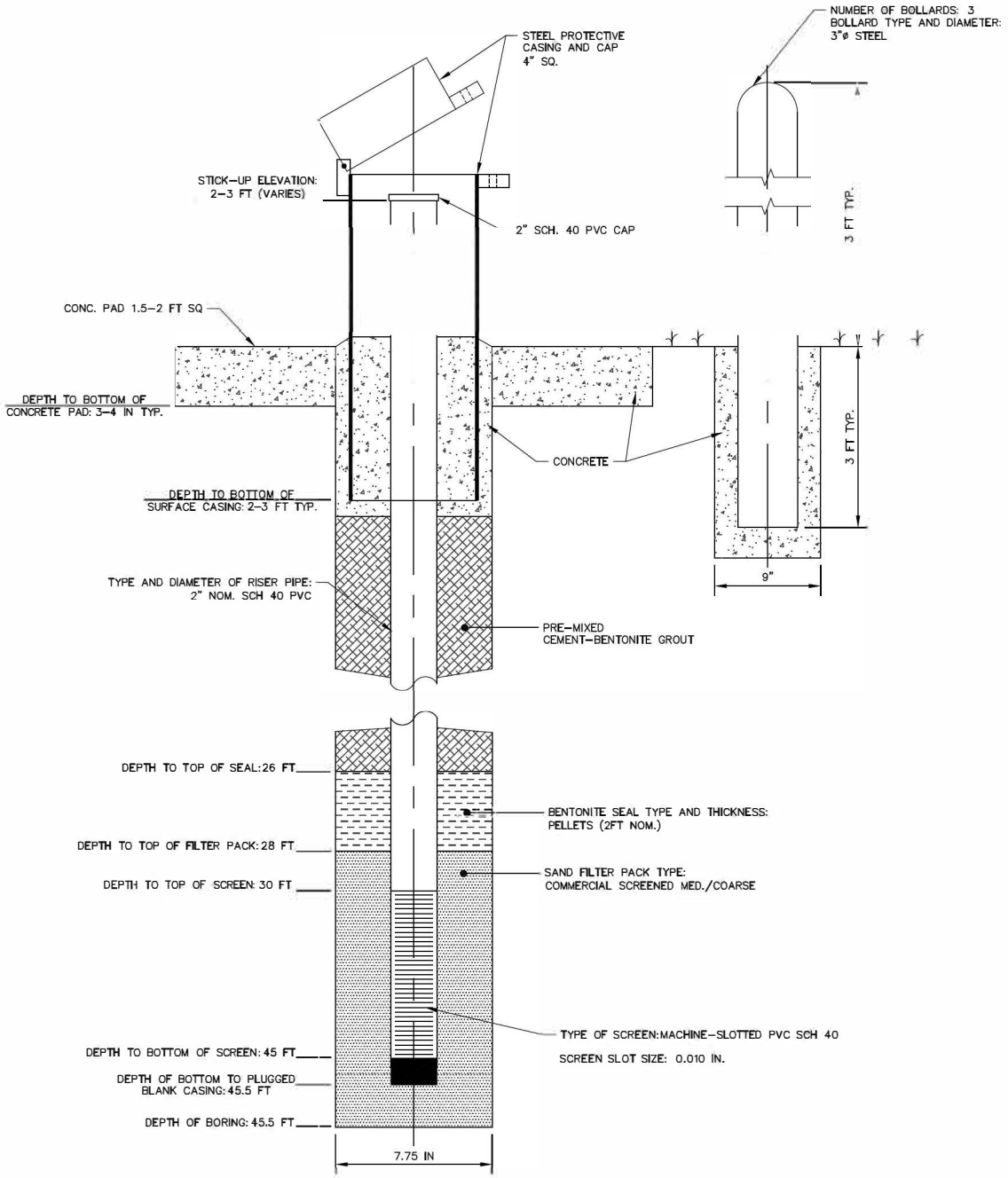
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P006	Date Installed	8/10/2015	Time	
Installed By		Observed By	AECOM	Total Depth	45 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.1 FT
Screened Interval	30-45 FT	Completion Zone	POND #1 FOUNDATION		
Remarks	OFFSET 5' SOUTH FROM COF-B005	Groundwater Level(s)	22.2 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

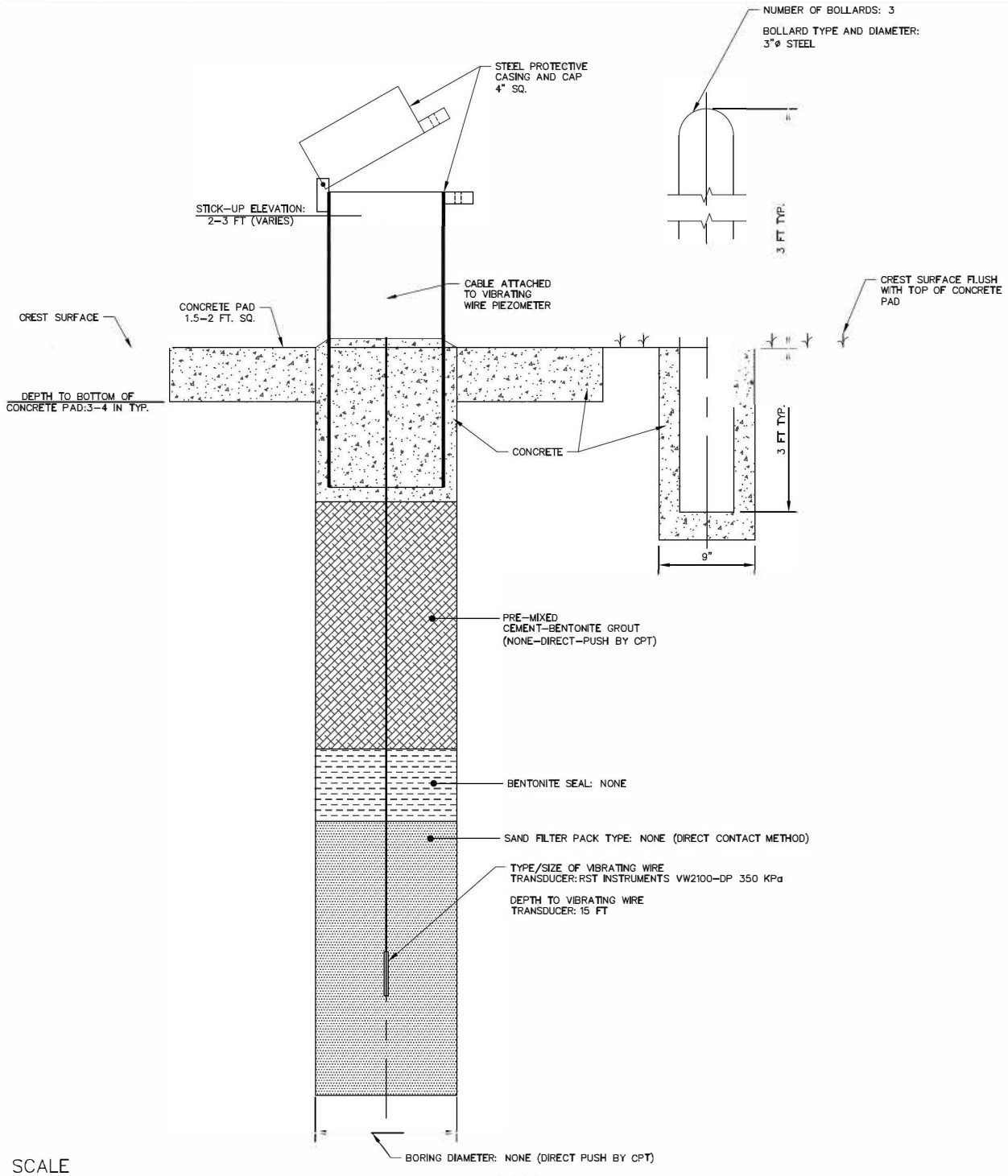
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P007	Date Installed	8/12/2015	Time	
Installed By		Observed By	AECOM	Total Depth	15 FT
Method of Installation	CPT - DIRECT PUSH	Drilling Contractor	CONETEC, INC.	Surface Elevation	617.5 FT
Screened Interval	N/A	Completion Zone	POND #1 FOUNDATION		
Remarks		Groundwater Level(s)	6.1 FT ON 8/29/2015		



NOT TO SCALE

NOT TO SCALE

Project: Dynegy

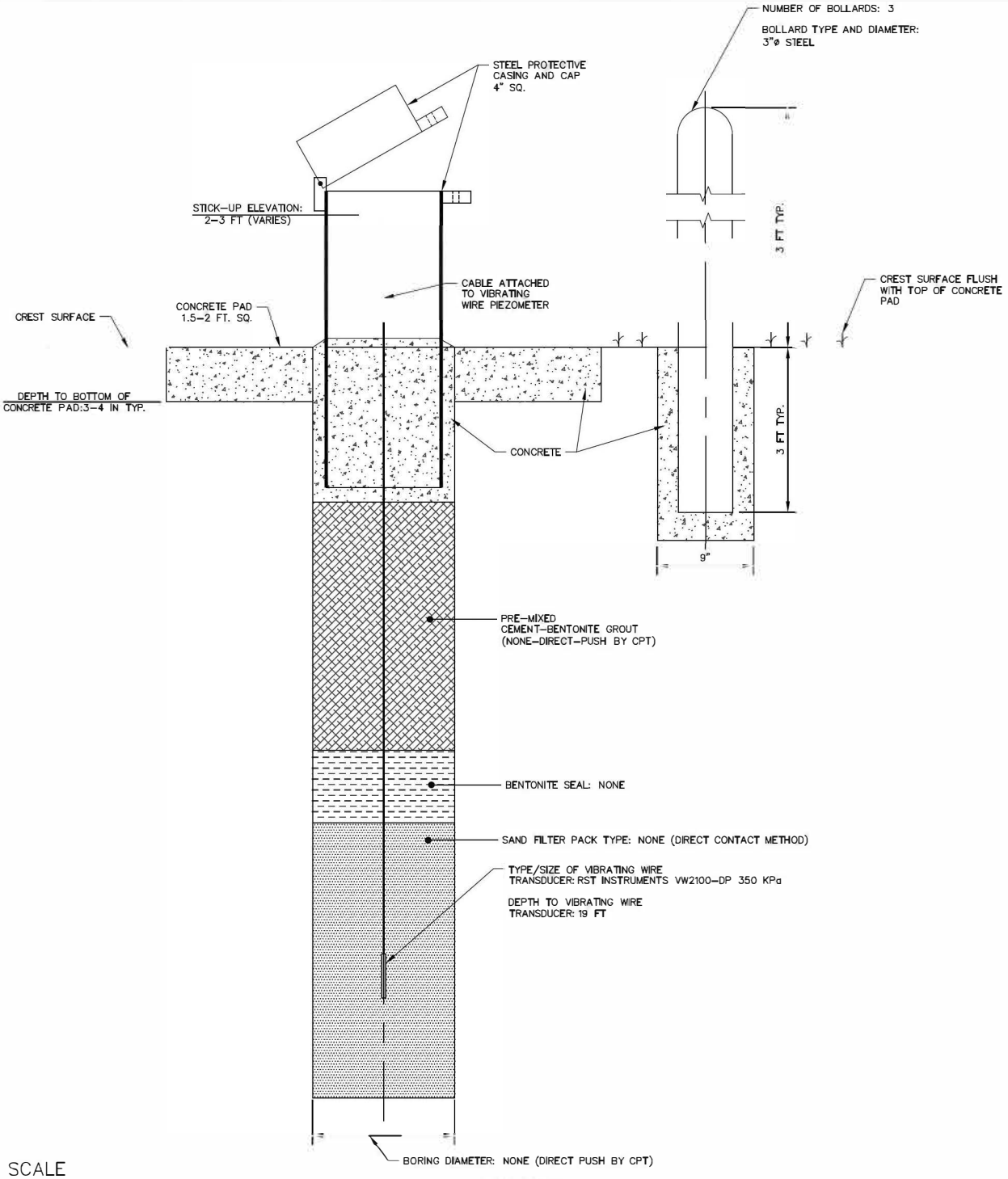
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P008	Date Installed	8/12/2015	Time	
Installed By		Observed By	AECOM	Total Depth	19 FT
Method of Installation	CPT - DIRECT PUSH	Drilling Contractor	CONETEC, INC.	Surface Elevation	625.1 FT
Screened Interval	N/A	Completion Zone	POND #1 FOUNDATION		
Remarks		Groundwater Level(s)	2.6 FT ON 8/29/2015		



NOT TO SCALE

NOT TO SCALE

Project: Dynegy

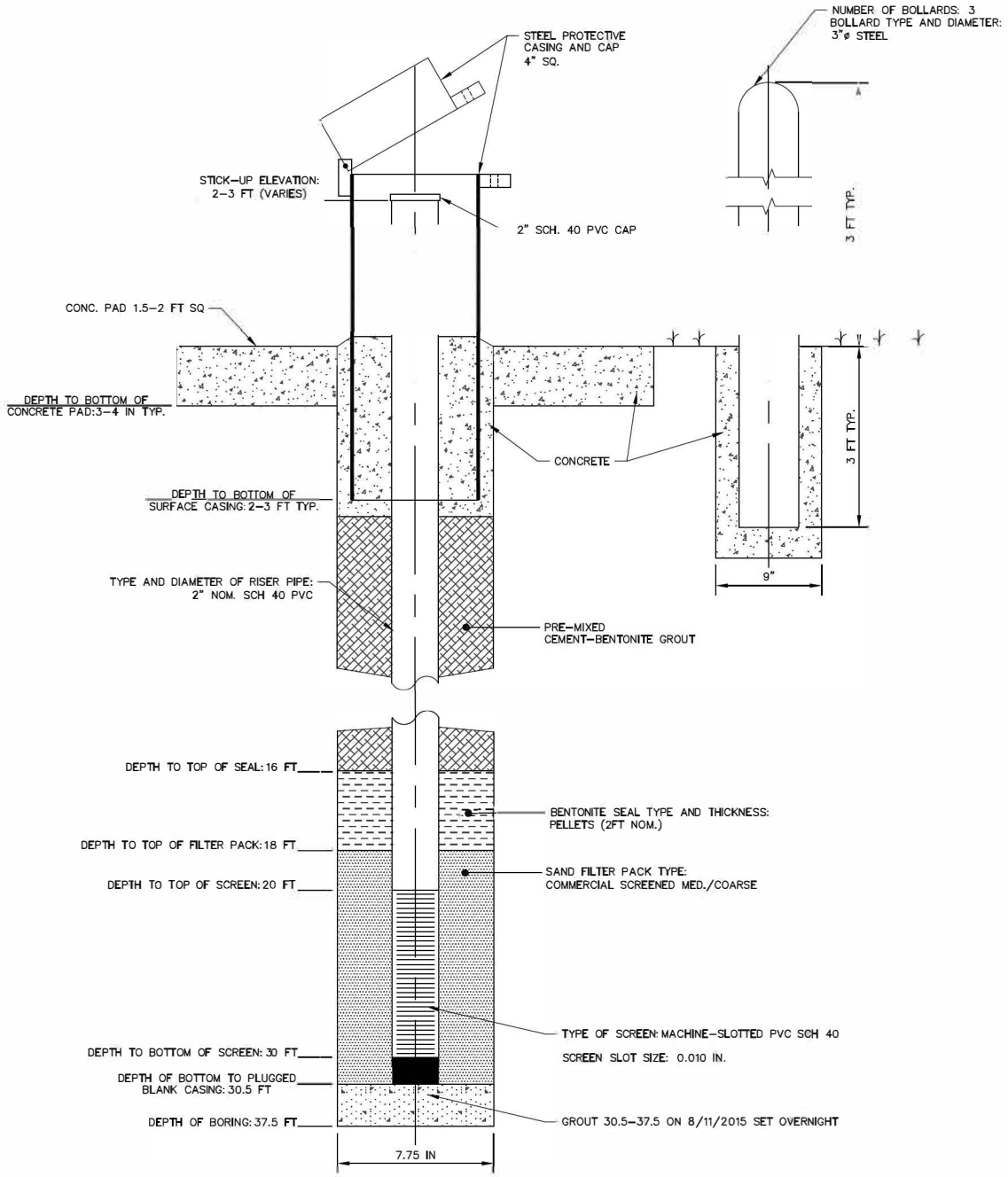
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P009	Date Installed	8/12/2015	Time	
Installed By		Observed By	AECOM	Total Depth	37.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	638.0 FT
Screened Interval	20-30 FT	Completion Zone	POND #2 FOUNDATION		
Remarks	INSTALL IN COF-B007	Groundwater Level(s)			



NOT TO SCALE

Project: Dynegy

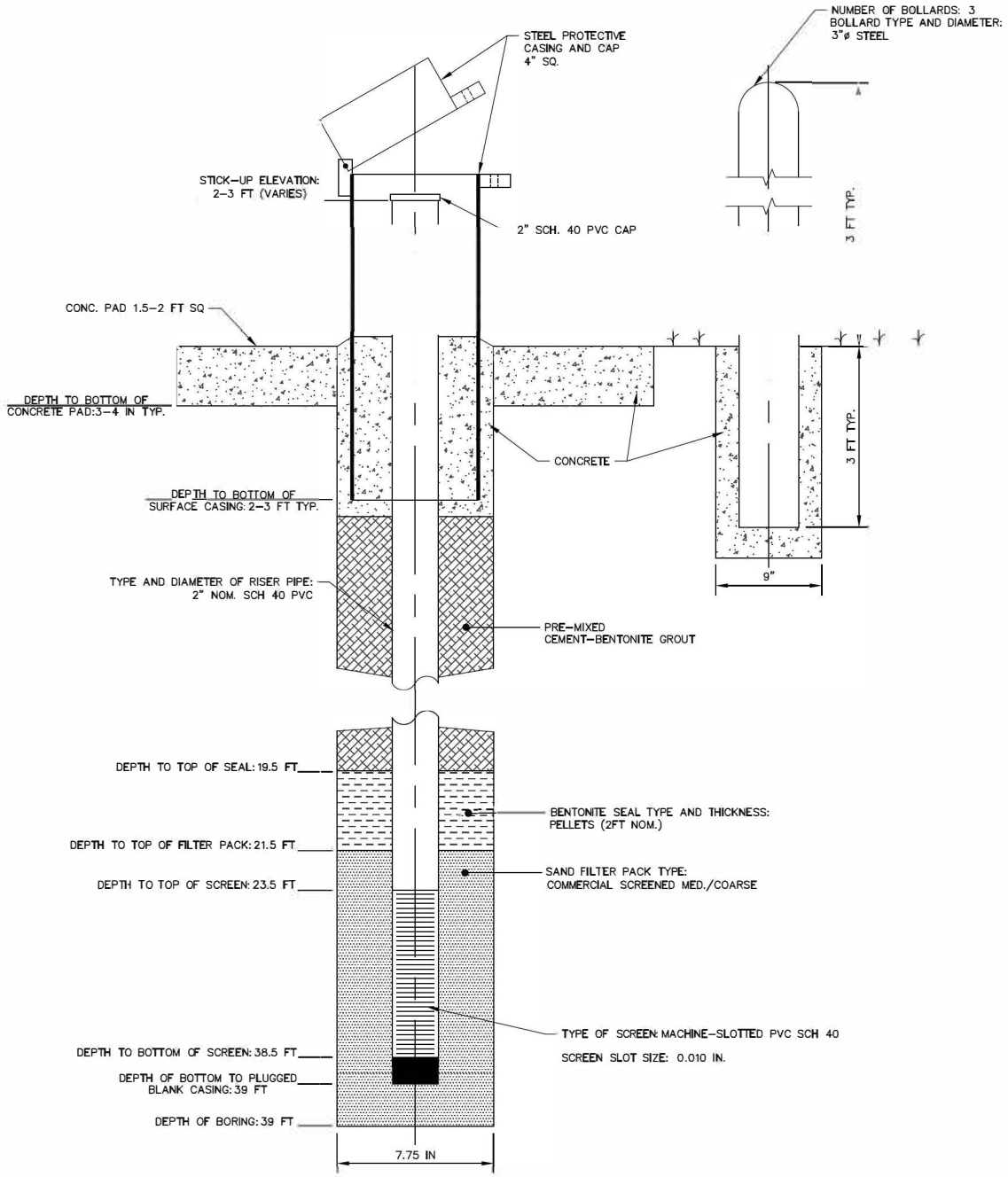
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P010	Date Installed	8/13/2015	Time	
Installed By		Observed By	AECOM	Total Depth	38.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.2 FT
Screened Interval	23.5-38.5 FT	Completion Zone	POND #2 FOUNDATION		
Remarks	INSTALL IN COF-B009	Groundwater Level(s)	29.6 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

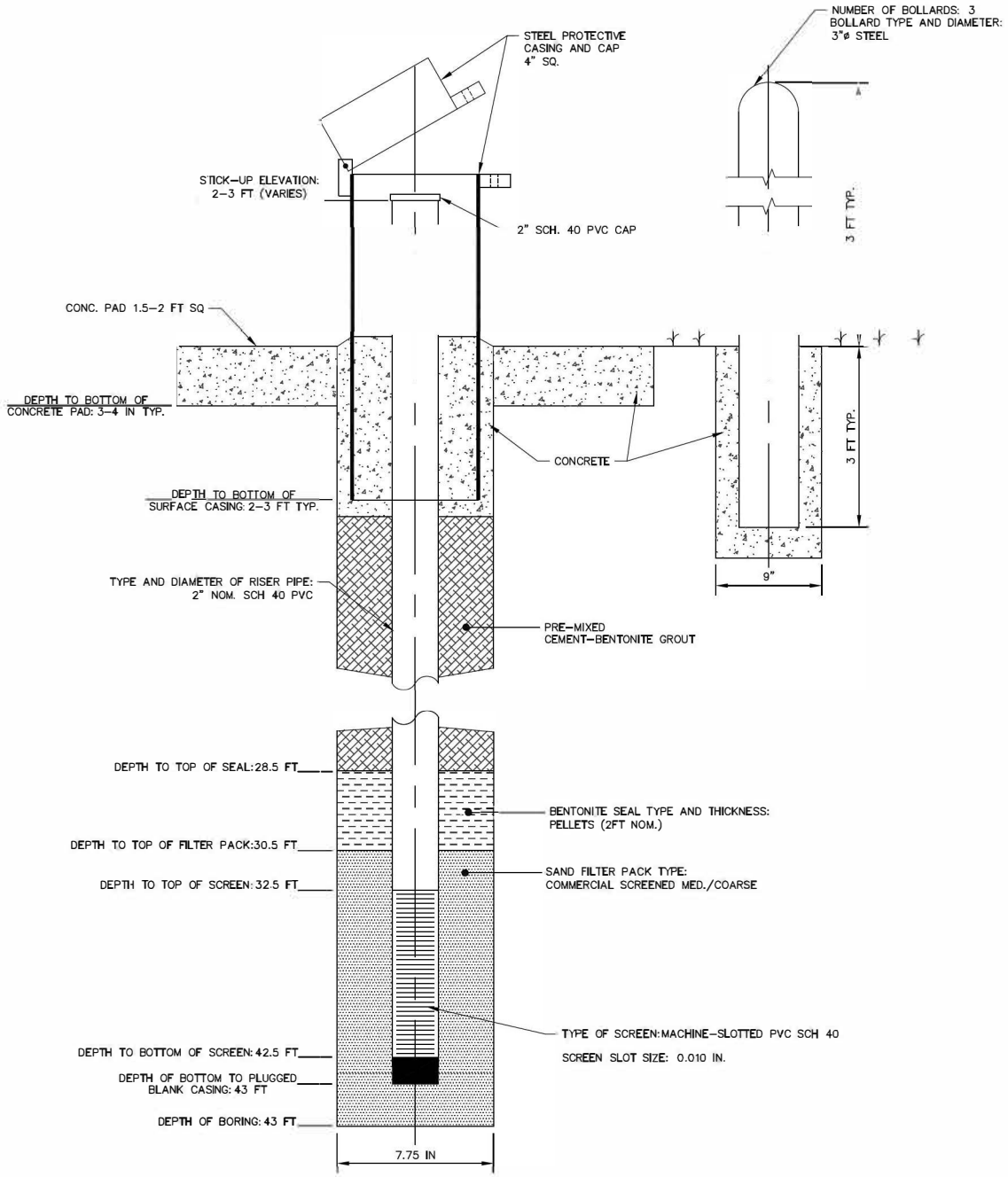
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P012	Date Installed	8/11/2015	Time	
Installed By		Observed By	AECOM	Total Depth	42.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	635.1 FT
Screened Interval	32.5-42.5 FT	Completion Zone	POND #2 FOUNDATION		
Remarks	INSTALL IN COF-B010	Groundwater Level(s)	16.8 FT ON 8/29/2015		



NOT TO SCALE

Project: Dynegy

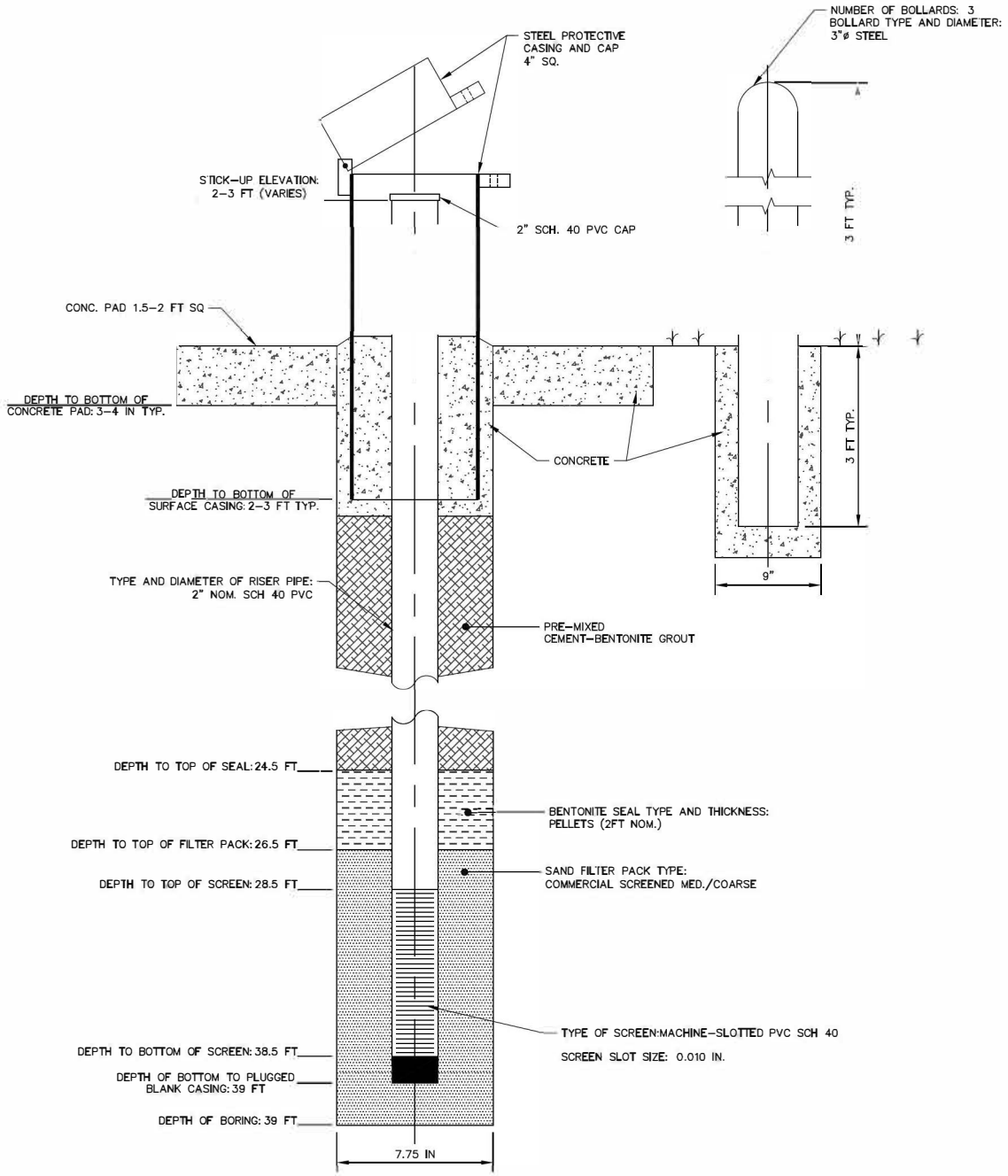
Project Location: COFFEEN POWER STATION, ILLINOIS

Project Number: 60440742

Log of Piezometer

Sheet 1 of 1

Piezometer Location	COF-P014	Date Installed	8/11/2015	Time	
Installed By		Observed By	AECOM	Total Depth	38.5 FT
Method of Installation	HOLLOW STEM AUGER	Drilling Contractor	GEOTECHNOLOGY, INC.	Surface Elevation	642.2 FT
Screened Interval	28.5-38.5 FT	Completion Zone	POND #2 FOUNDATION		
Remarks	INSTALL IN COF-B011	Groundwater Level(s)	21.5 FT ON 8/29/2015		



NOT TO SCALE

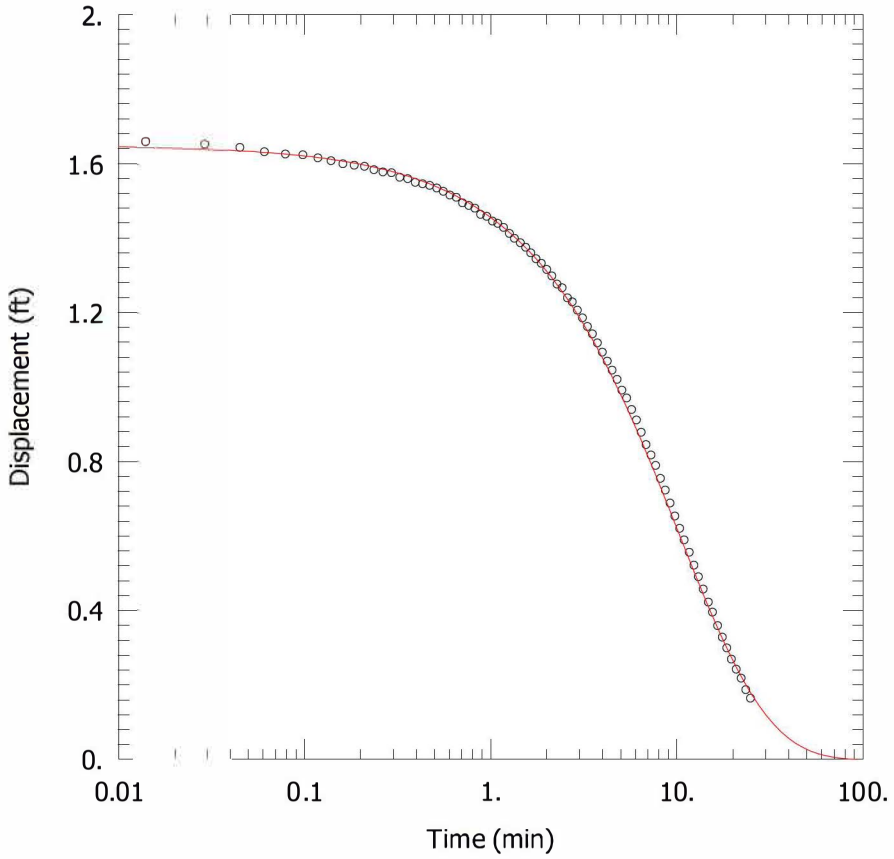
APPENDIX B

HYDRAULIC CONDUCTIVITY TEST RESULTS

APPENDIX B1

HYDRAULIC CONDUCTIVITY ANALYSES (WELLS)

R001277



G105 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G105
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00015 cm/sec
Ss = 6.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 14.82 ft

WELL DATA (G105)

Initial Displacement: 1.65 ft
Total Well Penetration Depth: 14.82 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.82 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001278

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G105fh.aqt
Title: G105 @ CCR Landfill – Falling Head Test
Date: 11/11/16
Time: 11:38:43

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G105

AQUIFER DATA

Saturated Thickness: 14.82 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G105

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.65 ft
Static Water Column Height: 14.82 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 14.82 ft

No. of Observations: 82

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.656	0.953	1.458	5.723	0.939
0.014	1.66	1.023	1.445	6.073	0.911
0.029	1.652	1.093	1.439	6.443	0.878
0.045	1.643	1.173	1.428	6.843	0.845
0.061	1.631	1.263	1.412	7.263	0.817
0.079	1.625	1.343	1.399	7.703	0.789
0.098	1.623	1.443	1.387	8.173	0.754
0.118	1.615	1.543	1.375	8.673	0.723
0.139	1.607	1.643	1.36	9.203	0.688
0.161	1.599	1.753	1.344	9.763	0.653
0.185	1.595	1.873	1.332	10.36	0.62
0.21	1.592	2.003	1.315	10.96	0.589
0.236	1.583	2.133	1.298	11.66	0.556

R0001279

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.264	1.577	2.273	1.276	12.36	0.521
0.294	1.575	2.423	1.266	13.06	0.49
0.325	1.563	2.583	1.239	13.86	0.457
0.359	1.559	2.743	1.228	14.76	0.422
0.394	1.549	2.923	1.206	15.56	0.395
0.431	1.545	3.113	1.185	16.56	0.359
0.471	1.541	3.313	1.162	17.56	0.328
0.513	1.534	3.523	1.142	18.56	0.299
0.557	1.525	3.743	1.118	19.66	0.269
0.604	1.515	3.983	1.093	20.86	0.242
0.654	1.509	4.233	1.069	22.16	0.218
0.707	1.494	4.493	1.045	23.46	0.187
0.763	1.487	4.773	1.02	24.86	0.164
0.823	1.48	5.073	0.991		
0.883	1.463	5.383	0.97		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00015	cm/sec
Ss	6.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.06776 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001464	1.653E-5	+/- 3.29E-5	8.858	cm/sec
Ss	5.669E-5	3.386E-5	+/- 6.739E-5	1.674	ft^{-1}
Kz/Kr	1.	1.041	+/- 2.071	0.961	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.06614 cm^2/sec

Parameter Correlations

R001280

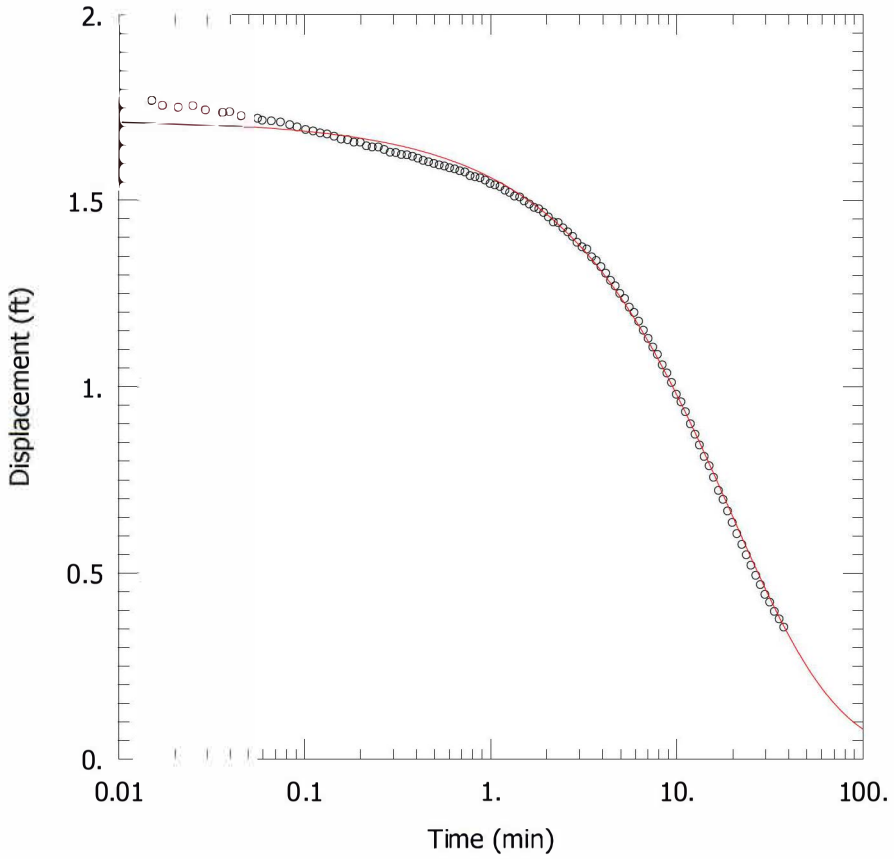
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.006265 ft^2
Variance . . . . . 7.93E-5 ft^2
Std. Deviation . . . . . 0.008905 ft
Mean. . . . . -0.002224 ft
No. of Residuals 82
No. of Estimates. 3

R001281



G105 @CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G105
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 5.7E-5 cm/sec
Ss = 0.001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 14.82 ft

WELL DATA (G105)

Initial Displacement: 1.72 ft
Total Well Penetration Depth: 14.82 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.82 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001282

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G105rh.aqt
Title: G105 @CCR Landfill – Rising Head Test
Date: 11/11/16
Time: 11:43:09

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G105

AQUIFER DATA

Saturated Thickness: 14.82 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G105

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.72 ft
Static Water Column Height: 14.82 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 14.82 ft

No. of Observations: 112

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.834	0.4953	1.6	4.943	1.251
0.004167	1.767	0.5293	1.596	5.243	1.237
0.008333	1.773	0.5643	1.593	5.553	1.214
0.01505	1.77	0.6013	1.588	5.893	1.2
0.01712	1.758	0.6413	1.585	6.243	1.176
0.02083	1.753	0.6833	1.58	6.613	1.152
0.025	1.757	0.7273	1.577	7.013	1.13
0.02917	1.746	0.7746	1.567	7.433	1.107
0.03612	1.738	0.8243	1.564	7.873	1.087
0.03933	1.74	0.8773	1.561	8.343	1.059
0.04537	1.729	0.9333	1.555	8.843	1.037
0.05595	1.721	0.9933	1.546	9.373	1.012
0.05933	1.716	1.053	1.542	9.933	0.98

R001283

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06633	1.714	1.123	1.538	10.53	0.96
0.07433	1.711	1.193	1.528	11.13	0.933
0.08333	1.704	1.263	1.522	11.83	0.901
0.09133	1.698	1.343	1.512	12.53	0.873
0.1013	1.691	1.433	1.51	13.23	0.844
0.1113	1.687	1.513	1.499	14.03	0.813
0.1213	1.682	1.613	1.491	14.93	0.788
0.1323	1.679	1.713	1.482	15.73	0.757
0.1443	1.673	1.813	1.478	16.73	0.722
0.1573	1.665	1.923	1.468	17.73	0.698
0.1703	1.664	2.043	1.456	18.73	0.667
0.1843	1.657	2.173	1.443	19.83	0.636
0.1993	1.657	2.303	1.441	21.03	0.606
0.2153	1.647	2.443	1.427	22.33	0.577
0.2313	1.644	2.593	1.416	23.63	0.549
0.2493	1.644	2.753	1.404	25.03	0.521
0.2683	1.637	2.913	1.388	26.53	0.494
0.2883	1.63	3.093	1.376	28.13	0.469
0.3093	1.629	3.283	1.37	29.73	0.443
0.3313	1.624	3.483	1.349	31.53	0.422
0.3553	1.623	3.693	1.339	33.43	0.397
0.3803	1.619	3.913	1.323	35.43	0.377
0.4063	1.614	4.153	1.305	37.53	0.355
0.4343	1.608	4.403	1.286		
0.4643	1.604	4.663	1.271		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

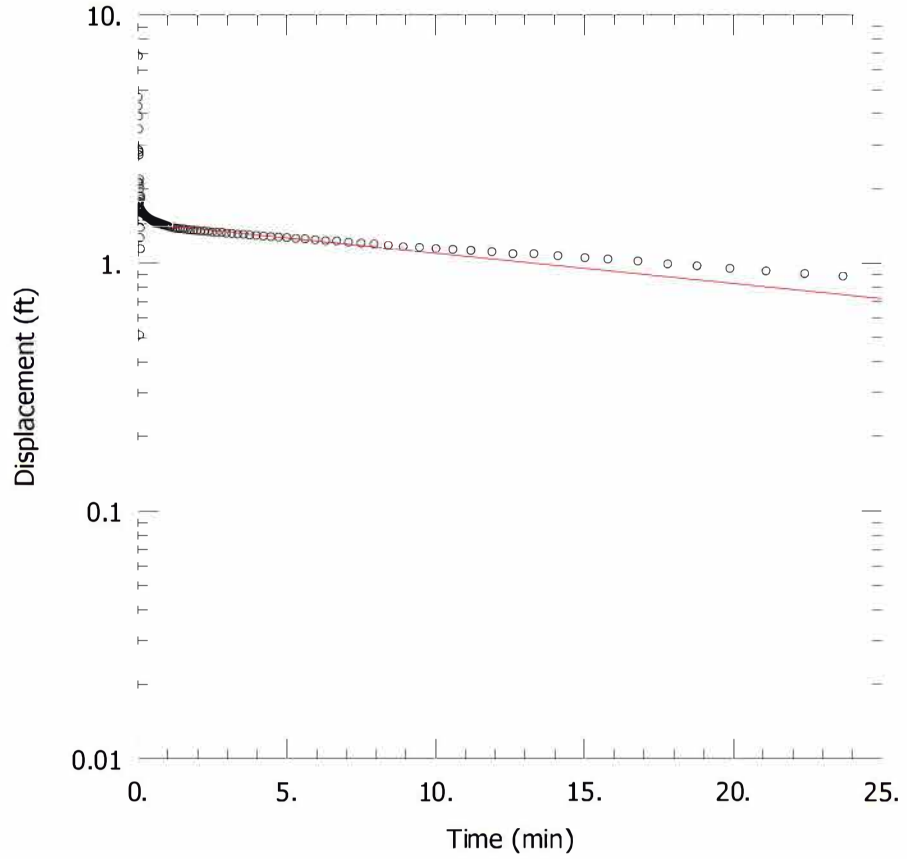
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	5.7E-5	cm/sec
Ss	0.001	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02575 cm^2/sec

R001284



G106 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G106
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 4.0E-5 cm/sec
y0 = 1.45 ft

AQUIFER DATA

Saturated Thickness: 12.5 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G106)

Initial Displacement: 1.67 ft
Total Well Penetration Depth: 12.5 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.5 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001285

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G106fh.aqt
Title: G106 @ CCR Landfill – Falling Head Test
Date: 12/01/16
Time: 09:04:15

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G106

AQUIFER DATA

Saturated Thickness: 12.5 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G106

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.67 ft
Static Water Column Height: 12.5 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 12.5 ft

No. of Observations: 121

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.00455	4.279	0.282	1.547	2.98	1.317
0.008333	6.825	0.298	1.542	3.16	1.316
0.0125	4.654	0.316	1.537	3.35	1.306
0.01667	2.121	0.335	1.534	3.55	1.303
0.02083	2.856	0.355	1.527	3.76	1.294
0.025	3.905	0.376	1.518	3.98	1.29
0.02917	3.468	0.398	1.516	4.22	1.283
0.03745	2.726	0.422	1.505	4.47	1.274
0.04113	2.798	0.447	1.499	4.73	1.271
0.0448	1.772	0.473	1.496	5.01	1.263
0.04847	0.514	0.501	1.487	5.31	1.257
0.05212	1.755	0.531	1.477	5.62	1.25
0.0603	2.176	0.562	1.474	5.96	1.24

R001286

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06397	2.082	0.596	1.444	6.31	1.229
0.06767	1.996	0.631	1.461	6.68	1.226
0.07133	1.85	0.668	1.451	7.08	1.213
0.075	1.264	0.708	1.444	7.5	1.202
0.07865	1.141	0.75	1.44	7.94	1.191
0.08232	1.388	0.794	1.432	8.41	1.183
0.08598	1.706	0.841	1.421	8.91	1.168
0.08965	1.859	0.891	1.42	9.44	1.159
0.09332	1.805	0.944	1.414	10.	1.148
0.09697	1.651	1.	1.408	10.6	1.137
0.1006	1.533	1.06	1.399	11.2	1.127
0.106	1.534	1.12	1.396	11.9	1.11
0.112	1.644	1.19	1.386	12.6	1.095
0.1208	1.639	1.26	1.382	13.3	1.085
0.126	1.59	1.33	1.378	14.1	1.068
0.133	1.594	1.41	1.374	15.	1.048
0.141	1.623	1.5	1.371	15.8	1.031
0.15	1.59	1.58	1.367	16.8	1.013
0.158	1.592	1.68	1.362	17.8	0.992
0.168	1.594	1.78	1.358	18.8	0.976
0.178	1.583	1.88	1.353	19.9	0.953
0.188	1.584	1.99	1.351	21.1	0.929
0.199	1.58	2.11	1.344	22.4	0.909
0.211	1.573	2.24	1.343	23.7	0.884
0.224	1.569	2.37	1.337	25.1	0.858
0.237	1.565	2.51	1.332	26.6	0.833
0.251	1.56	2.66	1.328		
0.266	1.552	2.82	1.327		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 3.694

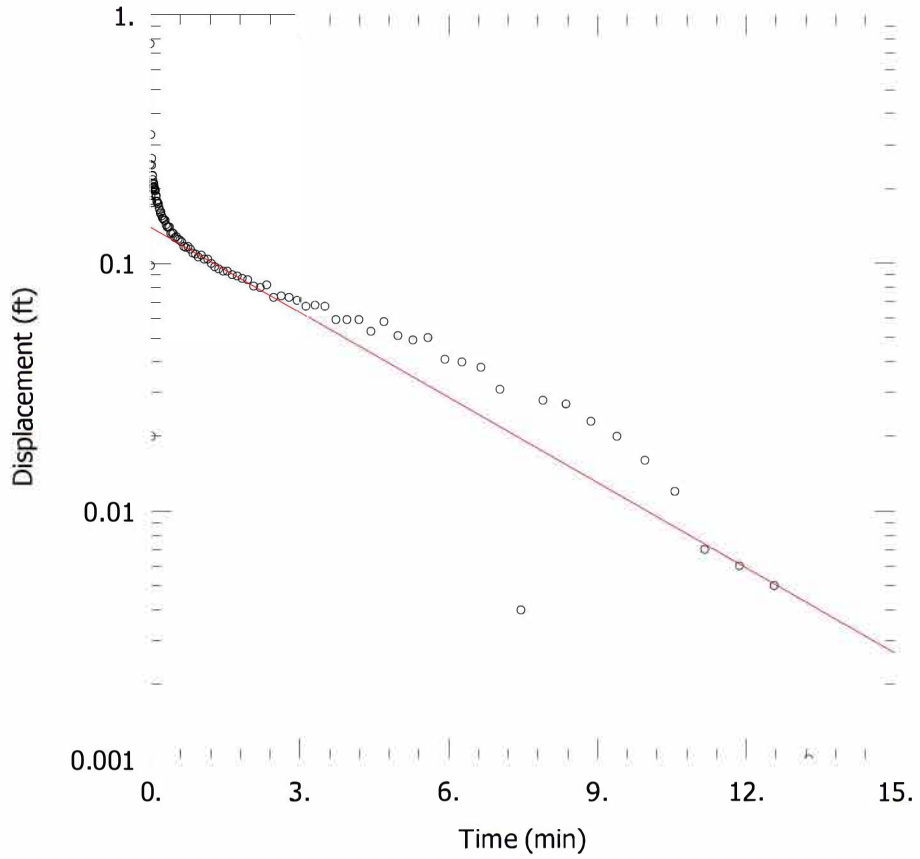
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	4.0E-5	cm/sec
y0	1.45	ft

T = K*b = 0.01524 cm²/sec

R001287



G106 @CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G106
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.00074 cm/sec
y0 = 0.14 ft

AQUIFER DATA

Saturated Thickness: 12.5 ft

Anisotropy Ratio (Kz/Kr): 0.001

WELL DATA (G106)

Initial Displacement: 0.25 ft
Total Well Penetration Depth: 12.5 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.5 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001288

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G106rh.aqt
Title: G106 @CCR Landfill – Rising Head Test
Date: 11/18/16
Time: 11:53:58

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G106

AQUIFER DATA

Saturated Thickness: 12.5 ft
Anisotropy Ratio (Kz/Kr): 0.001

SLUG TEST WELL DATA

Test Well: G106

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.25 ft
Static Water Column Height: 12.5 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 12.5 ft

No. of Observations: 102

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	0.763	0.2487	0.152	1.957	0.086
0.00785	0.098	0.2647	0.151	2.077	0.081
0.01152	0.02	0.2827	0.149	2.207	0.08
0.0152	0.329	0.3017	0.149	2.337	0.082
0.01887	0.187	0.3217	0.143	2.477	0.073
0.02662	0.179	0.3427	0.14	2.627	0.074
0.03028	0.248	0.3647	0.14	2.787	0.073
0.03395	0.264	0.3887	0.14	2.947	0.071
0.03762	0.175	0.4137	0.132	3.127	0.067
0.04558	0.225	0.4397	0.133	3.317	0.068
0.04927	0.226	0.4677	0.132	3.517	0.067
0.05293	0.217	0.4977	0.127	3.727	0.059
0.05662	0.202	0.5287	0.128	3.947	0.059

R001289

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06387	0.2	0.5627	0.125	4.187	0.059
0.06753	0.21	0.5977	0.124	4.437	0.053
0.07125	0.21	0.6347	0.122	4.697	0.058
0.07532	0.208	0.6747	0.117	4.977	0.051
0.079	0.204	0.7167	0.116	5.277	0.049
0.08268	0.202	0.7607	0.117	5.587	0.05
0.08637	0.196	0.8077	0.114	5.927	0.041
0.09267	0.198	0.8577	0.11	6.277	0.04
0.09967	0.199	0.9107	0.109	6.647	0.038
0.1077	0.196	0.9667	0.106	7.047	0.031
0.1167	0.186	1.027	0.108	7.467	0.004
0.1247	0.187	1.087	0.104	7.907	0.028
0.1347	0.178	1.157	0.104	8.377	0.027
0.1447	0.177	1.227	0.1	8.877	0.023
0.1547	0.174	1.297	0.097	9.407	0.02
0.1657	0.174	1.377	0.095	9.967	0.016
0.1777	0.168	1.467	0.093	10.57	0.012
0.1907	0.164	1.547	0.093	11.17	0.007
0.2037	0.159	1.647	0.09	11.87	0.006
0.2177	0.161	1.747	0.089	12.57	0.005
0.2327	0.155	1.847	0.087	13.27	0.001

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 7.28

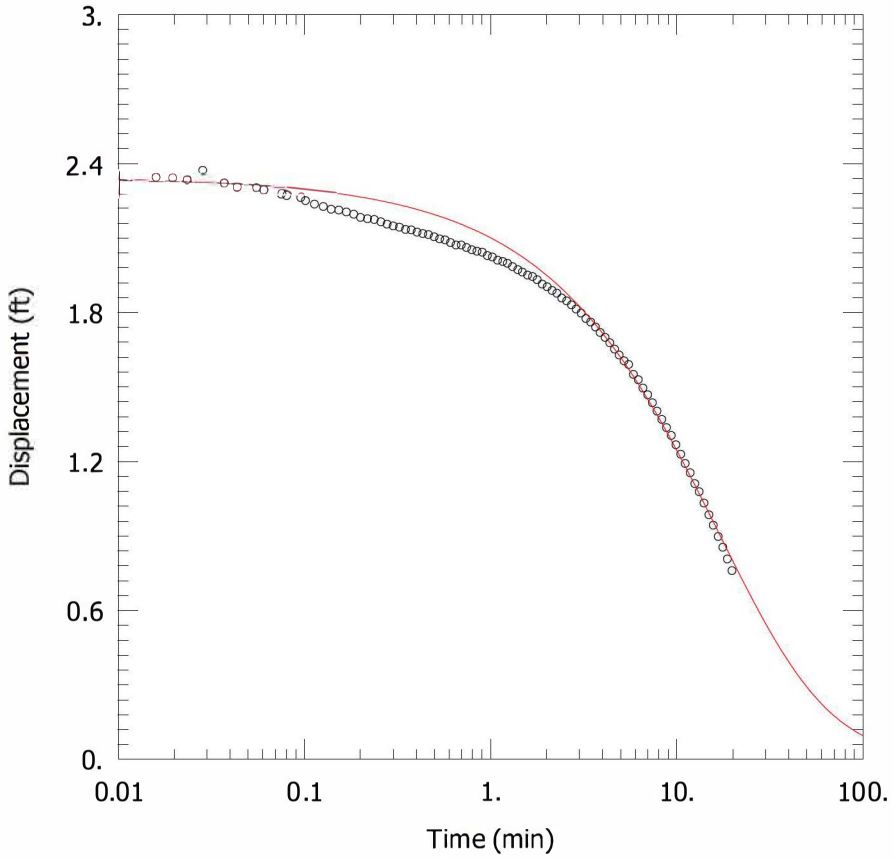
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00074	cm/sec
y0	0.14	ft

$T = K*b = 0.2819$ cm²/sec

R001290



G107 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G107
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 6.3E-5 cm/sec
Ss = 0.0015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.86 ft

WELL DATA (G107)

Initial Displacement: 2.35 ft
Total Well Penetration Depth: 10.86 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.86 ft
Screen Length: 4.48 ft
Well Radius: 0.08333 ft

R001291

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G107fh.aqt
Title: G107 @ CCR Landfill – Falling Head Test
Date: 11/28/16
Time: 10:25:40

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G107

AQUIFER DATA

Saturated Thickness: 10.86 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G107

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.35 ft
Static Water Column Height: 10.86 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.48 ft
Total Well Penetration Depth: 10.86 ft

No. of Observations: 103

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.03917	2.789	0.3245	2.143	3.063	1.797
-0.035	2.535	0.3495	2.134	3.252	1.775
-0.03078	2.269	0.3755	2.132	3.453	1.761
-0.02297	2.403	0.4035	2.123	3.663	1.741
-0.01928	2.442	0.4335	2.117	3.882	1.719
-0.01558	2.401	0.4645	2.113	4.122	1.699
-0.0119	2.368	0.4985	2.104	4.372	1.678
-0.003683	2.371	0.5335	2.096	4.633	1.652
0.	2.38	0.5705	2.092	4.912	1.628
0.003683	2.362	0.6105	2.081	5.213	1.605
0.00735	2.355	0.6525	2.071	5.523	1.59
0.01582	2.349	0.6965	2.071	5.862	1.55
0.01953	2.344	0.7435	2.061	6.213	1.529

R001292

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.02323	2.335	0.7935	2.052	6.582	1.495
0.0285	2.372	0.8465	2.046	6.982	1.468
0.03668	2.321	0.9025	2.042	7.402	1.436
0.0435	2.304	0.9625	2.029	7.843	1.402
0.05523	2.301	1.023	2.023	8.313	1.369
0.0605	2.292	1.093	2.01	8.813	1.336
0.07527	2.276	1.163	2.005	9.342	1.304
0.0805	2.27	1.232	1.998	9.902	1.267
0.09568	2.262	1.313	1.984	10.5	1.229
0.1015	2.25	1.403	1.972	11.1	1.191
0.1135	2.236	1.482	1.962	11.8	1.154
0.1265	2.226	1.583	1.95	12.5	1.11
0.1395	2.215	1.683	1.944	13.2	1.078
0.1535	2.212	1.783	1.931	14.	1.032
0.1685	2.204	1.893	1.914	14.9	0.985
0.1845	2.195	2.013	1.903	15.7	0.943
0.2005	2.182	2.143	1.888	16.7	0.897
0.2185	2.177	2.273	1.877	17.7	0.854
0.2375	2.174	2.413	1.858	18.7	0.807
0.2575	2.165	2.563	1.846	19.8	0.76
0.2785	2.155	2.723	1.83		
0.3005	2.148	2.882	1.813		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	6.3E-5	cm/sec
Ss	0.0015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02085 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	4.079E-5	3.684E-6	+/- 7.31E-6	11.07	cm/sec
Ss	0.008117	0.001889	+/- 0.003747	4.297	ft^{-1}
Kz/Kr	1.	1.82	+/- 3.611	0.5494	

C.I. is approximate 95% confidence interval for parameter

R001293

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.0135 cm²/sec

Parameter Correlations

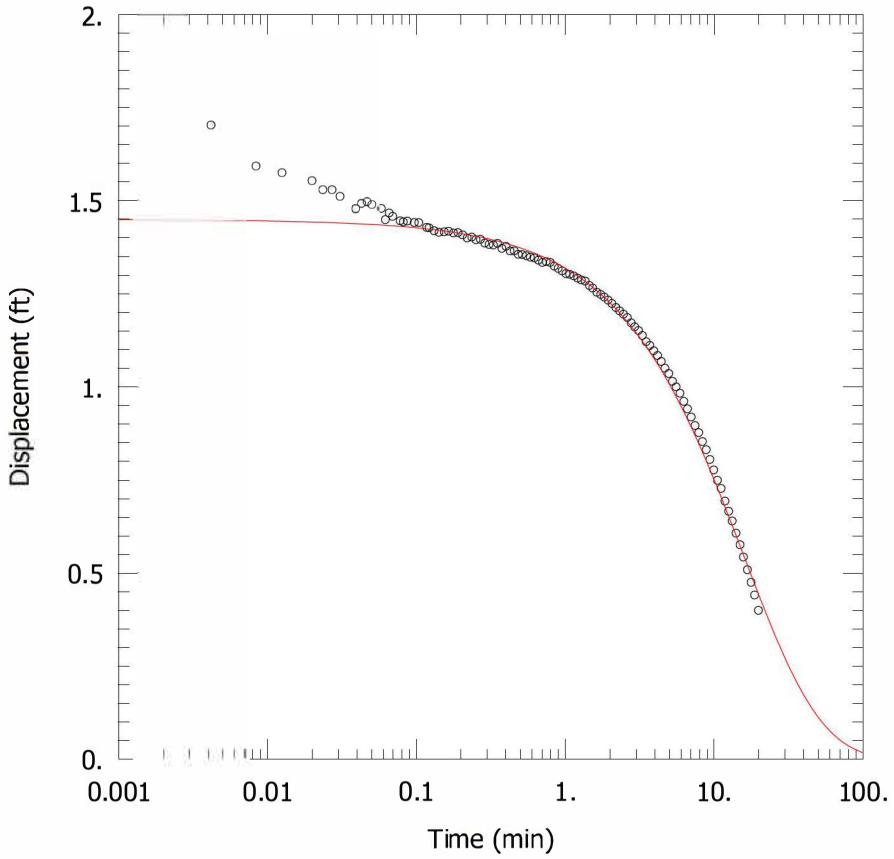
	Kr	Ss	Kz/Kr
Kr	1.00	-0.96	-0.37
Ss	-0.96	1.00	0.19
Kz/Kr	-0.37	0.19	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.3683 ft^2
Variance . . . . . 0.003683 ft^2
Std. Deviation . . . . . 0.06069 ft
Mean. . . . . 0.002549 ft
No. of Residuals 103
No. of Estimates. 3

R001294



G107 @CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G107
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 8.9E-5 cm/sec
Ss = 0.0002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.86 ft

WELL DATA (G107)

Initial Displacement: 1.45 ft
Total Well Penetration Depth: 10.86 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.86 ft
Screen Length: 4.48 ft
Well Radius: 0.08333 ft

R001295

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G107rh.aqt
Title: G107 @CCR Landfill – Rising Head Test
Date: 11/18/16
Time: 11:55:10

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G107

AQUIFER DATA

Saturated Thickness: 10.86 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G107

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.45 ft
Static Water Column Height: 10.86 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.48 ft
Total Well Penetration Depth: 10.86 ft

No. of Observations: 106

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.826	0.3302	1.381	2.934	1.161
0.004167	1.704	0.3522	1.385	3.114	1.151
0.008333	1.594	0.3762	1.372	3.304	1.138
0.0125	1.576	0.4012	1.377	3.504	1.121
0.01975	1.555	0.4272	1.365	3.714	1.111
0.02345	1.531	0.4552	1.365	3.934	1.097
0.02713	1.53	0.4852	1.356	4.174	1.084
0.0308	1.513	0.5162	1.355	4.424	1.068
0.03893	1.479	0.5502	1.352	4.684	1.05
0.04263	1.493	0.5852	1.348	4.964	1.036
0.04632	1.498	0.6222	1.346	5.264	1.015
0.04998	1.49	0.6622	1.34	5.574	1.
0.05843	1.479	0.7042	1.334	5.914	0.983

R001296

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06212	1.449	0.7482	1.336	6.264	0.961
0.06582	1.467	0.7952	1.334	6.634	0.941
0.06952	1.458	0.8452	1.324	7.034	0.919
0.07817	1.446	0.8982	1.318	7.454	0.896
0.08188	1.443	0.9542	1.311	7.894	0.877
0.08717	1.445	1.014	1.304	8.364	0.853
0.09723	1.441	1.074	1.302	8.864	0.831
0.1042	1.441	1.144	1.298	9.394	0.805
0.1175	1.428	1.214	1.292	9.954	0.777
0.1222	1.427	1.284	1.287	10.55	0.749
0.1322	1.419	1.364	1.284	11.15	0.727
0.1422	1.415	1.454	1.272	11.85	0.693
0.1544	1.416	1.534	1.265	12.55	0.666
0.1652	1.418	1.634	1.254	13.25	0.64
0.1782	1.413	1.734	1.248	14.05	0.607
0.1912	1.414	1.834	1.241	14.95	0.576
0.2052	1.408	1.944	1.233	15.75	0.543
0.2202	1.4	2.064	1.224	16.75	0.509
0.2362	1.402	2.194	1.213	17.75	0.475
0.2522	1.395	2.324	1.204	18.75	0.441
0.2702	1.396	2.464	1.195	19.85	0.4
0.2892	1.386	2.614	1.186		
0.3092	1.382	2.774	1.172		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

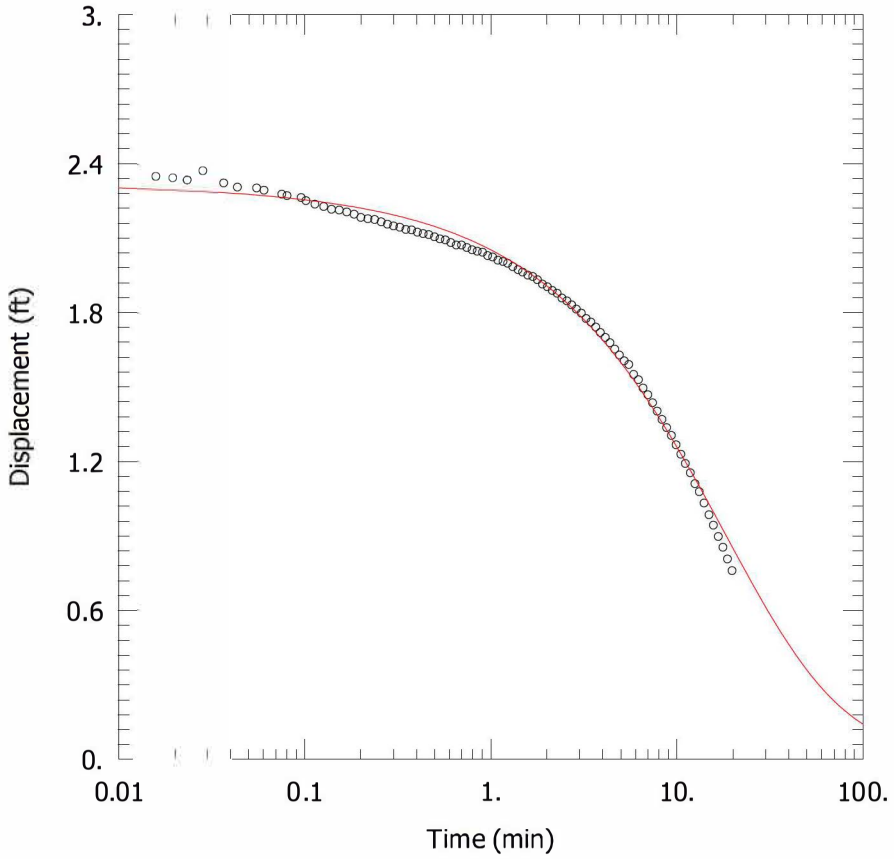
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	8.9E-5	cm/sec
Ss	0.0002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02946 cm^2/sec

R001297



G110 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G110
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.7E-5 cm/sec
Ss = 0.004 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.21 ft

WELL DATA (G110)

Initial Displacement: 2.32 ft
Total Well Penetration Depth: 10.21 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.21 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001298

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G110fh.aqt
Title: G110 @ CCR Landfill – Falling Head Test
Date: 11/28/16
Time: 10:27:16

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G110

AQUIFER DATA

Saturated Thickness: 10.21 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G110

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.32 ft
Static Water Column Height: 10.21 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 10.21 ft

No. of Observations: 103

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.03917	2.789	0.3245	2.143	3.063	1.797
-0.035	2.535	0.3495	2.134	3.252	1.775
-0.03078	2.269	0.3755	2.132	3.453	1.761
-0.02297	2.403	0.4035	2.123	3.663	1.741
-0.01928	2.442	0.4335	2.117	3.882	1.719
-0.01558	2.401	0.4645	2.113	4.122	1.699
-0.0119	2.368	0.4985	2.104	4.372	1.678
-0.003683	2.371	0.5335	2.096	4.633	1.652
0.	2.38	0.5705	2.092	4.912	1.628
0.003683	2.362	0.6105	2.081	5.213	1.605
0.00735	2.355	0.6525	2.071	5.523	1.59
0.01582	2.349	0.6965	2.071	5.862	1.55
0.01953	2.344	0.7435	2.061	6.213	1.529

R001299

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.02323	2.335	0.7935	2.052	6.582	1.495
0.0285	2.372	0.8465	2.046	6.982	1.468
0.03668	2.321	0.9025	2.042	7.402	1.436
0.0435	2.304	0.9625	2.029	7.843	1.402
0.05523	2.301	1.023	2.023	8.313	1.369
0.0605	2.292	1.093	2.01	8.813	1.336
0.07527	2.276	1.163	2.005	9.342	1.304
0.0805	2.27	1.232	1.998	9.902	1.267
0.09568	2.262	1.313	1.984	10.5	1.229
0.1015	2.25	1.403	1.972	11.1	1.191
0.1135	2.236	1.482	1.962	11.8	1.154
0.1265	2.226	1.583	1.95	12.5	1.11
0.1395	2.215	1.683	1.944	13.2	1.078
0.1535	2.212	1.783	1.931	14.	1.032
0.1685	2.204	1.893	1.914	14.9	0.985
0.1845	2.195	2.013	1.903	15.7	0.943
0.2005	2.182	2.143	1.888	16.7	0.897
0.2185	2.177	2.273	1.877	17.7	0.854
0.2375	2.174	2.413	1.858	18.7	0.807
0.2575	2.165	2.563	1.846	19.8	0.76
0.2785	2.155	2.723	1.83		
0.3005	2.148	2.882	1.813		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.7E-5	cm/sec
Ss	0.004	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.01463 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	4.675E-5	2.299E-5	+/- 4.561E-5	2.034	cm/sec
Ss	0.004389	0.004059	+/- 0.008053	1.081	ft^{-1}
Kz/Kr	1.	19.63	+/- 38.94	0.05095	

C.I. is approximate 95% confidence interval for parameter

R001300

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.01455 cm²/sec

Parameter Correlations

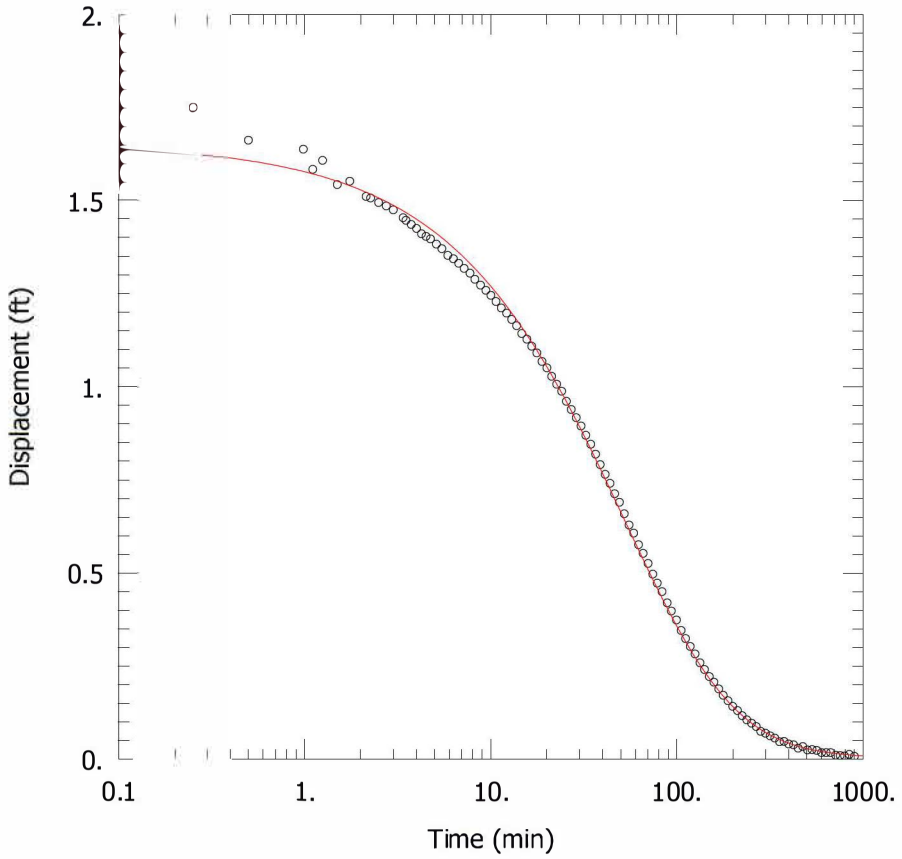
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.98
Ss	-0.99	1.00	0.95
Kz/Kr	-0.98	0.95	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.4068 ft^2
Variance . . . . . 0.004068 ft^2
Std. Deviation . . . . . 0.06378 ft
Mean. . . . . 0.009142 ft
No. of Residuals 103
No. of Estimates. 3

R001301



G110 @ CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G110
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 2.0E-5 cm/sec
Ss = 0.0015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.21 ft

WELL DATA (G110)

Initial Displacement: 1.66 ft
Total Well Penetration Depth: 10.21 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.21 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001302

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G110rh.aqt
Title: G110 @ CCR Landfill – Rising Head Test
Date: 11/18/16
Time: 11:56:09

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G110

AQUIFER DATA

Saturated Thickness: 10.21 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G110

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.66 ft
Static Water Column Height: 10.21 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 10.21 ft

No. of Observations: 107

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.475	14.71	1.143	125.3	0.283
0.25	1.751	15.67	1.128	133.1	0.259
0.5	1.662	16.63	1.109	140.9	0.241
0.986	1.638	17.71	1.091	149.3	0.222
1.108	1.584	18.85	1.068	158.3	0.207
1.25	1.608	20.05	1.051	167.9	0.189
1.5	1.543	21.31	1.028	177.5	0.172
1.75	1.552	22.63	1.007	188.3	0.157
2.142	1.511	24.07	0.988	199.7	0.142
2.265	1.507	25.57	0.961	211.7	0.131
2.5	1.495	27.13	0.939	224.3	0.117
2.75	1.486	28.81	0.917	237.5	0.106
3.	1.475	30.61	0.895	251.9	0.097

R001303

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
3.386	1.454	32.47	0.87	266.9	0.088
3.509	1.447	34.51	0.846	282.5	0.075
3.75	1.436	36.61	0.819	299.3	0.07
4.	1.425	38.83	0.791	317.3	0.063
4.25	1.411	41.23	0.765	335.9	0.057
4.5	1.404	43.75	0.741	356.4	0.047
4.75	1.397	46.39	0.713	377.3	0.048
5.11	1.383	49.21	0.69	399.5	0.041
5.47	1.371	52.21	0.659	423.5	0.039
5.89	1.353	55.39	0.629	448.7	0.03
6.31	1.344	58.75	0.607	475.1	0.034
6.73	1.332	62.35	0.576	503.3	0.025
7.21	1.318	65.95	0.553	533.3	0.026
7.75	1.305	70.15	0.526	565.1	0.024
8.23	1.289	74.35	0.497	598.7	0.018
8.83	1.273	78.55	0.473	634.9	0.018
9.43	1.259	83.35	0.45	670.7	0.018
10.03	1.246	88.75	0.42	712.7	0.011
10.69	1.229	93.55	0.398	754.7	0.01
11.41	1.212	99.55	0.374	796.7	0.009
12.19	1.198	105.5	0.346	844.7	0.013
12.97	1.181	111.5	0.324	898.7	0.008
13.81	1.164	118.1	0.303		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	2.0E-5	cm/sec
Ss	0.0015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.006224 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	1.835E-5	1.521E-6	+/- 3.015E-6	12.07	cm/sec
Ss	0.002304	0.0005947	+/- 0.001179	3.874	ft^{-1}
Kz/Kr	1.	1.446	+/- 2.867	0.6918	

R001304

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.00571 cm²/sec

Parameter Correlations

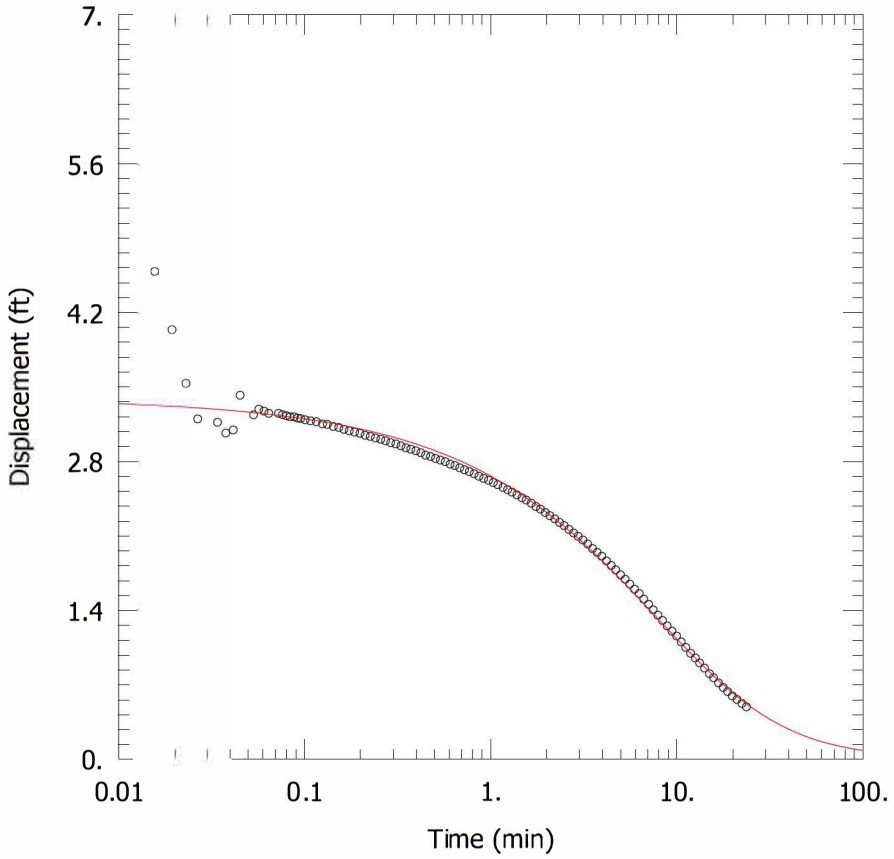
	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.95
Ss	-0.98	1.00	0.88
Kz/Kr	-0.95	0.88	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.074 ft^2
Variance . . . . . 0.0007115 ft^2
Std. Deviation . . . . . 0.02667 ft
Mean. . . . . -0.002906 ft
No. of Residuals 107
No. of Estimates. 3

R001305



G119 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G119
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 8.6E-5 cm/sec
Ss = 0.01 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 9.17 ft

WELL DATA (G119)

Initial Displacement: 3.4 ft
Total Well Penetration Depth: 9.17 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 9.17 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001306

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G119fh.aqt
Title: G119 @ CCR Landfill – Falling Head Test
Date: 11/18/16
Time: 11:57:05

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G119

AQUIFER DATA

Saturated Thickness: 9.17 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G119

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.4 ft
Static Water Column Height: 9.17 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 9.17 ft

No. of Observations: 114

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	5.641	0.291	2.976	2.795	2.126
0.004167	6.01	0.31	2.963	2.955	2.094
0.008333	5.281	0.33	2.945	3.135	2.06
0.01565	4.584	0.351	2.927	3.325	2.023
0.01932	4.038	0.373	2.913	3.525	1.981
0.02303	3.534	0.397	2.899	3.735	1.944
0.02672	3.198	0.422	2.881	3.955	1.908
0.03417	3.166	0.448	2.858	4.195	1.864
0.03785	3.065	0.476	2.845	4.445	1.821
0.04152	3.094	0.506	2.826	4.705	1.78
0.0452	3.421	0.537	2.812	4.985	1.734
0.05333	3.237	0.571	2.796	5.285	1.691
0.05702	3.29	0.606	2.773	5.595	1.646

R001307

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06068	3.272	0.643	2.76	5.935	1.598
0.0644	3.251	0.683	2.739	6.285	1.557
0.07275	3.251	0.725	2.721	6.655	1.504
0.07642	3.239	0.769	2.703	7.055	1.456
0.0801	3.228	0.816	2.683	7.475	1.404
0.08383	3.218	0.866	2.66	7.915	1.354
0.08827	3.217	0.919	2.64	8.385	1.305
0.09195	3.206	0.975	2.622	8.885	1.253
0.09563	3.201	1.035	2.601	9.415	1.203
0.101	3.19	1.095	2.579	9.975	1.158
0.108	3.18	1.165	2.556	10.57	1.103
0.116	3.172	1.235	2.534	11.18	1.051
0.125	3.151	1.305	2.51	11.88	0.996
0.133	3.147	1.385	2.484	12.57	0.952
0.143	3.128	1.475	2.458	13.28	0.906
0.153	3.119	1.555	2.437	14.07	0.858
0.163	3.101	1.655	2.406	14.98	0.805
0.174	3.087	1.755	2.375	15.78	0.765
0.186	3.075	1.855	2.35	16.77	0.718
0.199	3.063	1.965	2.319	17.77	0.675
0.212	3.045	2.085	2.289	18.77	0.636
0.226	3.034	2.215	2.259	19.88	0.595
0.241	3.019	2.345	2.226	21.07	0.563
0.257	3.007	2.485	2.195	22.38	0.524
0.273	2.993	2.635	2.161	23.68	0.493

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	8.6E-5	cm/sec
Ss	0.01	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02404 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	8.635E-5	7.858E-5	+/- 0.0001557	1.099	cm/sec
Ss	0.01033	0.01841	+/- 0.03648	0.5609	ft^{-1}

Kz/Kr	0.03458	7.758	+/- 15.38	0.004457

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.02413 cm²/sec

Parameter Correlations

	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.96
Ss	-0.99	1.00	0.91
Kz/Kr	-0.96	0.91	1.00

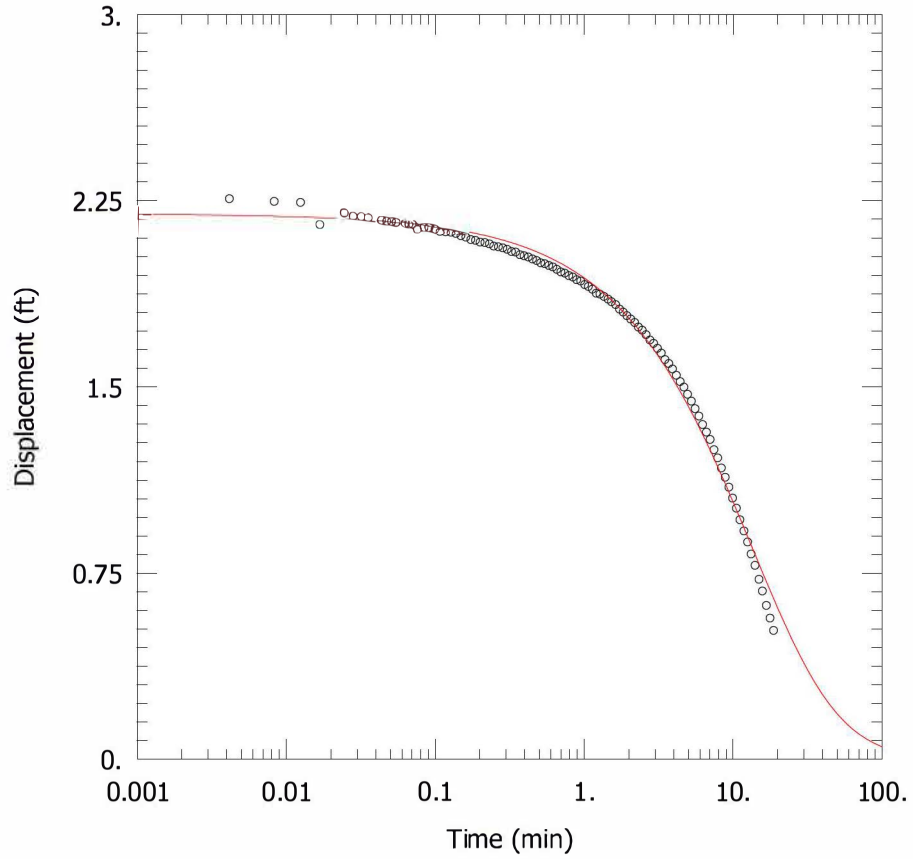
Residual Statistics

for weighted residuals

Sum of Squares . . . . . 18.21 ft^2
Variance . . . . . 0.164 ft^2
Std. Deviation . . . . . 0.405 ft
Mean. . . . . 0.06266 ft
No. of Residuals 114
No. of Estimates 3

R001308

R001309



G119 @CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G119
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 8.2E-5 cm/sec
Ss = 0.001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 9.17 ft

WELL DATA (G119)

Initial Displacement: 2.2 ft
Total Well Penetration Depth: 9.17 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 9.17 ft
Screen Length: 4.58 ft
Well Radius: 0.08333 ft

R001310

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G119rh.aqt
Title: G119 @CCR Landfill – Rising Head Test
Date: 11/28/16
Time: 10:28:38

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G119

AQUIFER DATA

Saturated Thickness: 9.17 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G119

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.2 ft
Static Water Column Height: 9.17 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.58 ft
Total Well Penetration Depth: 9.17 ft

No. of Observations: 104

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.268	0.326	2.045	2.77	1.689
0.004167	2.258	0.348	2.043	2.93	1.675
0.008333	2.247	0.372	2.032	3.11	1.655
0.0125	2.243	0.397	2.028	3.3	1.636
0.01667	2.155	0.423	2.023	3.5	1.61
0.02452	2.201	0.451	2.015	3.71	1.594
0.0282	2.189	0.481	2.009	3.93	1.572
0.03187	2.189	0.512	2.	4.17	1.547
0.03555	2.184	0.546	1.996	4.42	1.521
0.04347	2.171	0.581	1.989	4.68	1.499
0.04715	2.168	0.618	1.983	4.96	1.47
0.05082	2.167	0.658	1.973	5.26	1.442
0.0545	2.165	0.7	1.963	5.57	1.412

R001311

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06295	2.156	0.744	1.958	5.91	1.382
0.06663	2.154	0.791	1.948	6.26	1.348
0.07033	2.155	0.841	1.942	6.63	1.318
0.076	2.134	0.894	1.931	7.03	1.288
0.08445	2.143	0.95	1.926	7.45	1.247
0.091	2.143	1.01	1.912	7.89	1.214
0.1	2.138	1.07	1.904	8.36	1.173
0.108	2.126	1.14	1.893	8.86	1.136
0.118	2.124	1.21	1.877	9.39	1.096
0.128	2.123	1.28	1.873	9.95	1.052
0.138	2.118	1.36	1.864	10.55	1.011
0.149	2.109	1.45	1.853	11.15	0.965
0.161	2.103	1.53	1.843	11.85	0.92
0.174	2.093	1.63	1.831	12.55	0.875
0.187	2.09	1.73	1.813	13.25	0.827
0.201	2.083	1.83	1.801	14.05	0.781
0.216	2.081	1.94	1.787	14.95	0.725
0.232	2.076	2.06	1.773	15.75	0.678
0.248	2.067	2.19	1.759	16.75	0.62
0.266	2.064	2.32	1.741	17.75	0.569
0.285	2.06	2.46	1.728	18.75	0.519
0.305	2.054	2.61	1.71		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

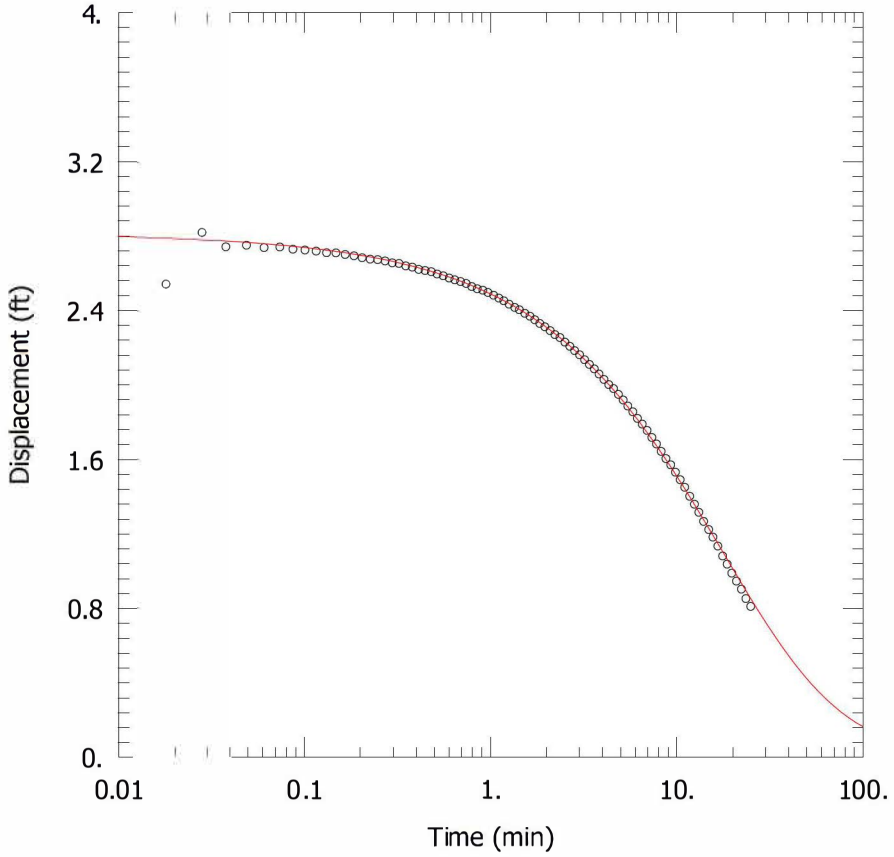
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	8.2E-5	cm/sec
Ss	0.001	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02292 cm^2/sec

R001312



G125 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G125
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.8E-5 cm/sec
Ss = 0.004 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 8.72 ft

WELL DATA (G125)

Initial Displacement: 2.82 ft
Total Well Penetration Depth: 8.67 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 8.72 ft
Screen Length: 4.53 ft
Well Radius: 0.08333 ft

R001313

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G125fh.aqt
Title: G125 @ CCR Landfill – Falling Head Test
Date: 11/28/16
Time: 09:18:08

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G125

AQUIFER DATA

Saturated Thickness: 8.72 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G125

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.82 ft
Static Water Column Height: 8.72 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.53 ft
Total Well Penetration Depth: 8.67 ft

No. of Observations: 90

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.869	0.691	2.554	4.58	1.98
0.008	3.276	0.741	2.544	4.86	1.949
0.018	2.542	0.794	2.528	5.16	1.919
0.02802	2.821	0.85	2.516	5.47	1.886
0.038	2.741	0.91	2.508	5.81	1.855
0.049	2.75	0.97	2.496	6.16	1.82
0.061	2.737	1.04	2.481	6.53	1.789
0.074	2.74	1.11	2.466	6.93	1.755
0.087	2.728	1.18	2.451	7.35	1.717
0.101	2.724	1.26	2.433	7.79	1.682
0.116	2.718	1.35	2.416	8.26	1.643
0.132	2.709	1.43	2.403	8.76	1.604
0.148	2.708	1.53	2.384	9.29	1.57

R001314

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.166	2.7	1.63	2.369	9.85	1.531
0.185	2.693	1.73	2.35	10.45	1.49
0.205	2.683	1.84	2.33	11.05	1.45
0.226	2.675	1.96	2.312	11.75	1.402
0.248	2.672	2.09	2.291	12.45	1.359
0.272	2.665	2.22	2.27	13.15	1.316
0.297	2.655	2.36	2.254	13.95	1.267
0.323	2.652	2.51	2.229	14.85	1.223
0.351	2.639	2.67	2.207	15.65	1.182
0.381	2.632	2.83	2.184	16.65	1.134
0.412	2.62	3.01	2.161	17.65	1.081
0.446	2.614	3.2	2.135	18.65	1.037
0.481	2.608	3.4	2.11	19.75	0.989
0.518	2.595	3.61	2.086	20.95	0.946
0.558	2.585	3.83	2.058	22.25	0.903
0.6	2.573	4.07	2.029	23.55	0.852
0.644	2.564	4.32	2.001	24.95	0.81

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.8E-5	cm/sec
Ss	0.004	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.01276 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	4.918E-5	3.398E-5	+/- 6.756E-5	1.447	cm/sec
Ss	0.003764	0.005048	+/- 0.01004	0.7457	ft^{-1}
Kz/Kr	1.	23.17	+/- 46.07	0.04315	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.01307 cm^2/sec

R001315

Parameter Correlations

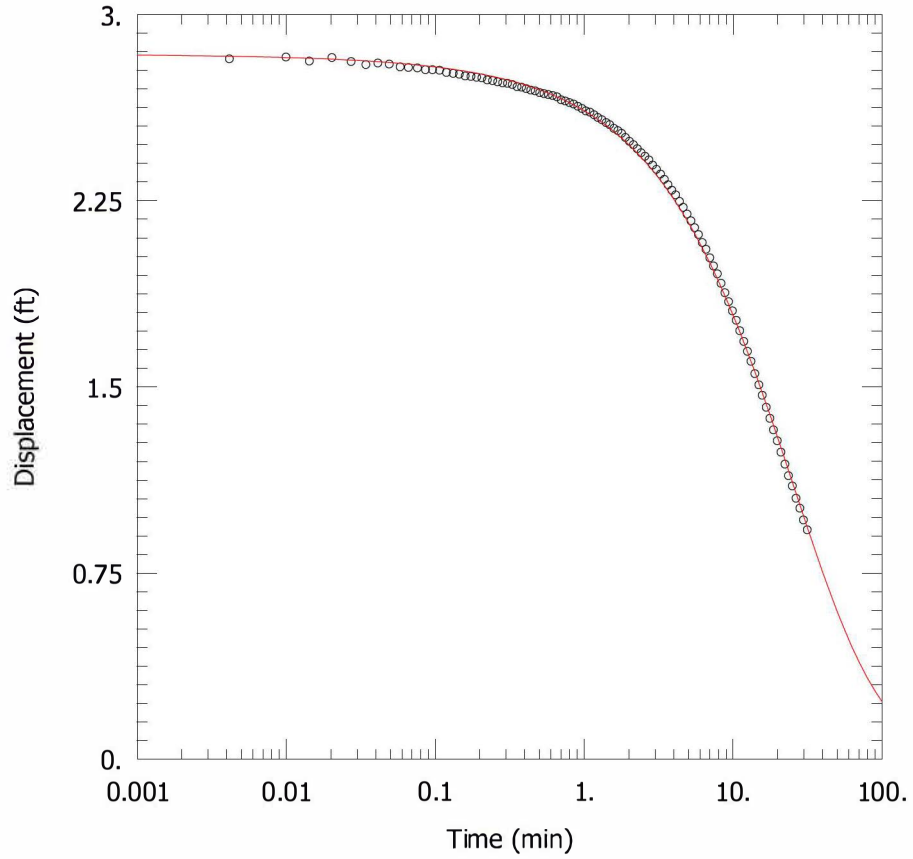
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.95
Kz/Kr	-0.99	0.95	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 1.205 ft^2
Variance . . . . . 0.01385 ft^2
Std. Deviation . . . . . 0.1177 ft
Mean. . . . . -0.01063 ft
No. of Residuals 90
No. of Estimates 3

R001316



G125 @CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G125
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 4.1E-5 cm^{1}/sec
Ss = 0.0015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 8.72 ft

WELL DATA (G125)

Initial Displacement: 2.84 ft
Total Well Penetration Depth: 8.72 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 8.72 ft
Screen Length: 4.53 ft
Well Radius: 0.08333 ft

R001317

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G125rh.aqt
Title: G125 @CCR Landfill – Rising Head Test
Date: 11/28/16
Time: 09:18:43

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G125

AQUIFER DATA

Saturated Thickness: 8.72 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G125

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.84 ft
Static Water Column Height: 8.72 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.53 ft
Total Well Penetration Depth: 8.72 ft

No. of Observations: 113

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.04167	2.799	0.3553	2.709	3.888	2.292
-0.0375	2.992	0.3813	2.707	4.128	2.273
-0.03098	2.871	0.4093	2.701	4.378	2.247
-0.02893	2.922	0.4393	2.695	4.638	2.223
-0.025	2.865	0.4703	2.692	4.918	2.196
-0.02083	2.851	0.5043	2.685	5.218	2.169
-0.01667	2.867	0.5393	2.681	5.528	2.141
-0.009933	2.861	0.5763	2.677	5.868	2.113
-0.007867	2.868	0.6163	2.673	6.218	2.081
-0.004167	2.838	0.6583	2.668	6.588	2.054
0.	2.846	0.7023	2.656	6.988	2.02
0.004167	2.821	0.7493	2.651	7.408	1.987
0.009984	2.828	0.7993	2.645	7.848	1.955

R001318

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.01433	2.812	0.8523	2.639	8.318	1.917
0.02033	2.826	0.9083	2.63	8.818	1.879
0.02733	2.81	0.9683	2.621	9.348	1.843
0.03433	2.798	1.028	2.611	9.908	1.806
0.04133	2.804	1.098	2.606	10.51	1.768
0.04933	2.8	1.168	2.596	11.11	1.726
0.05833	2.789	1.238	2.585	11.81	1.683
0.06633	2.786	1.318	2.576	12.51	1.643
0.07633	2.784	1.409	2.564	13.21	1.603
0.08633	2.777	1.488	2.556	14.01	1.553
0.09633	2.777	1.588	2.541	14.91	1.508
0.1073	2.775	1.688	2.532	15.71	1.466
0.1193	2.766	1.788	2.521	16.71	1.418
0.1323	2.762	1.898	2.504	17.71	1.373
0.1453	2.759	2.018	2.489	18.71	1.327
0.1593	2.752	2.148	2.475	19.81	1.283
0.1743	2.75	2.278	2.459	21.01	1.237
0.1903	2.747	2.418	2.443	22.31	1.189
0.2063	2.744	2.568	2.429	23.61	1.142
0.2243	2.736	2.728	2.414	25.01	1.101
0.2433	2.733	2.888	2.393	26.51	1.051
0.2633	2.728	3.068	2.376	28.11	1.011
0.2843	2.724	3.258	2.357	29.71	0.964
0.3063	2.722	3.458	2.336	31.51	0.924
0.3303	2.718	3.668	2.314		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

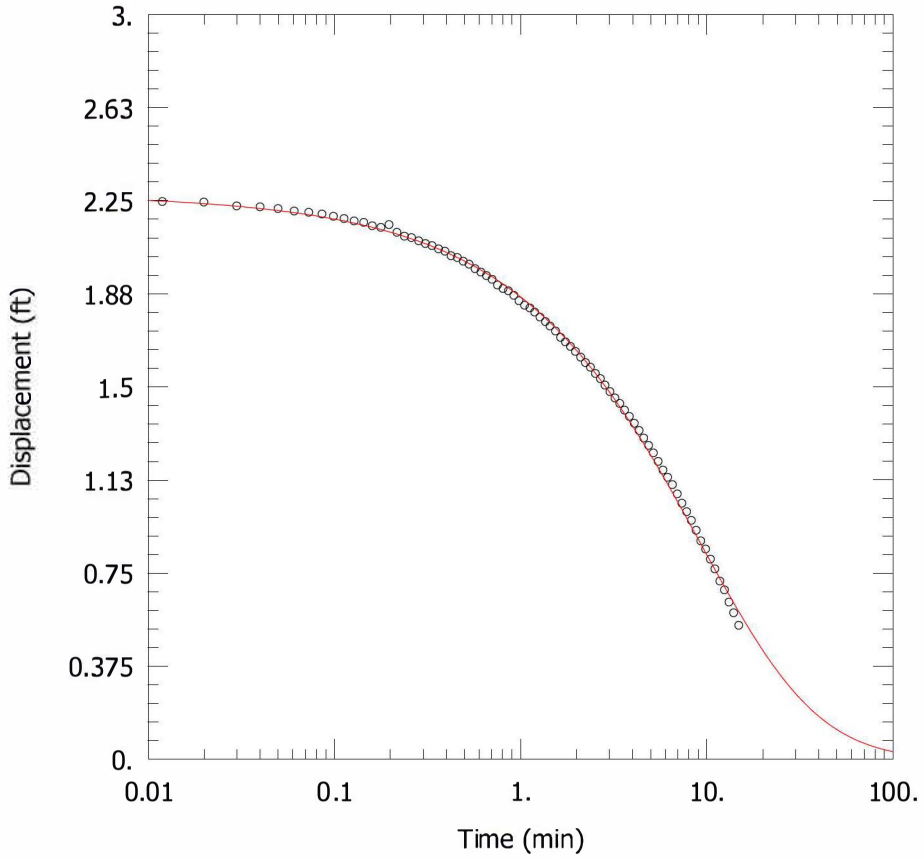
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.1E-5	cm/sec
Ss	0.0015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.0109 cm^2/sec

R001319



G153 @ SW DETENTION POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G153
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00025 cm/sec
Ss = 0.015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 3. ft

WELL DATA (G153)

Initial Displacement: 2.28 ft
Total Well Penetration Depth: 11.78 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.78 ft
Screen Length: 4.44 ft
Well Radius: 0.08333 ft

R001320

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G153fh.aqt
Title: G153 @ SW Detention Pond – Falling Head Test
Date: 11/28/16
Time: 09:19:16

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G153

AQUIFER DATA

Saturated Thickness: 3. ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G153

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.28 ft
Static Water Column Height: 11.78 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.44 ft
Total Well Penetration Depth: 11.78 ft

No. of Observations: 83

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.241	0.5299	1.994	3.212	1.455
0.0037	2.266	0.5699	1.976	3.412	1.433
0.01193	2.246	0.6119	1.962	3.622	1.406
0.01993	2.244	0.656	1.948	3.842	1.381
0.02993	2.229	0.7029	1.933	4.082	1.353
0.03995	2.225	0.7529	1.91	4.332	1.324
0.04993	2.218	0.806	1.896	4.592	1.294
0.06093	2.208	0.8619	1.887	4.872	1.264
0.07293	2.203	0.9219	1.869	5.172	1.234
0.08593	2.196	0.9819	1.847	5.482	1.2
0.09893	2.187	1.052	1.829	5.822	1.165
0.1129	2.178	1.122	1.818	6.172	1.136
0.128	2.168	1.192	1.801	6.542	1.106

R0001321

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.1439	2.162	1.272	1.781	6.942	1.069
0.16	2.149	1.362	1.763	7.362	1.031
0.178	2.142	1.442	1.745	7.802	0.997
0.1969	2.153	1.542	1.725	8.272	0.962
0.2169	2.122	1.642	1.699	8.772	0.922
0.2379	2.107	1.742	1.681	9.302	0.88
0.2599	2.101	1.852	1.663	9.862	0.847
0.2839	2.088	1.972	1.643	10.46	0.806
0.309	2.077	2.102	1.62	11.06	0.767
0.335	2.069	2.232	1.598	11.76	0.718
0.3629	2.056	2.372	1.579	12.46	0.682
0.3929	2.046	2.522	1.554	13.16	0.633
0.4239	2.028	2.682	1.533	13.96	0.59
0.458	2.021	2.842	1.507	14.86	0.54
0.4929	2.006	3.022	1.481		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00025	cm/sec
Ss	0.015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02286 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0002498	2.214E-5	+/- 4.406E-5	11.28	cm/sec
Ss	0.0138	0.002624	+/- 0.005222	5.259	ft^{-1}
Kz/Kr	1.	1.248	+/- 2.484	0.801	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.02284 cm^2/sec

Parameter Correlations

R001322

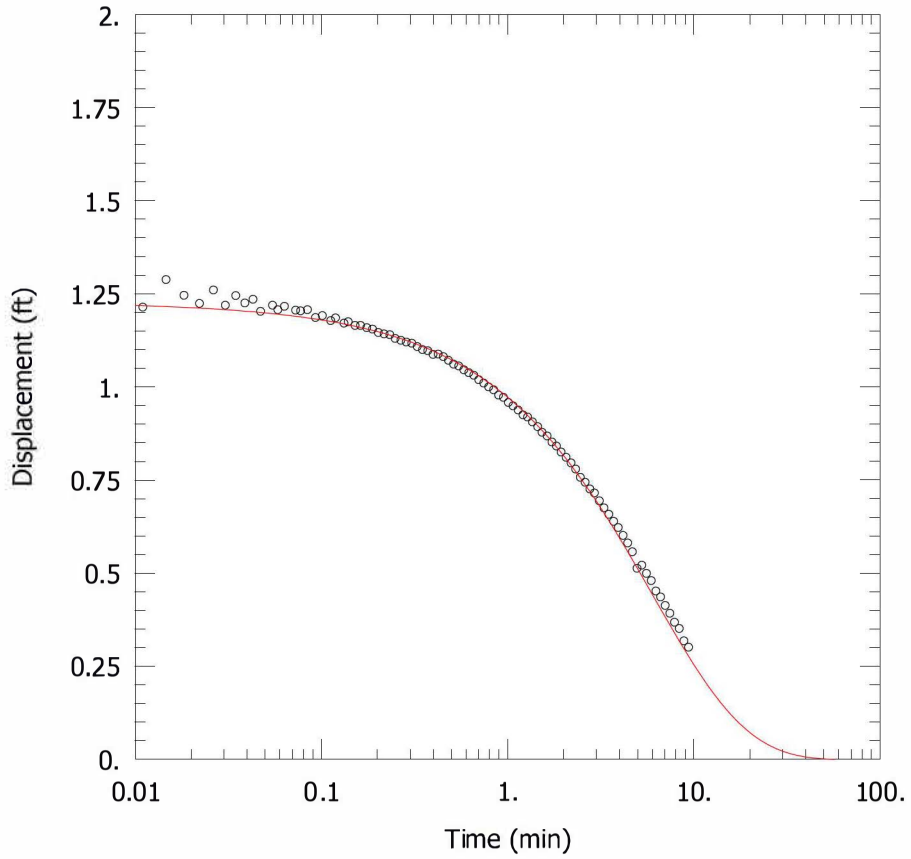
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.98
Ss	-0.99	1.00	0.95
Kz/Kr	-0.98	0.95	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02333 ft^2
Variance . . . . . 0.0002916 ft^2
Std. Deviation . . . . . 0.01708 ft
Mean. . . . . 0.0007214 ft
No. of Residuals 83
No. of Estimates. 3

R001323



G153 @ SW DETENTION POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G153
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00054 cm/sec
Ss = 0.0025 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 3. ft

WELL DATA (G153)

Initial Displacement: 1.23 ft
Total Well Penetration Depth: 11.78 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.78 ft
Screen Length: 4.44 ft
Well Radius: 0.08333 ft

R001324

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G153rh.aqt
Title: G153 @ SW Detention Pond – Rising Head Test
Date: 11/28/16
Time: 09:19:48

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G153

AQUIFER DATA

Saturated Thickness: 3. ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G153

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.23 ft
Static Water Column Height: 11.78 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.44 ft
Total Well Penetration Depth: 11.78 ft

No. of Observations: 93

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.222	0.2334	1.14	1.631	0.868
0.003666	1.261	0.2494	1.13	1.731	0.852
0.007333	1.285	0.2674	1.125	1.831	0.841
0.011	1.214	0.2864	1.12	1.941	0.825
0.01467	1.288	0.3064	1.117	2.061	0.811
0.01832	1.246	0.3274	1.108	2.191	0.796
0.02222	1.224	0.3494	1.1	2.321	0.779
0.02638	1.26	0.3734	1.097	2.461	0.757
0.03055	1.219	0.3984	1.087	2.611	0.744
0.03472	1.245	0.4244	1.088	2.771	0.726
0.03888	1.225	0.4524	1.081	2.931	0.715
0.04305	1.235	0.4824	1.071	3.111	0.694
0.04722	1.203	0.5134	1.061	3.301	0.675

R001325

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05473	1.219	0.5474	1.056	3.503	0.658
0.05843	1.207	0.5824	1.046	3.711	0.639
0.06338	1.216	0.6194	1.038	3.931	0.622
0.0728	1.206	0.6594	1.031	4.171	0.601
0.07738	1.204	0.7014	1.019	4.421	0.581
0.08438	1.207	0.7454	1.01	4.681	0.557
0.09303	1.186	0.7924	1.	4.961	0.513
0.1014	1.191	0.8424	0.992	5.261	0.521
0.1124	1.178	0.8954	0.978	5.571	0.499
0.1194	1.185	0.9514	0.972	5.911	0.48
0.1325	1.171	1.011	0.958	6.261	0.452
0.1394	1.175	1.071	0.949	6.631	0.436
0.1518	1.165	1.141	0.938	7.031	0.413
0.1626	1.165	1.211	0.925	7.451	0.392
0.1754	1.159	1.281	0.919	7.891	0.368
0.1884	1.155	1.361	0.906	8.361	0.351
0.2024	1.146	1.451	0.893	8.861	0.318
0.2174	1.142	1.531	0.878	9.391	0.301

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00054	cm/sec
Ss	0.0025	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.04938 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0005399	9.804E-5	+/- 0.0001948	5.507	cm/sec
Ss	0.00256	0.001483	+/- 0.002947	1.726	ft^{-1}
Kz/Kr	1.	1.411	+/- 2.803	0.7089	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.04937 cm^2/sec

R001326

Parameter Correlations

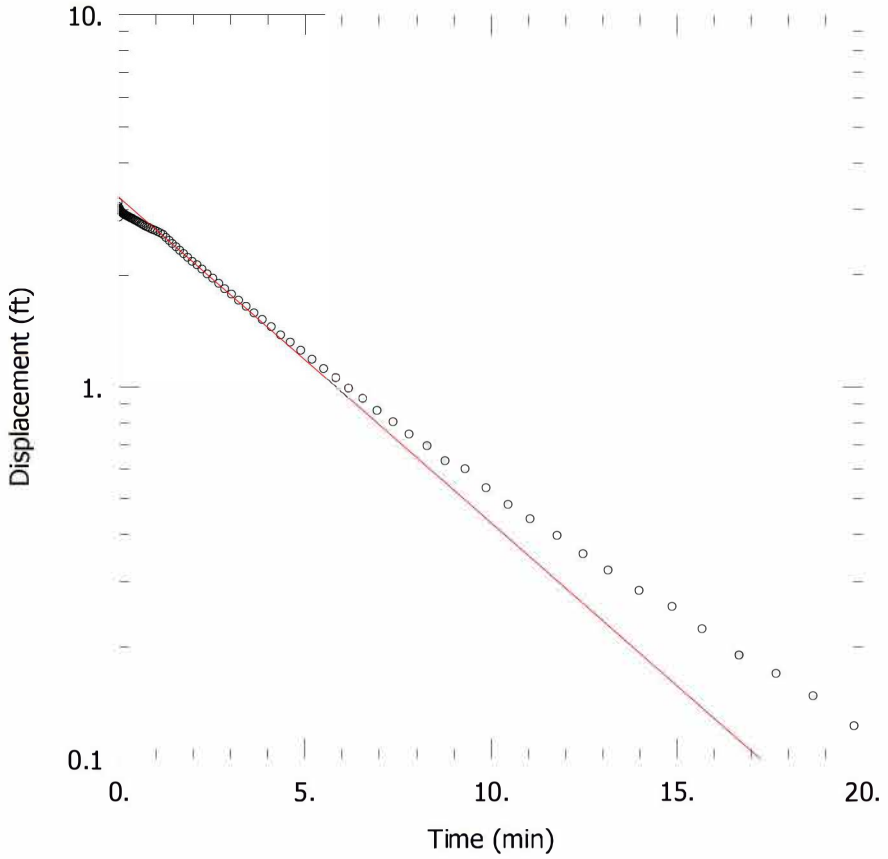
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.97
Kz/Kr	-0.99	0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.0362 ft^2
Variance . . . . . 0.0004022 ft^2
Std. Deviation . . . . . 0.02005 ft
Mean. . . . . -0.005578 ft
No. of Residuals 93
No. of Estimates. 3

R001327



G206 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G206
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.0003 cm/sec
y0 = 3.25 ft

AQUIFER DATA

Saturated Thickness: 13.15 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G206)

Initial Displacement: 3.01 ft
Total Well Penetration Depth: 13.15 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.15 ft
Screen Length: 4.41 ft
Well Radius: 0.08333 ft

R001328

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G206fh.aqt
Title: G206 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 10:38:25

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G206

AQUIFER DATA

Saturated Thickness: 13.15 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G206

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.01 ft
Static Water Column Height: 13.15 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.41 ft
Total Well Penetration Depth: 13.15 ft

No. of Observations: 89

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.143	0.617	2.752	4.087	1.458
0.008	3.062	0.661	2.737	4.337	1.386
0.017	2.865	0.708	2.718	4.597	1.325
0.025	3.029	0.758	2.701	4.877	1.26
0.035	3.023	0.811	2.69	5.177	1.192
0.045	2.995	0.867	2.669	5.487	1.126
0.055	2.986	0.927	2.655	5.827	1.06
0.066	2.978	0.987	2.64	6.177	0.994
0.078	2.97	1.057	2.619	6.547	0.933
0.091	2.963	1.127	2.599	6.947	0.864
0.104	2.95	1.197	2.576	7.367	0.807
0.118	2.941	1.277	2.527	7.807	0.748
0.133	2.926	1.367	2.48	8.277	0.696

R001329

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.149	2.927	1.447	2.434	8.777	0.634
0.165	2.92	1.547	2.388	9.307	0.604
0.183	2.906	1.647	2.336	9.867	0.536
0.202	2.901	1.747	2.288	10.47	0.483
0.222	2.895	1.857	2.236	11.07	0.442
0.243	2.887	1.977	2.182	11.77	0.399
0.265	2.878	2.107	2.136	12.47	0.356
0.289	2.874	2.237	2.081	13.17	0.322
0.314	2.859	2.377	2.019	13.97	0.284
0.34	2.849	2.527	1.965	14.87	0.257
0.368	2.846	2.687	1.905	15.67	0.224
0.398	2.836	2.847	1.841	16.67	0.19
0.429	2.819	3.027	1.782	17.67	0.17
0.463	2.81	3.217	1.717	18.67	0.148
0.498	2.8	3.417	1.653	19.77	0.123
0.535	2.784	3.627	1.588	20.97	0.112
0.575	2.77	3.847	1.524		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 3.715

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0003	cm/sec
y0	3.25	ft

T = K*b = 0.1202 cm²/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
K	0.0002598	2.211E-6	+/- 4.395E-6	117.5	cm/sec
y0	3.047	0.007694	+/- 0.0153	396.	ft

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1041 cm²/sec

Parameter Correlations

R001330

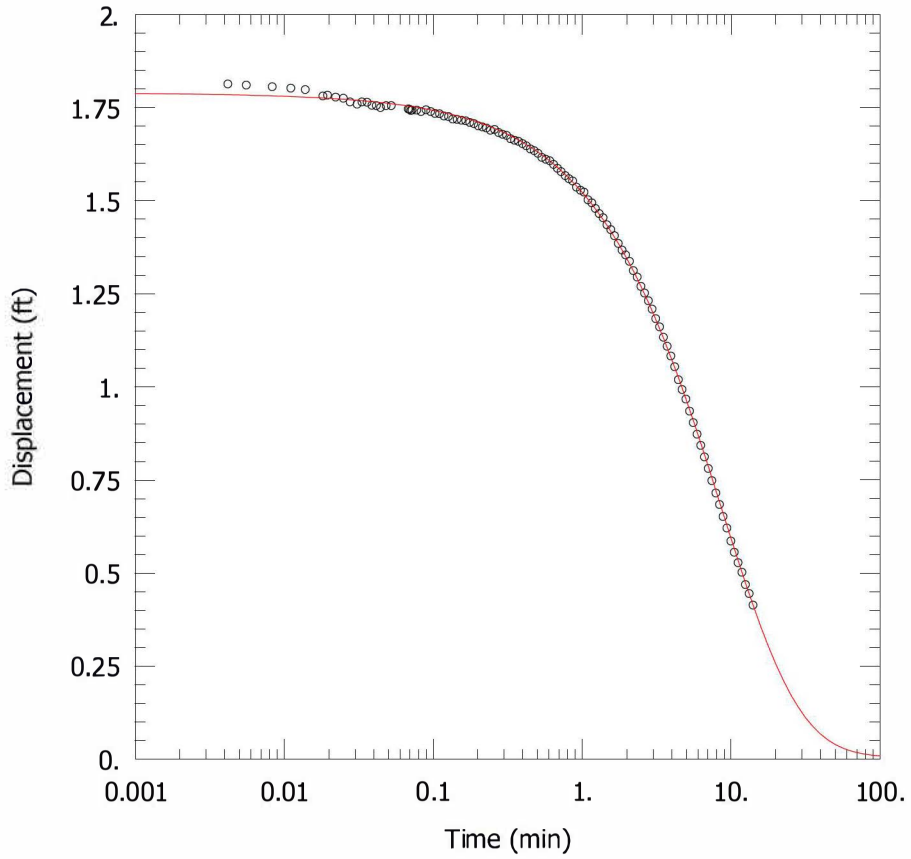
	K	y0
K	1.00	0.55
y0	0.55	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.168 ft^2
Variance . . . . . 0.001931 ft^2
Std. Deviation . . . . . 0.04394 ft
Mean. . . . . 0.0007809 ft
No. of Residuals 89
No. of Estimates. 2

R001331



G206 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G206
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00016 cm/sec
Ss = 0.0003 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.15 ft

WELL DATA (G206)

Initial Displacement: 1.79 ft
Total Well Penetration Depth: 13.15 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.15 ft
Screen Length: 4.41 ft
Well Radius: 0.08333 ft

R001332

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G206rh.aqt
Title: G206 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:20:24

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G206

AQUIFER DATA

Saturated Thickness: 13.15 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G206

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.79 ft
Static Water Column Height: 13.15 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.41 ft
Total Well Penetration Depth: 13.15 ft

No. of Observations: 110

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.857	0.2011	1.701	1.858	1.367
0.0042	1.813	0.2144	1.698	1.964	1.354
0.005578	1.81	0.2284	1.695	2.084	1.337
0.008333	1.806	0.2431	1.689	2.211	1.312
0.01111	1.802	0.2591	1.691	2.344	1.295
0.01389	1.798	0.2758	1.683	2.484	1.27
0.01823	1.781	0.2931	1.678	2.631	1.252
0.0196	1.783	0.3118	1.675	2.791	1.231
0.02222	1.778	0.3318	1.666	2.958	1.209
0.025	1.775	0.3524	1.662	3.131	1.183
0.02778	1.765	0.3751	1.659	3.318	1.161
0.03093	1.759	0.3984	1.653	3.518	1.133
0.03333	1.765	0.4231	1.647	3.724	1.109

R001333

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.03611	1.764	0.4498	1.639	3.951	1.083
0.03889	1.756	0.4778	1.634	4.184	1.054
0.04167	1.755	0.5071	1.627	4.431	1.019
0.04444	1.75	0.5384	1.616	4.698	0.993
0.04843	1.755	0.5718	1.611	4.978	0.967
0.05244	1.755	0.6071	1.607	5.271	0.935
0.06822	1.746	0.6444	1.597	5.584	0.904
0.0696	1.745	0.6844	1.587	5.918	0.873
0.07099	1.742	0.7244	1.578	6.271	0.843
0.07236	1.743	0.7711	1.567	6.644	0.812
0.07777	1.743	0.8178	1.559	7.044	0.781
0.0831	1.739	0.8644	1.553	7.444	0.748
0.08977	1.744	0.9178	1.536	7.911	0.715
0.09644	1.739	0.9778	1.528	8.378	0.684
0.1031	1.734	1.031	1.523	8.844	0.652
0.1104	1.733	1.098	1.502	9.378	0.621
0.1184	1.727	1.164	1.494	9.978	0.586
0.1271	1.726	1.231	1.479	10.51	0.556
0.1358	1.719	1.304	1.465	11.18	0.528
0.1451	1.718	1.384	1.454	11.84	0.502
0.1551	1.716	1.471	1.435	12.51	0.469
0.1658	1.714	1.558	1.422	13.24	0.445
0.1764	1.71	1.651	1.406	14.04	0.414
0.1884	1.707	1.751	1.385		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00016	cm/sec
Ss	0.0003	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.06413 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001598	1.133E-5	+/- 2.245E-5	14.1	cm/sec
Ss	0.0003168	8.69E-5	+/- 0.0001722	3.645	ft^{-1}
Kz/Kr	1.	0.8787	+/- 1.742	1.138	

R001334

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.06404 cm²/sec

Parameter Correlations

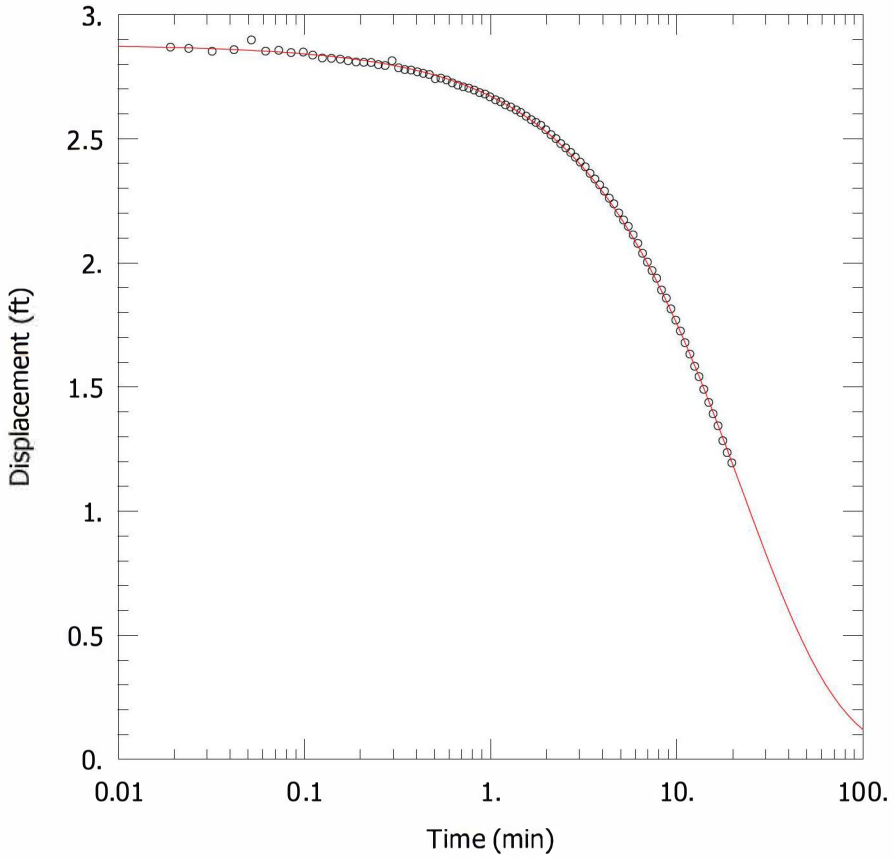
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.96
Kz/Kr	-0.99	0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01105 ft^2
Variance . . . . . 0.0001033 ft^2
Std. Deviation . . . . . 0.01016 ft
Mean. . . . . -7.742E-5 ft
No. of Residuals 110
No. of Estimates. 3

R001335



G208 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G208
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 6.0E-5 cm/sec
Ss = 0.0003 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 18.08 ft

WELL DATA (G208)

Initial Displacement: 2.88 ft
Total Well Penetration Depth: 18.08 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 18.08 ft
Screen Length: 4.53 ft
Well Radius: 0.08333 ft

R001336

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G208fh.aqt
Title: G208 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:21:07

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G208

AQUIFER DATA

Saturated Thickness: 18.08 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G208

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.88 ft
Static Water Column Height: 18.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.53 ft
Total Well Penetration Depth: 18.08 ft

No. of Observations: 89

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.84	0.582	2.736	3.854	2.313
0.007	2.857	0.624	2.724	4.095	2.288
0.01912	2.868	0.668	2.715	4.344	2.26
0.024	2.863	0.715	2.708	4.604	2.237
0.032	2.851	0.765	2.703	4.884	2.2
0.042	2.858	0.818	2.695	5.184	2.172
0.052	2.897	0.874	2.685	5.494	2.146
0.062	2.852	0.934	2.679	5.834	2.112
0.073	2.855	0.994	2.668	6.184	2.078
0.085	2.846	1.064	2.656	6.554	2.038
0.09877	2.848	1.134	2.648	6.954	2.002
0.111	2.836	1.204	2.635	7.374	1.968
0.125	2.824	1.284	2.627	7.814	1.937

R001337

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.14	2.823	1.374	2.615	8.284	1.89
0.156	2.82	1.454	2.605	8.784	1.857
0.172	2.813	1.554	2.59	9.314	1.814
0.19	2.808	1.654	2.576	9.874	1.769
0.209	2.807	1.754	2.565	10.47	1.725
0.229	2.806	1.864	2.553	11.07	1.678
0.25	2.798	1.984	2.535	11.77	1.632
0.272	2.794	2.114	2.516	12.47	1.583
0.296	2.813	2.244	2.5	13.18	1.541
0.321	2.785	2.384	2.48	13.97	1.49
0.347	2.778	2.534	2.462	14.87	1.437
0.375	2.776	2.694	2.444	15.68	1.391
0.405	2.769	2.854	2.425	16.67	1.343
0.436	2.762	3.034	2.405	17.67	1.283
0.47	2.758	3.224	2.386	18.67	1.235
0.505	2.741	3.424	2.36	19.77	1.194
0.542	2.743	3.634	2.337		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	6.0E-5	cm/sec
Ss	0.0003	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.03306\ cm^2/sec$

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	6.04E-5	4.084E-6	+/- 8.118E-6	14.79	cm/sec
Ss	0.0002752	6.697E-5	+/- 0.0001331	4.109	ft^{-1}
Kz/Kr	1.	0.9578	+/- 1.904	1.044	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

$T = K*b = 0.03329\ cm^2/sec$

R001338

Parameter Correlations

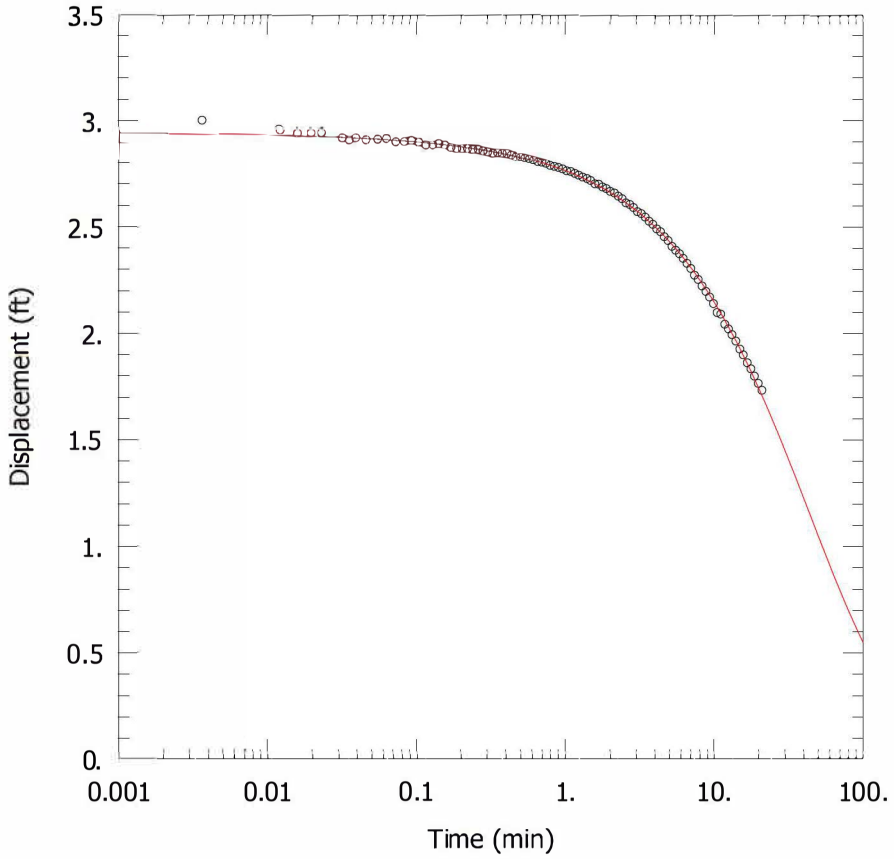
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.96
Kz/Kr	-0.99	0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.007952 ft^2
Variance . . . . . 9.246E-5 ft^2
Std. Deviation . . . . . 0.009616 ft
Mean. . . . . -0.001847 ft
No. of Residuals 89
No. of Estimates. 3

R001339



G208 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G208
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 2.1E-5 cm/sec
Ss = 0.0028 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 18.08 ft

WELL DATA (G208)

Initial Displacement: 2.95 ft
Total Well Penetration Depth: 18.08 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 18.08 ft
Screen Length: 4.53 ft
Well Radius: 0.08333 ft

R001340

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G208rh.aqt
Title: G208 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:21:28

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G208

AQUIFER DATA

Saturated Thickness: 18.08 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G208

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.95 ft
Static Water Column Height: 18.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.53 ft
Total Well Penetration Depth: 18.08 ft

No. of Observations: 97

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.003	0.4671	2.833	3.665	2.528
0.003667	3.002	0.5011	2.831	3.885	2.513
0.01203	2.96	0.5361	2.827	4.125	2.492
0.01573	2.946	0.5731	2.822	4.375	2.478
0.01943	2.946	0.6131	2.816	4.635	2.455
0.02312	2.947	0.6551	2.808	4.915	2.437
0.03195	2.923	0.6991	2.805	5.215	2.41
0.03565	2.913	0.7461	2.8	5.525	2.392
0.03937	2.923	0.7961	2.79	5.865	2.375
0.04613	2.914	0.8491	2.785	6.215	2.353
0.05507	2.917	0.9051	2.78	6.585	2.33
0.06312	2.92	0.9651	2.773	6.985	2.306
0.07312	2.905	1.025	2.764	7.405	2.274

R001341

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.08313	2.906	1.095	2.761	7.845	2.254
0.09312	2.91	1.165	2.752	8.315	2.224
0.1041	2.903	1.235	2.744	8.815	2.198
0.1161	2.89	1.315	2.735	9.345	2.172
0.1291	2.89	1.405	2.728	9.905	2.141
0.1421	2.896	1.485	2.719	10.51	2.099
0.1561	2.889	1.585	2.703	11.11	2.091
0.1711	2.878	1.685	2.702	11.81	2.044
0.1871	2.873	1.785	2.688	12.51	2.022
0.2031	2.873	1.895	2.681	13.21	1.995
0.2211	2.873	2.015	2.668	14.01	1.965
0.2401	2.869	2.145	2.66	14.91	1.927
0.2601	2.869	2.275	2.645	15.71	1.9
0.2811	2.861	2.416	2.633	16.71	1.863
0.3031	2.857	2.565	2.614	17.71	1.835
0.3271	2.851	2.725	2.606	18.71	1.8
0.3521	2.853	2.885	2.592	19.81	1.766
0.3781	2.85	3.065	2.572	21.01	1.734
0.4061	2.849	3.255	2.563		
0.4361	2.842	3.455	2.547		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	2.1E-5	cm/sec
Ss	0.0028	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.01157 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	2.111E-5	2.793E-6	+/- 5.544E-6	7.557	cm/sec
Ss	0.002783	0.000655	+/- 0.0013	4.25	ft^{-1}
Kz/Kr	1.	5.786	+/- 11.48	0.1728	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001342

T = K*b = 0.01163 cm²/sec

Parameter Correlations

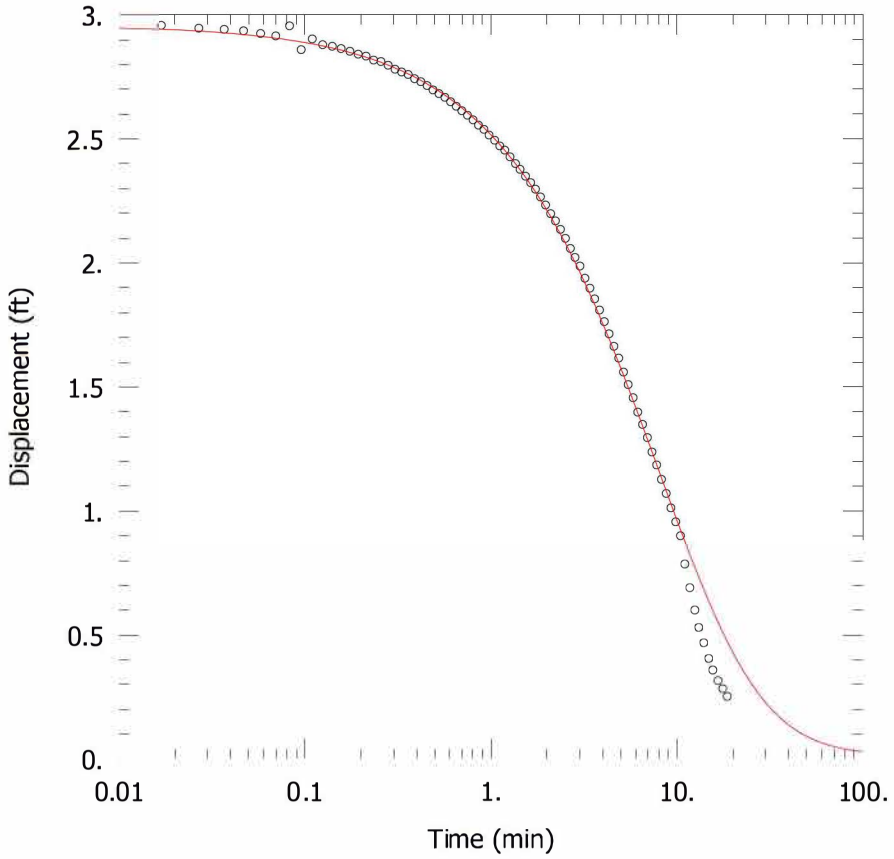
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.96
Kz/Kr	-0.99	0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01242 ft^2
Variance . . . . . 0.0001321 ft^2
Std. Deviation . . . . . 0.01149 ft
Mean. . . . . 0.001463 ft
No. of Residuals 97
No. of Estimates. 3

R001343



G209 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G209
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0002 cm/sec
Ss = 0.0001 ft^{-1}
Kz/Kr = 0.01

AQUIFER DATA

Saturated Thickness: 25.48 ft

WELL DATA (G209)

Initial Displacement: 2.96 ft
Total Well Penetration Depth: 25.48 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 25.48 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001344

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G209fh.aqt
Title: G209 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:22:04

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G209

AQUIFER DATA

Saturated Thickness: 25.48 ft
Anisotropy Ratio (Kz/Kr): 0.01

SLUG TEST WELL DATA

Test Well: G209

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.96 ft
Static Water Column Height: 25.48 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 25.48 ft

No. of Observations: 86

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.947	0.609	2.648	3.839	1.809
0.009	2.943	0.653	2.63	4.079	1.762
0.017	2.956	0.7	2.612	4.329	1.713
0.027	2.944	0.75	2.594	4.589	1.663
0.037	2.94	0.803	2.575	4.869	1.615
0.047	2.934	0.859	2.554	5.169	1.559
0.058	2.923	0.919	2.537	5.479	1.509
0.07	2.913	0.979	2.514	5.819	1.456
0.083	2.954	1.049	2.493	6.169	1.398
0.096	2.858	1.119	2.47	6.539	1.348
0.11	2.901	1.189	2.453	6.939	1.295
0.125	2.878	1.269	2.426	7.359	1.237
0.141	2.871	1.359	2.399	7.799	1.185

R001345

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.157	2.862	1.439	2.376	8.269	1.127
0.175	2.851	1.539	2.348	8.769	1.07
0.194	2.84	1.639	2.322	9.299	1.012
0.214	2.832	1.739	2.296	9.859	0.956
0.235	2.816	1.849	2.265	10.46	0.9
0.257	2.81	1.969	2.232	11.06	0.787
0.281	2.795	2.099	2.197	11.76	0.691
0.306	2.779	2.229	2.168	12.46	0.601
0.332	2.768	2.369	2.134	13.16	0.53
0.36	2.758	2.519	2.098	13.96	0.468
0.39	2.741	2.679	2.057	14.86	0.406
0.421	2.729	2.839	2.021	15.66	0.359
0.455	2.713	3.019	1.986	16.66	0.315
0.49	2.696	3.209	1.937	17.66	0.283
0.527	2.681	3.409	1.897	18.66	0.252
0.567	2.666	3.619	1.854		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

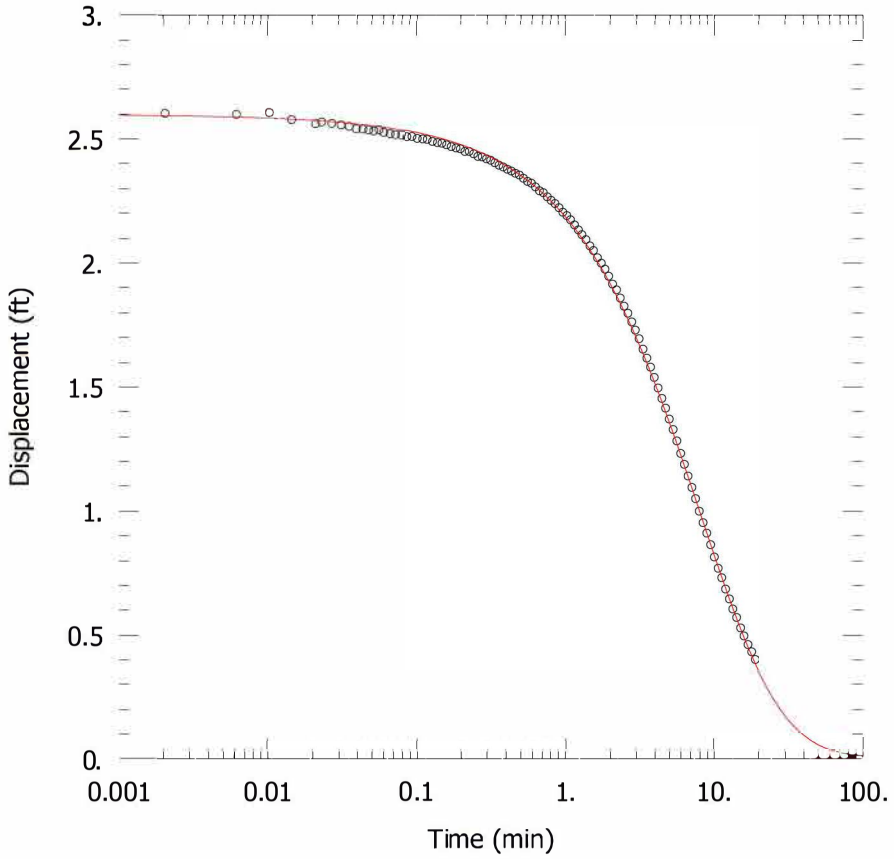
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0002	cm/sec
Ss	0.0001	ft^{-1}
Kz/Kr	0.01	

T = K*b = 0.1553 cm^2/sec

R001346



G209 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G209
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00016 cm/sec
Ss = 0.0004 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 25.48 ft

WELL DATA (G209)

Initial Displacement: 2.6 ft
Total Well Penetration Depth: 25.48 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 25.48 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001347

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G209rh.aqt
Title: G209 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:22:32

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G209

AQUIFER DATA

Saturated Thickness: 25.48 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G209

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.6 ft
Static Water Column Height: 25.48 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 25.48 ft

No. of Observations: 107

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.613	0.2953	2.417	2.62	1.796
0.00205	2.603	0.3153	2.411	2.78	1.761
0.006167	2.599	0.3363	2.401	2.94	1.728
0.01033	2.606	0.3583	2.391	3.12	1.693
0.0145	2.577	0.3823	2.384	3.31	1.651
0.02102	2.561	0.4073	2.375	3.51	1.615
0.02307	2.568	0.4333	2.368	3.72	1.579
0.027	2.562	0.4613	2.359	3.94	1.538
0.03117	2.556	0.4913	2.352	4.18	1.495
0.03533	2.55	0.5223	2.339	4.43	1.453
0.0395	2.541	0.5563	2.326	4.69	1.414
0.04367	2.539	0.5913	2.319	4.97	1.37
0.04783	2.536	0.6283	2.304	5.27	1.328

R001348

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.052	2.532	0.6683	2.289	5.581	1.282
0.05617	2.537	0.7103	2.281	5.92	1.232
0.06033	2.526	0.7543	2.264	6.27	1.188
0.06633	2.521	0.8013	2.25	6.64	1.141
0.07233	2.517	0.8513	2.237	7.04	1.095
0.07933	2.516	0.9043	2.22	7.46	1.05
0.08633	2.506	0.9603	2.202	7.9	1.
0.09333	2.507	1.02	2.189	8.37	0.953
0.1013	2.499	1.08	2.172	8.87	0.911
0.1103	2.497	1.15	2.151	9.4	0.865
0.1183	2.495	1.22	2.131	9.96	0.815
0.1283	2.487	1.29	2.112	10.56	0.77
0.1383	2.482	1.37	2.092	11.16	0.732
0.1483	2.48	1.46	2.067	11.86	0.686
0.1593	2.473	1.54	2.048	12.56	0.647
0.1713	2.466	1.64	2.019	13.26	0.606
0.1843	2.461	1.74	1.997	14.06	0.572
0.1973	2.457	1.84	1.973	14.96	0.53
0.2113	2.447	1.95	1.945	15.76	0.498
0.2263	2.447	2.07	1.913	16.76	0.463
0.2423	2.437	2.2	1.89	17.76	0.434
0.2583	2.427	2.33	1.857	18.76	0.403
0.2763	2.425	2.47	1.824		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00016	cm/sec
Ss	0.0004	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1243 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001569	8.484E-6	+/- 1.682E-5	18.49	cm/sec
Ss	0.0004212	8.747E-5	+/- 0.0001734	4.816	ft^{-1}
Kz/Kr	1.	0.6918	+/- 1.372	1.446	

R001349

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1218 cm²/sec

Parameter Correlations

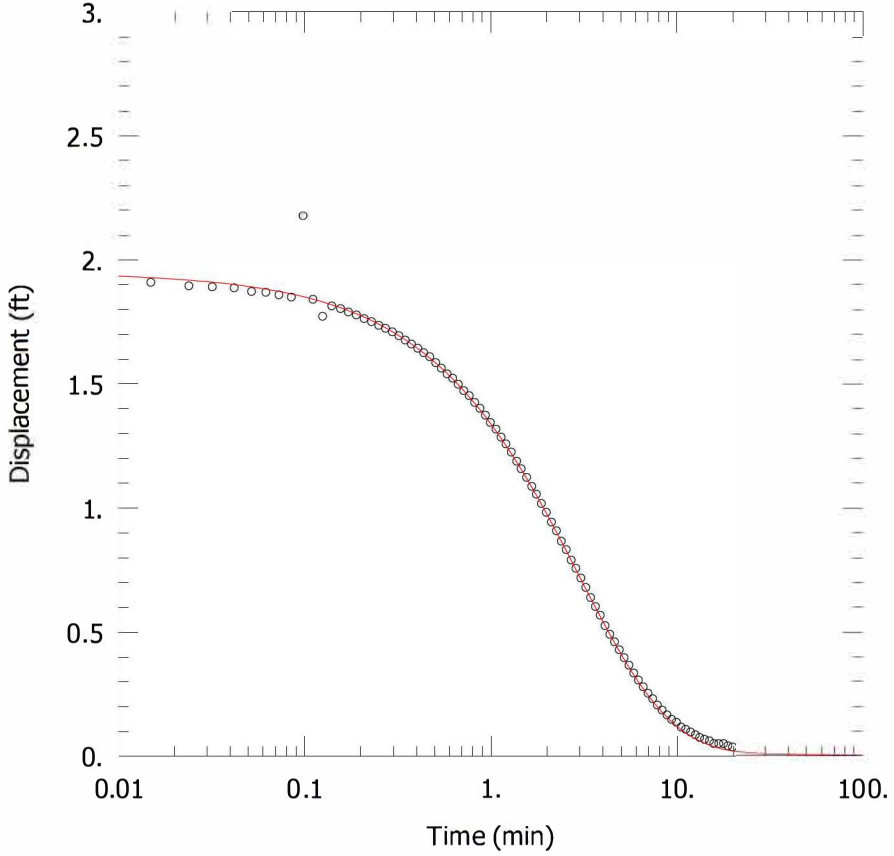
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.95
Kz/Kr	-0.99	0.95	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02054 ft^2
Variance . . . . . 0.0001975 ft^2
Std. Deviation . . . . . 0.01405 ft
Mean. . . . . -0.004298 ft
No. of Residuals 107
No. of Estimates. 3

R001350



G210 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G210
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0005 cm/sec
Ss = 0.0001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 15.7 ft

WELL DATA (G210)

Initial Displacement: 1.95 ft
Total Well Penetration Depth: 15.7 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.7 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001351

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G210fh.aqt
Title: G210 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:23:01

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G210

AQUIFER DATA

Saturated Thickness: 15.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G210

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.95 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 15.7 ft

No. of Observations: 89

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.988	0.582	1.54	3.854	0.568
0.007	1.947	0.624	1.522	4.094	0.526
0.015	1.908	0.668	1.498	4.344	0.491
0.024	1.894	0.715	1.472	4.604	0.461
0.032	1.89	0.765	1.452	4.884	0.429
0.042	1.886	0.818	1.425	5.184	0.397
0.052	1.871	0.874	1.401	5.494	0.367
0.062	1.868	0.934	1.373	5.834	0.335
0.073	1.858	0.994	1.344	6.184	0.307
0.085	1.849	1.064	1.317	6.554	0.28
0.098	2.179	1.134	1.285	6.954	0.254
0.111	1.84	1.204	1.258	7.374	0.232
0.125	1.771	1.284	1.225	7.814	0.206

R001352

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.14	1.813	1.374	1.188	8.284	0.186
0.156	1.802	1.454	1.158	8.784	0.167
0.172	1.789	1.554	1.123	9.314	0.149
0.19	1.777	1.654	1.087	9.874	0.137
0.209	1.762	1.754	1.055	10.47	0.118
0.229	1.75	1.864	1.018	11.07	0.109
0.25	1.735	1.984	0.982	11.77	0.098
0.272	1.723	2.114	0.943	12.47	0.087
0.296	1.709	2.244	0.908	13.17	0.076
0.321	1.693	2.384	0.866	13.97	0.068
0.347	1.676	2.534	0.832	14.87	0.062
0.375	1.66	2.694	0.79	15.67	0.051
0.405	1.643	2.854	0.757	16.67	0.051
0.436	1.625	3.034	0.718	17.67	0.051
0.47	1.609	3.224	0.68	18.67	0.042
0.505	1.585	3.424	0.639	19.77	0.038
0.542	1.563	3.634	0.603		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0005	cm/sec
Ss	0.0001	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.2393 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004908	0.000128	+/- 0.0002545	3.835	cm/sec
Ss	0.0001094	0.0001408	+/- 0.0002798	0.7771	ft^{-1}
Kz/Kr	1.	2.525	+/- 5.019	0.3961	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.2349 cm^2/sec

R001353

Parameter Correlations

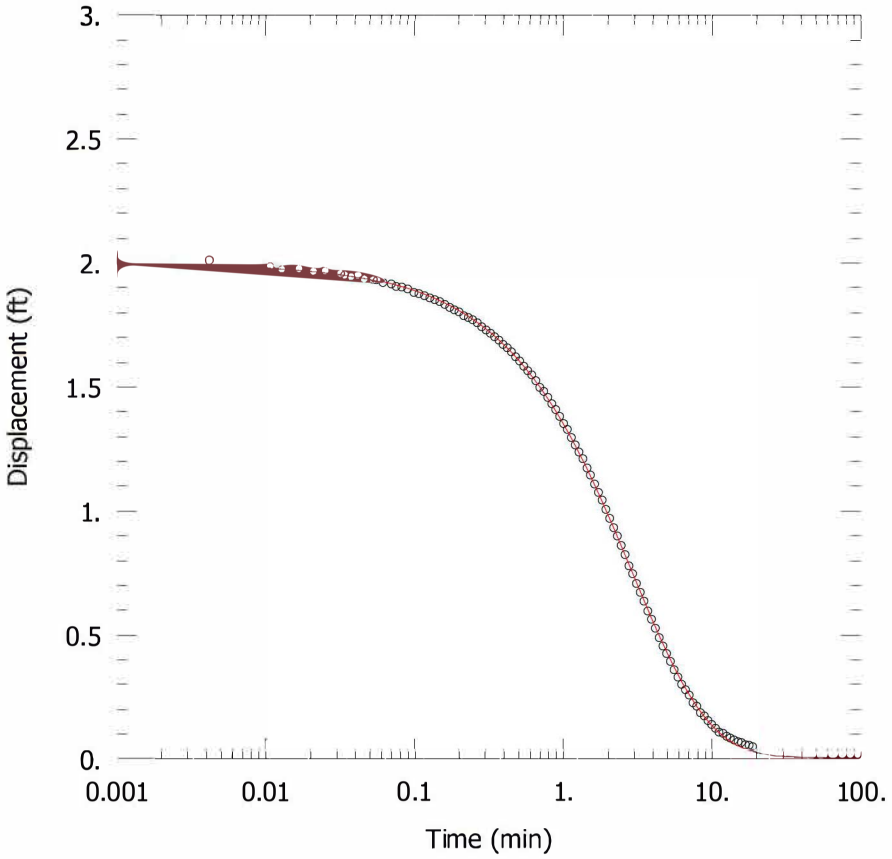
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.98
Kz/Kr	-1.00	0.98	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.1181 ft^2
Variance . . . . . 0.001373 ft^2
Std. Deviation . . . . . 0.03705 ft
Mean. . . . . 0.003124 ft
No. of Residuals 89
No. of Estimates. 3

R001354



G210 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G210
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00048 cm/sec
Ss = 0.0002 ft^{-1}
Kz/Kr = 0.9532

AQUIFER DATA

Saturated Thickness: 15.7 ft

WELL DATA (G210)

Initial Displacement: 2. ft
Total Well Penetration Depth: 15.7 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.7 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001355

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G210rh.aqt
Title: G210 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:23:24

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G210

AQUIFER DATA

Saturated Thickness: 15.7 ft
Anisotropy Ratio (Kz/Kr): 0.9532

SLUG TEST WELL DATA

Test Well: G210

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2. ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 15.7 ft

No. of Observations: 104

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.058	0.326	1.714	2.77	0.778
0.004167	2.011	0.348	1.7	2.93	0.746
0.01072	1.989	0.372	1.686	3.11	0.707
0.01277	1.976	0.397	1.669	3.3	0.671
0.01667	1.977	0.423	1.655	3.5	0.636
0.02083	1.967	0.451	1.639	3.71	0.596
0.025	1.969	0.481	1.619	3.93	0.563
0.03177	1.957	0.512	1.602	4.17	0.527
0.03382	1.951	0.546	1.581	4.42	0.489
0.0375	1.945	0.581	1.563	4.68	0.455
0.04167	1.95	0.618	1.546	4.96	0.425
0.04583	1.936	0.658	1.523	5.26	0.393
0.05278	1.932	0.7	1.496	5.57	0.36

R001356

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.056	1.929	0.744	1.48	5.91	0.33
0.06203	1.918	0.791	1.456	6.26	0.301
0.07057	1.912	0.841	1.43	6.63	0.279
0.076	1.902	0.894	1.407	7.03	0.258
0.083	1.9	0.95	1.379	7.45	0.227
0.091	1.892	1.01	1.35	7.89	0.213
0.1	1.878	1.07	1.327	8.36	0.187
0.108	1.873	1.14	1.294	8.86	0.174
0.118	1.865	1.21	1.264	9.39	0.155
0.128	1.856	1.28	1.236	9.95	0.14
0.138	1.849	1.36	1.209	10.55	0.124
0.149	1.841	1.45	1.171	11.15	0.109
0.161	1.83	1.53	1.143	11.85	0.104
0.174	1.818	1.63	1.107	12.55	0.092
0.187	1.808	1.73	1.073	13.25	0.085
0.201	1.8	1.83	1.042	14.05	0.077
0.216	1.784	1.94	1.005	14.95	0.07
0.232	1.777	2.06	0.969	15.75	0.067
0.248	1.768	2.19	0.931	16.75	0.058
0.266	1.756	2.32	0.898	17.75	0.056
0.285	1.74	2.46	0.86	18.75	0.05
0.305	1.727	2.61	0.823		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00048	cm/sec
Ss	0.0002	ft^{-1}
Kz/Kr	0.9532	

T = K*b = 0.2297 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004796	2.439E-5	+/- 4.839E-5	19.66	cm/sec
Ss	0.0002031	4.796E-5	+/- 9.515E-5	4.235	ft^{-1}
Kz/Kr	0.9532	0.495	+/- 0.9822	1.925	

C.I. is approximate 95% confidence interval for parameter

R001357

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.2295 cm²/sec

Parameter Correlations

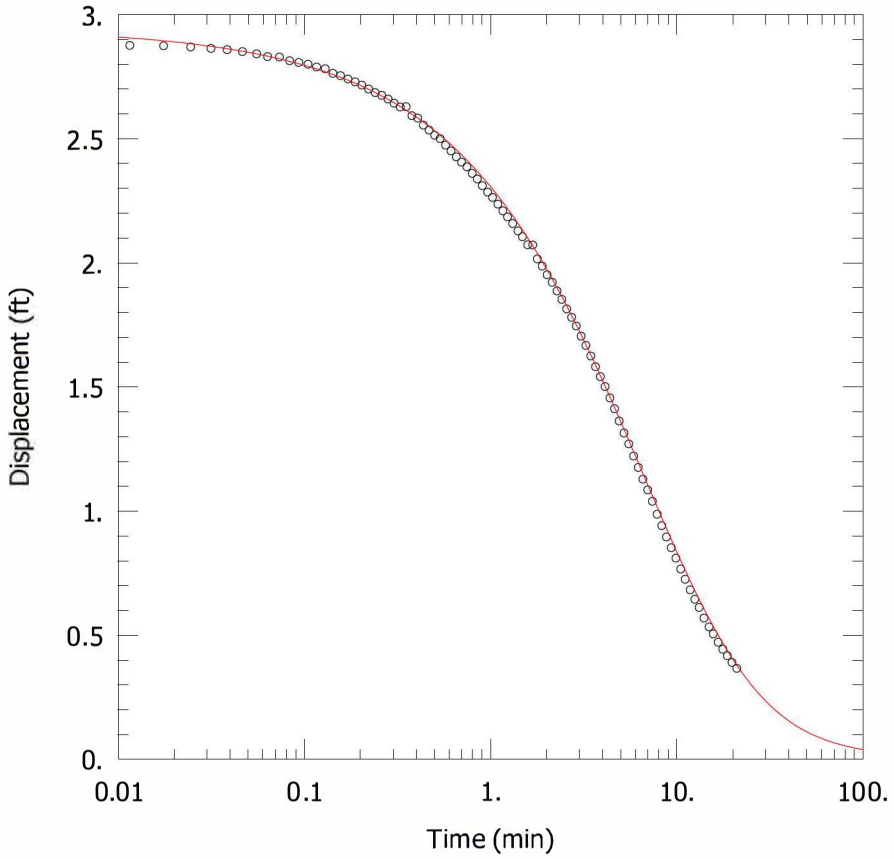
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.98
Kz/Kr	-0.99	0.98	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.008583 ft^2
Variance . . . . . 8.498E-5 ft^2
Std. Deviation . . . . . 0.009219 ft
Mean. . . . . 0.001622 ft
No. of Residuals 104
No. of Estimates. 3

R001358



G212 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G212
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00013 cm/sec
Ss = 0.004 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 12.71 ft

WELL DATA (G212)

Initial Displacement: 2.95 ft
Total Well Penetration Depth: 12.71 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.71 ft
Screen Length: 4.55 ft
Well Radius: 0.08333 ft

R001359

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G212fh.aqt
Title: G212 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:23:53

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G212

AQUIFER DATA

Saturated Thickness: 12.71 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G212

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.95 ft
Static Water Column Height: 12.71 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.55 ft
Total Well Penetration Depth: 12.71 ft

No. of Observations: 96

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.913	0.4676	2.534	3.456	1.624
0.00365	2.884	0.5016	2.513	3.666	1.581
0.0073	2.877	0.5366	2.5	3.886	1.541
0.01157	2.875	0.5736	2.473	4.126	1.501
0.01758	2.873	0.6136	2.45	4.376	1.455
0.02457	2.869	0.6556	2.426	4.636	1.412
0.03157	2.863	0.6996	2.405	4.916	1.362
0.03857	2.858	0.7466	2.386	5.216	1.314
0.04657	2.85	0.7966	2.36	5.526	1.27
0.05557	2.841	0.8496	2.337	5.866	1.221
0.06357	2.83	0.9056	2.31	6.216	1.175
0.07357	2.828	0.9656	2.284	6.586	1.128
0.08357	2.813	1.026	2.263	6.986	1.085

R001360

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.09357	2.806	1.096	2.236	7.406	1.039
0.1046	2.799	1.166	2.209	7.846	0.987
0.1166	2.788	1.236	2.184	8.316	0.941
0.1296	2.781	1.316	2.158	8.816	0.895
0.1426	2.762	1.406	2.128	9.346	0.852
0.1566	2.753	1.486	2.104	9.906	0.81
0.1716	2.74	1.586	2.072	10.51	0.766
0.1876	2.728	1.686	2.071	11.11	0.725
0.2036	2.715	1.786	2.015	11.81	0.682
0.2216	2.699	1.896	1.986	12.51	0.644
0.2406	2.685	2.016	1.951	13.21	0.611
0.2606	2.674	2.146	1.921	14.01	0.569
0.2816	2.659	2.276	1.886	14.91	0.533
0.3036	2.642	2.416	1.852	15.71	0.505
0.3276	2.627	2.566	1.814	16.71	0.471
0.3526	2.628	2.726	1.78	17.71	0.443
0.3786	2.592	2.886	1.745	18.71	0.417
0.4066	2.582	3.066	1.704	19.81	0.39
0.4366	2.554	3.256	1.667	21.01	0.366

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00013	cm/sec
Ss	0.004	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.05036 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001337	5.707E-6	+/- 1.133E-5	23.42	cm/sec
Ss	0.004071	0.0003972	+/- 0.0007888	10.25	ft^{-1}
Kz/Kr	1.	1.219	+/- 2.421	0.8205	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001361

T = K*b = 0.05178 cm²/sec

Parameter Correlations

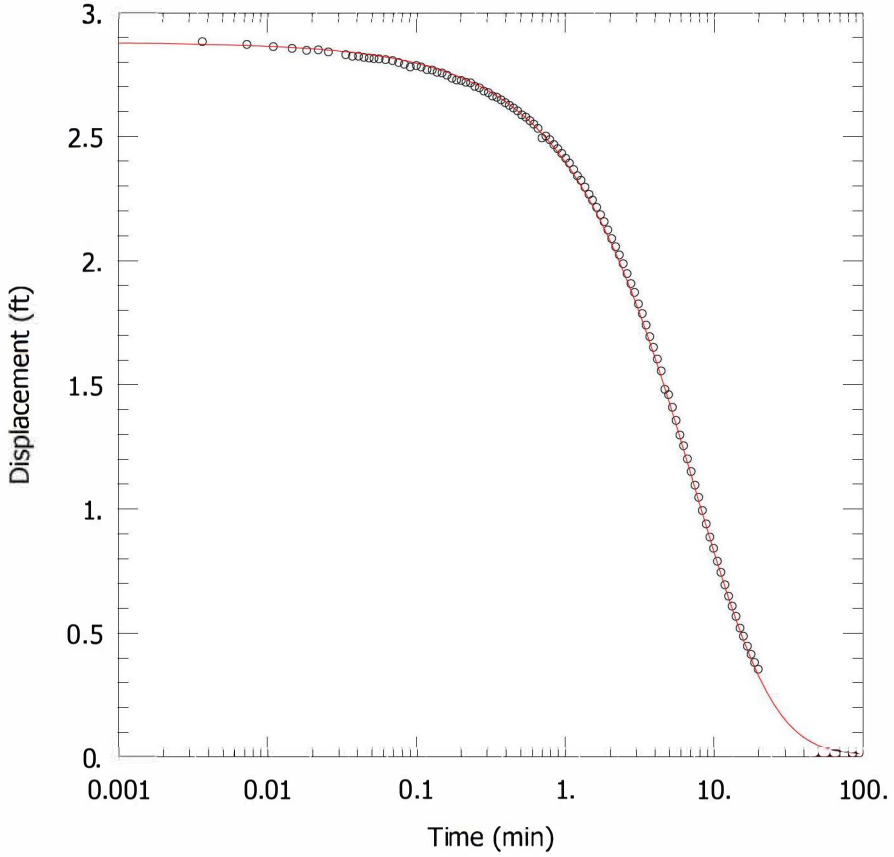
	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.97
Ss	-0.98	1.00	0.93
Kz/Kr	-0.97	0.93	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01956 ft^2
Variance . . . . . 0.0002103 ft^2
Std. Deviation . . . . . 0.0145 ft
Mean. . . . . -0.002036 ft
No. of Residuals 96
No. of Estimates. 3

R001362



G212 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G212
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00018 cm/sec
Ss = 0.0003 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 12.71 ft

WELL DATA (G212)

Initial Displacement: 2.88 ft
Total Well Penetration Depth: 12.71 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.71 ft
Screen Length: 4.55 ft
Well Radius: 0.08333 ft

R001363

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G212rh.aqt
Title: G212 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:24:15

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G212

AQUIFER DATA

Saturated Thickness: 12.71 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G212

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.88 ft
Static Water Column Height: 12.71 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.55 ft
Total Well Penetration Depth: 12.71 ft

No. of Observations: 106

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.866	0.3265	2.662	2.93	1.871
0.003683	2.881	0.3485	2.657	3.111	1.825
0.007333	2.87	0.3725	2.647	3.301	1.786
0.01102	2.861	0.3975	2.635	3.501	1.74
0.01473	2.854	0.4235	2.625	3.711	1.693
0.01843	2.846	0.4515	2.614	3.93	1.65
0.02213	2.848	0.4815	2.602	4.17	1.603
0.02583	2.84	0.5125	2.586	4.42	1.555
0.0338	2.829	0.5465	2.577	4.681	1.481
0.03748	2.822	0.5815	2.563	4.96	1.46
0.04115	2.822	0.6185	2.549	5.261	1.409
0.0448	2.818	0.6585	2.532	5.571	1.356
0.04847	2.815	0.7005	2.493	5.911	1.297

R001364

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05215	2.813	0.7445	2.501	6.261	1.254
0.0565	2.812	0.7915	2.486	6.63	1.201
0.0625	2.809	0.8415	2.467	7.031	1.15
0.0695	2.805	0.8945	2.45	7.45	1.095
0.0765	2.797	0.9505	2.431	7.891	1.046
0.0835	2.79	1.011	2.411	8.361	0.993
0.0915	2.779	1.071	2.392	8.861	0.939
0.1005	2.785	1.141	2.366	9.39	0.886
0.1085	2.779	1.21	2.341	9.95	0.841
0.1185	2.769	1.281	2.323	10.55	0.789
0.1285	2.767	1.361	2.295	11.15	0.744
0.1385	2.758	1.45	2.266	11.85	0.694
0.1495	2.755	1.531	2.243	12.55	0.648
0.1615	2.746	1.631	2.214	13.25	0.608
0.1745	2.734	1.73	2.184	14.05	0.567
0.1875	2.727	1.831	2.156	14.95	0.52
0.2015	2.725	1.94	2.123	15.75	0.487
0.2165	2.718	2.061	2.088	16.75	0.447
0.2325	2.715	2.191	2.055	17.75	0.414
0.2485	2.701	2.321	2.022	18.75	0.381
0.2665	2.695	2.461	1.987	19.85	0.354
0.2855	2.682	2.611	1.947		
0.3055	2.676	2.771	1.907		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00018	cm/sec
Ss	0.0003	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.06973 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001762	7.1E-6	+/- 1.408E-5	24.81	cm/sec
Ss	0.0002962	4.965E-5	+/- 9.845E-5	5.966	ft^{-1}
Kz/Kr	1.	0.4616	+/- 0.9153	2.166	

R001365

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.06825 cm²/sec

Parameter Correlations

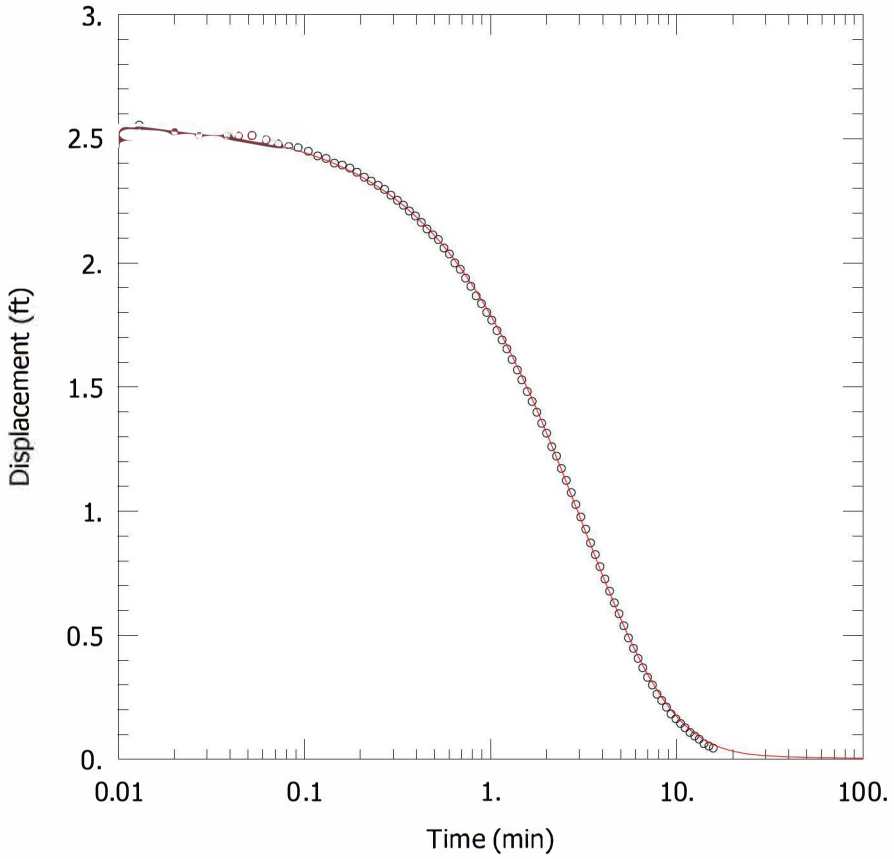
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.96
Kz/Kr	-0.99	0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01265 ft^2
Variance . . . . . 0.0001228 ft^2
Std. Deviation . . . . . 0.01108 ft
Mean. . . . . -0.003437 ft
No. of Residuals 106
No. of Estimates. 3

R001366



G215 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G215
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0005 cm/sec
Ss = 9.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 12.7 ft

WELL DATA (G215)

Initial Displacement: 2.57 ft
Total Well Penetration Depth: 12.7 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.7 ft
Screen Length: 4.39 ft
Well Radius: 0.08333 ft

R001367

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G215fh.aqt
Title: G215 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:24:40

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G215

AQUIFER DATA

Saturated Thickness: 12.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G215

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.57 ft
Static Water Column Height: 12.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.39 ft
Total Well Penetration Depth: 12.7 ft

No. of Observations: 88

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.543	0.49	2.112	3.244	0.927
0.006	2.561	0.525	2.093	3.444	0.871
0.013	2.554	0.562	2.059	3.654	0.824
0.02	2.533	0.602	2.035	3.874	0.776
0.027	2.518	0.644	1.999	4.114	0.726
0.03818	2.518	0.688	1.973	4.364	0.677
0.044	2.516	0.735	1.938	4.624	0.63
0.052	2.518	0.785	1.905	4.904	0.586
0.062	2.501	0.838	1.866	5.204	0.538
0.072	2.484	0.894	1.835	5.514	0.489
0.082	2.476	0.954	1.8	5.854	0.447
0.093	2.472	1.014	1.769	6.204	0.406
0.105	2.449	1.084	1.727	6.574	0.369

R001368

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.118	2.43	1.154	1.689	6.974	0.33
0.131	2.42	1.224	1.653	7.394	0.299
0.145	2.401	1.304	1.61	7.834	0.262
0.16	2.393	1.394	1.568	8.304	0.237
0.176	2.381	1.474	1.528	8.804	0.21
0.192	2.364	1.574	1.481	9.339	0.182
0.21	2.344	1.674	1.441	9.894	0.163
0.229	2.329	1.774	1.398	10.49	0.144
0.249	2.311	1.884	1.353	11.09	0.127
0.27	2.295	2.004	1.313	11.79	0.108
0.292	2.272	2.134	1.259	12.49	0.094
0.316	2.251	2.264	1.221	13.19	0.081
0.341	2.231	2.404	1.171	13.99	0.063
0.367	2.208	2.554	1.123	14.89	0.053
0.395	2.188	2.714	1.074	15.69	0.045
0.425	2.162	2.874	1.026		
0.456	2.136	3.054	0.976		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0005	cm/sec
Ss	9.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1935 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0005031	5.308E-5	+/- 0.0001055	9.478	cm/sec
Ss	8.802E-5	4.315E-5	+/- 8.578E-5	2.04	ft^{-1}
Kz/Kr	1.	1.055	+/- 2.097	0.9479	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1948 cm^2/sec

R001369

Parameter Correlations

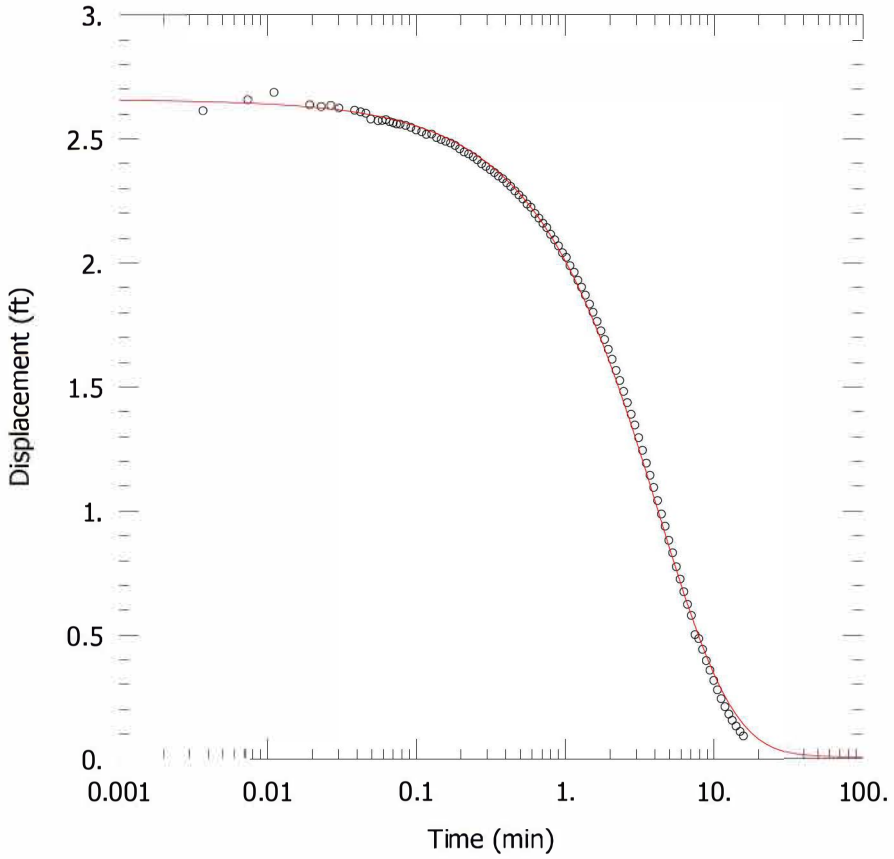
	Kr	Ss	Kz/Kr
Kr	1.00	-1.00	-1.00
Ss	-1.00	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.00943 ft^2
Variance . . . . . 0.0001109 ft^2
Std. Deviation . . . . . 0.01053 ft
Mean. . . . . 3.96E-5 ft
No. of Residuals 88
No. of Estimates. 3

R001370



G215 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G215
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00035 cm/sec
Ss = 0.00015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 12.7 ft

WELL DATA (G215)

Initial Displacement: 2.66 ft
Total Well Penetration Depth: 12.7 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 12.7 ft
Screen Length: 4.39 ft
Well Radius: 0.08333 ft

R0001371

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G215rh.aqt
Title: G215 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:25:02

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G215

AQUIFER DATA

Saturated Thickness: 12.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G215

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.66 ft
Static Water Column Height: 12.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.39 ft
Total Well Penetration Depth: 12.7 ft

No. of Observations: 104

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.653	0.275	2.4	2.329	1.526
0.003683	2.613	0.2939	2.389	2.469	1.482
0.00735	2.658	0.314	2.376	2.619	1.437
0.01102	2.688	0.335	2.364	2.779	1.39
0.01922	2.637	0.3569	2.35	2.939	1.347
0.02288	2.63	0.381	2.339	3.119	1.296
0.02657	2.635	0.4059	2.323	3.309	1.245
0.03023	2.624	0.432	2.308	3.509	1.193
0.03862	2.615	0.46	2.29	3.719	1.144
0.04228	2.609	0.49	2.274	3.939	1.095
0.04595	2.603	0.521	2.258	4.179	1.042
0.04962	2.58	0.555	2.237	4.429	0.988
0.05535	2.573	0.5899	2.224	4.689	0.939

R001372

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05905	2.574	0.627	2.199	4.969	0.882
0.06277	2.577	0.667	2.18	5.269	0.832
0.06643	2.569	0.7089	2.16	5.588	0.776
0.07012	2.565	0.753	2.142	5.921	0.726
0.0738	2.56	0.8	2.115	6.269	0.675
0.07795	2.559	0.8499	2.093	6.639	0.624
0.08495	2.554	0.903	2.069	7.039	0.58
0.09195	2.546	0.9589	2.041	7.459	0.502
0.09995	2.536	1.019	2.022	7.899	0.486
0.109	2.529	1.079	1.989	8.369	0.443
0.117	2.518	1.149	1.962	8.869	0.398
0.127	2.519	1.219	1.93	9.399	0.359
0.1369	2.505	1.289	1.902	9.959	0.318
0.147	2.497	1.369	1.87	10.56	0.28
0.158	2.49	1.459	1.834	11.16	0.244
0.1699	2.483	1.539	1.801	11.86	0.212
0.183	2.473	1.639	1.764	12.56	0.182
0.196	2.46	1.739	1.726	13.26	0.157
0.21	2.447	1.839	1.691	14.06	0.134
0.225	2.439	1.949	1.652	14.96	0.112
0.241	2.428	2.069	1.612	15.76	0.094
0.257	2.416	2.199	1.567		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00035	cm/sec
Ss	0.00015	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.1355\ cm^2/sec$

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0003512	5.917E-5	+/- 0.0001174	5.935	cm/sec
Ss	0.0001143	8.861E-5	+/- 0.0001758	1.29	ft^{-1}
Kz/Kr	1.	1.688	+/- 3.348	0.5925	

C.I. is approximate 95% confidence interval for parameter

R001373

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1359 cm²/sec

Parameter Correlations

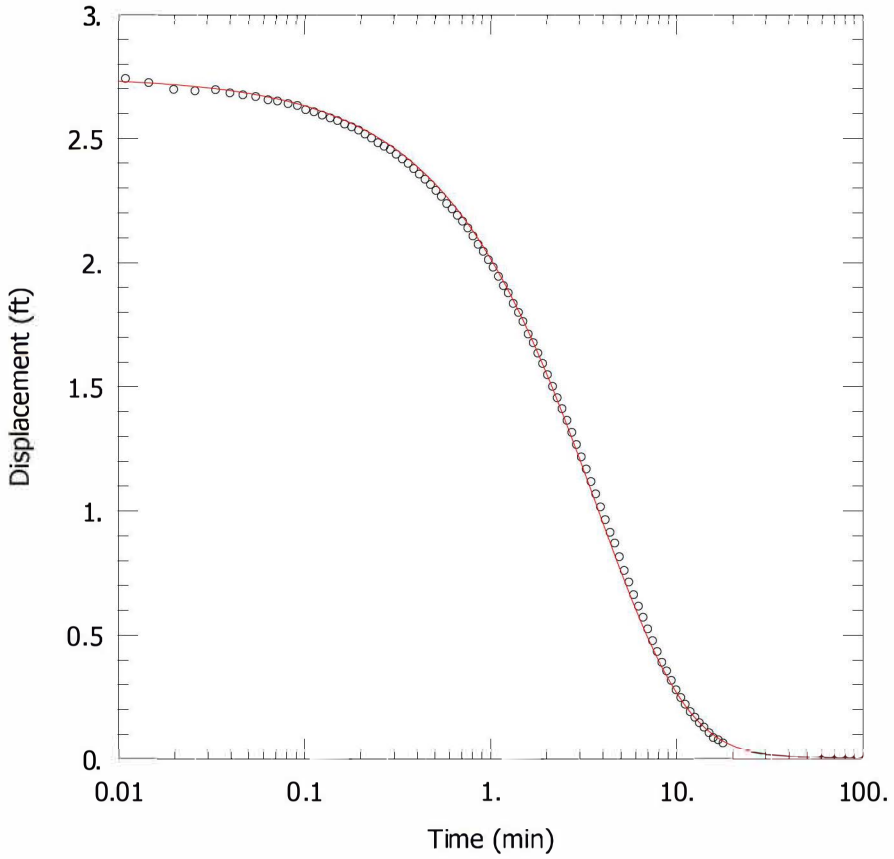
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.05196 ft^2
Variance . . . . . 0.0005144 ft^2
Std. Deviation . . . . . 0.02268 ft
Mean. . . . . -0.007737 ft
No. of Residuals 104
No. of Estimates. 3

R001374



G218 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G218
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00041 cm/sec
Ss = 0.0001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 14.16 ft

WELL DATA (G218)

Initial Displacement: 2.75 ft
Total Well Penetration Depth: 14.16 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.16 ft
Screen Length: 4.44 ft
Well Radius: 0.08333 ft

R001375

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G218fh.aqt
Title: G218 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:25:29

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G218

AQUIFER DATA

Saturated Thickness: 14.16 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G218

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.75 ft
Static Water Column Height: 14.16 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.44 ft
Total Well Penetration Depth: 14.16 ft

No. of Observations: 95

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.731	0.4149	2.356	3.074	1.217
0.00365	2.758	0.4449	2.335	3.264	1.168
0.007317	2.755	0.4759	2.314	3.464	1.118
0.01097	2.741	0.5099	2.29	3.674	1.068
0.01462	2.724	0.5449	2.266	3.894	1.016
0.01988	2.697	0.5819	2.237	4.134	0.964
0.02588	2.691	0.6219	2.216	4.384	0.913
0.03338	2.696	0.6639	2.19	4.644	0.87
0.03988	2.683	0.7079	2.166	4.924	0.815
0.04687	2.675	0.7549	2.139	5.224	0.76
0.05488	2.668	0.8049	2.107	5.534	0.713
0.06387	2.655	0.8579	2.073	5.874	0.662
0.07187	2.65	0.9139	2.045	6.224	0.616

R0001376

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.08188	2.64	0.9739	2.011	6.594	0.571
0.09188	2.632	1.034	1.981	6.994	0.524
0.1019	2.615	1.104	1.944	7.414	0.477
0.1129	2.607	1.174	1.907	7.854	0.433
0.1249	2.593	1.244	1.878	8.324	0.39
0.1379	2.582	1.324	1.835	8.824	0.355
0.1509	2.571	1.414	1.799	9.354	0.317
0.1649	2.557	1.494	1.762	9.918	0.279
0.1799	2.546	1.594	1.712	10.51	0.248
0.1959	2.533	1.694	1.677	11.11	0.221
0.2119	2.517	1.794	1.635	11.81	0.191
0.2299	2.501	1.904	1.593	12.51	0.169
0.2489	2.482	2.024	1.548	13.21	0.147
0.2689	2.468	2.154	1.501	14.01	0.129
0.2899	2.455	2.284	1.455	14.91	0.106
0.3119	2.436	2.424	1.411	15.71	0.087
0.3359	2.417	2.574	1.364	16.71	0.078
0.3609	2.399	2.734	1.316	17.71	0.065
0.3869	2.378	2.894	1.267		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00041	cm/sec
Ss	0.0001	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.177 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004038	6.674E-5	+/- 0.0001326	6.05	cm/sec
Ss	9.763E-5	7.71E-5	+/- 0.0001531	1.266	ft^{-1}
Kz/Kr	1.	1.614	+/- 3.206	0.6195	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001377

T = K*b = 0.1743 cm²/sec

Parameter Correlations

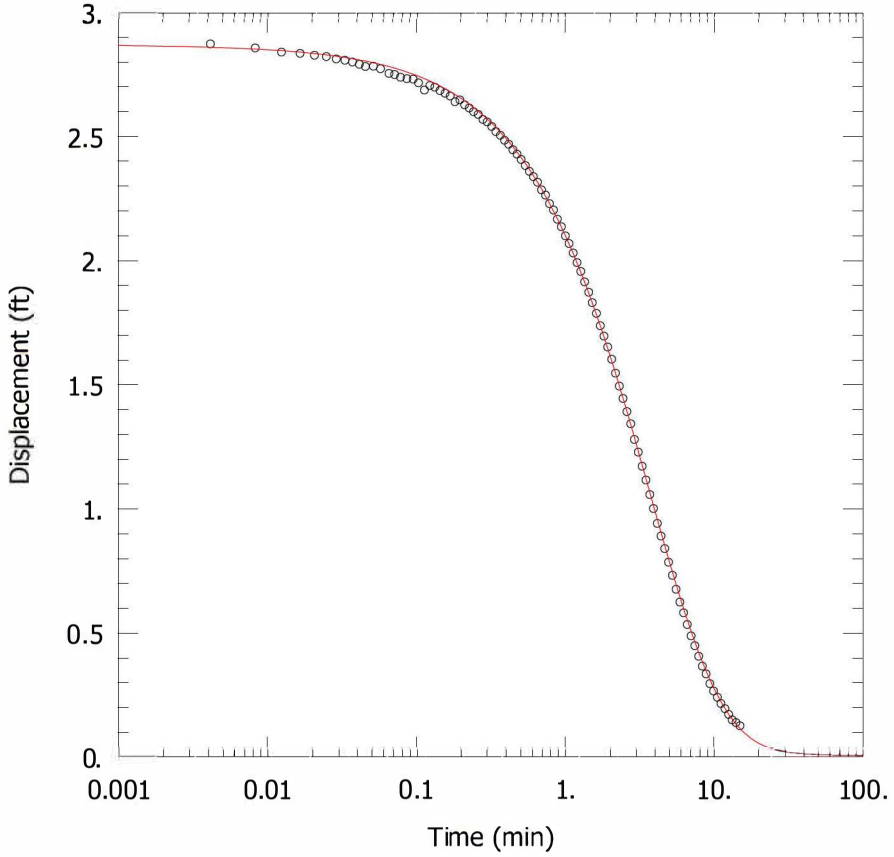
	Kr	Ss	Kz/Kr
Kr	1.00	-1.00	-1.00
Ss	-1.00	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.03742 ft^2
Variance . . . . . 0.0004068 ft^2
Std. Deviation . . . . . 0.02017 ft
Mean. . . . . -0.006913 ft
No. of Residuals 95
No. of Estimates. 3

R001378



G218 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G218
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00041 cm/sec
Ss = 0.0001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 14.16 ft

WELL DATA (G218)

Initial Displacement: 2.87 ft
Total Well Penetration Depth: 14.16 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.16 ft
Screen Length: 4.44 ft
Well Radius: 0.08333 ft

R001379

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G218rh.aqt
Title: G218 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:25:51

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: G218

AQUIFER DATA

Saturated Thickness: 14.16 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G218

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.87 ft
Static Water Column Height: 14.16 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.44 ft
Total Well Penetration Depth: 14.16 ft

No. of Observations: 99

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.887	0.3008	2.558	2.316	1.494
0.004167	2.872	0.3218	2.54	2.456	1.444
0.008333	2.856	0.3438	2.519	2.606	1.391
0.0125	2.839	0.3678	2.504	2.766	1.342
0.01667	2.834	0.3928	2.484	2.926	1.279
0.02083	2.826	0.4188	2.468	3.106	1.228
0.025	2.821	0.4469	2.446	3.296	1.171
0.02917	2.811	0.4768	2.428	3.496	1.116
0.03333	2.806	0.5078	2.407	3.706	1.057
0.0375	2.799	0.5418	2.382	3.926	1.001
0.04167	2.79	0.5768	2.359	4.166	0.941
0.04583	2.781	0.6138	2.338	4.416	0.89
0.05183	2.782	0.6538	2.315	4.676	0.84

R001380

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05785	2.772	0.6958	2.284	4.956	0.785
0.06585	2.753	0.7398	2.263	5.256	0.732
0.07183	2.749	0.7868	2.229	5.566	0.676
0.07883	2.738	0.8368	2.203	5.906	0.624
0.08693	2.732	0.8898	2.166	6.256	0.581
0.09583	2.73	0.9458	2.136	6.626	0.534
0.104	2.715	1.006	2.099	7.026	0.488
0.1138	2.686	1.066	2.068	7.446	0.449
0.1238	2.704	1.136	2.03	7.886	0.406
0.1338	2.698	1.206	1.991	8.356	0.366
0.1448	2.684	1.276	1.956	8.856	0.335
0.1568	2.673	1.356	1.914	9.386	0.296
0.1698	2.662	1.446	1.872	9.946	0.266
0.1828	2.639	1.526	1.83	10.55	0.241
0.1968	2.647	1.626	1.787	11.15	0.216
0.2118	2.627	1.726	1.737	11.85	0.195
0.2278	2.614	1.826	1.695	12.55	0.172
0.2438	2.599	1.936	1.651	13.25	0.15
0.2618	2.588	2.056	1.602	14.05	0.139
0.2808	2.568	2.186	1.546	14.95	0.126

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00041	cm/sec
Ss	0.0001	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.177\ cm^2/sec$

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004113	3.569E-5	+/- 7.084E-5	11.53	cm/sec
Ss	0.0001095	4.481E-5	+/- 8.895E-5	2.444	ft^{-1}
Kz/Kr	1.	0.8554	+/- 1.698	1.169	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001381

T = K*b = 0.1775 cm²/sec

Parameter Correlations

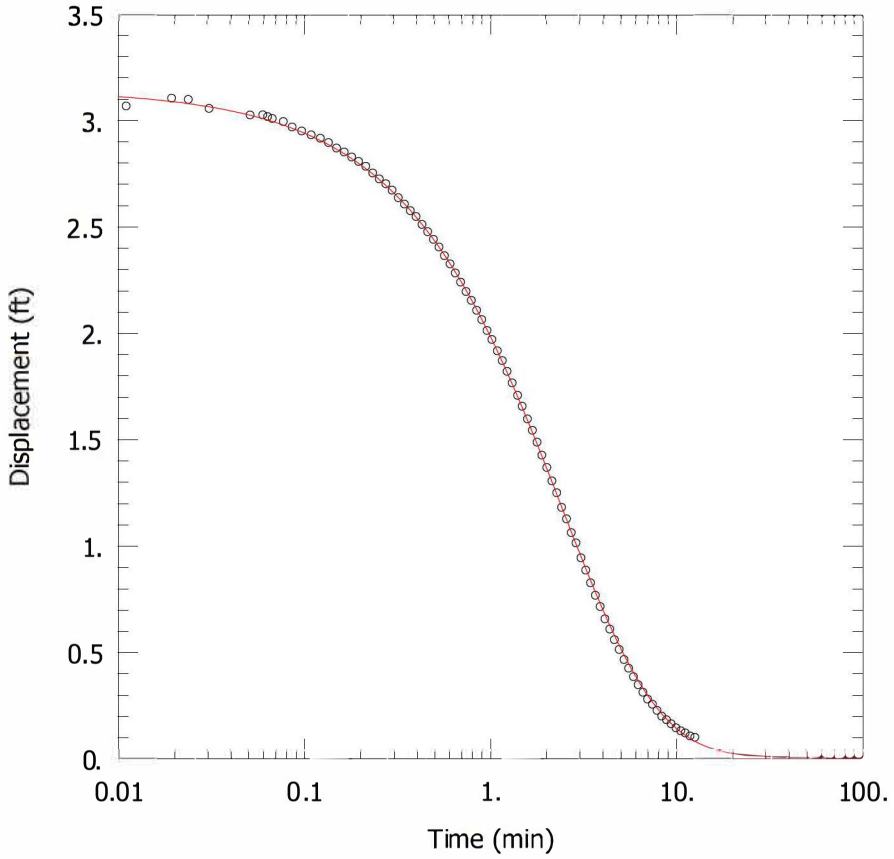
	Kr	Ss	Kz/Kr
Kr	1.00	-1.00	-1.00
Ss	-1.00	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01553 ft^2
Variance . . . . . 0.0001617 ft^2
Std. Deviation . . . . . 0.01272 ft
Mean. . . . . -0.004094 ft
No. of Residuals 99
No. of Estimates 3

R001382



G270 @ GMF RECYCLE POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G270
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00055 cm/sec
Ss = 0.0002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 16.41 ft

WELL DATA (G270)

Initial Displacement: 3.15 ft
Total Well Penetration Depth: 16.41 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 16.41 ft
Screen Length: 4.79 ft
Well Radius: 0.08333 ft

R001383

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G270fh.aqt
Title: G270 @ GMF Recycle Pond – Falling Head Test
Date: 11/28/16
Time: 09:26:15

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G270

AQUIFER DATA

Saturated Thickness: 16.41 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G270

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.15 ft
Static Water Column Height: 16.41 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.79 ft
Total Well Penetration Depth: 16.41 ft

No. of Observations: 86

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.166	0.3988	2.549	2.558	1.129
0.003684	3.185	0.4288	2.512	2.718	1.064
0.007367	3.122	0.4598	2.478	2.878	1.016
0.01105	3.068	0.4938	2.442	3.058	0.946
0.0194	3.105	0.5288	2.406	3.248	0.888
0.02382	3.099	0.5658	2.365	3.448	0.828
0.03082	3.057	0.6059	2.327	3.658	0.77
0.05118	3.026	0.6478	2.284	3.878	0.717
0.05982	3.027	0.6918	2.241	4.118	0.659
0.06355	3.019	0.7388	2.197	4.368	0.611
0.06725	3.01	0.7888	2.155	4.628	0.561
0.07712	2.995	0.8418	2.109	4.908	0.515
0.08595	2.97	0.8978	2.065	5.208	0.468

R001384

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.09682	2.951	0.9578	2.014	5.518	0.427
0.1088	2.933	1.018	1.972	5.858	0.387
0.1218	2.917	1.088	1.918	6.208	0.35
0.1348	2.897	1.158	1.872	6.578	0.314
0.1488	2.871	1.228	1.822	6.978	0.282
0.1638	2.852	1.308	1.768	7.398	0.258
0.1798	2.829	1.398	1.709	7.838	0.229
0.1958	2.808	1.478	1.658	8.308	0.202
0.2138	2.785	1.578	1.598	8.808	0.185
0.2328	2.754	1.678	1.545	9.338	0.166
0.2528	2.726	1.778	1.489	9.898	0.147
0.2738	2.703	1.888	1.428	10.5	0.133
0.2958	2.673	2.008	1.37	11.1	0.123
0.3198	2.638	2.138	1.307	11.8	0.109
0.3448	2.608	2.268	1.251	12.5	0.103
0.3708	2.577	2.408	1.183		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00055	cm/sec
Ss	0.0002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.2751 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0005615	2.665E-5	+/- 5.3E-5	21.07	cm/sec
Ss	0.0001649	3.741E-5	+/- 7.442E-5	4.408	ft^{-1}
Kz/Kr	1.	0.4806	+/- 0.9559	2.081	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.2809 cm^2/sec

Parameter Correlations

R001385

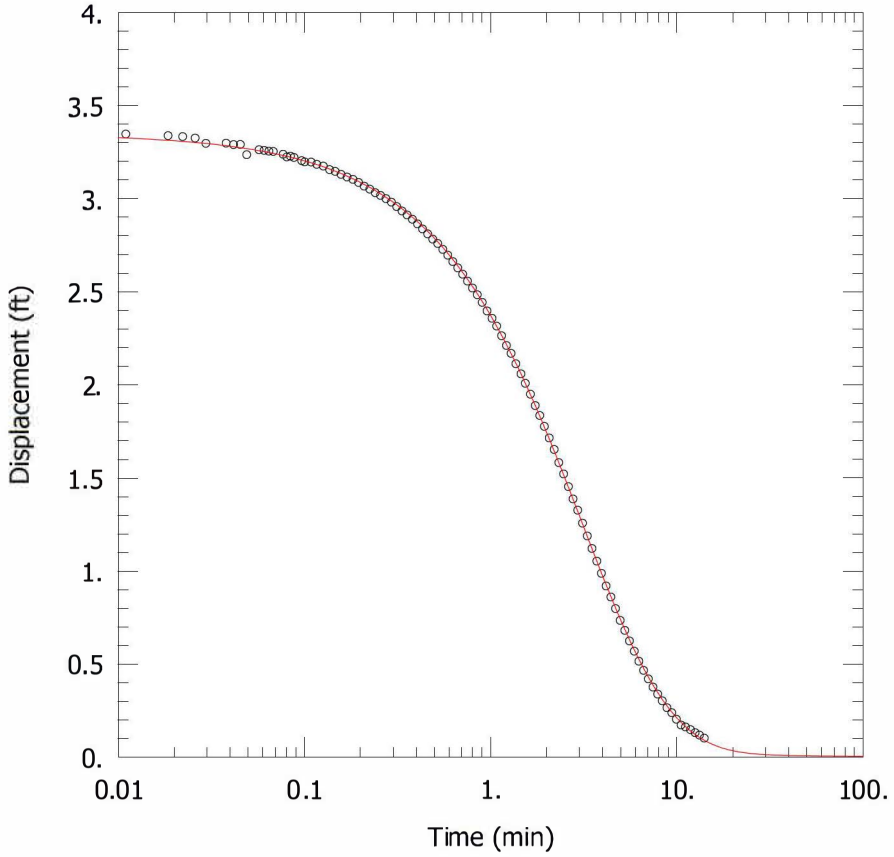
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.98
Kz/Kr	-1.00	0.98	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01042 ft^2
Variance . . . . . 0.0001255 ft^2
Std. Deviation . . . . . 0.0112 ft
Mean. . . . . 0.001403 ft
No. of Residuals 86
No. of Estimates. 3

R001386



G270 @ GMF RECYCLE POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G270
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00048 cm/sec
Ss = 3.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 16.41 ft

WELL DATA (G270)

Initial Displacement: 3.35 ft
Total Well Penetration Depth: 16.41 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 16.41 ft
Screen Length: 4.79 ft
Well Radius: 0.08333 ft

R001387

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G270rh.aqt
Title: G270 @ GMF Recycle Pond – Rising Head Test
Date: 11/28/16
Time: 09:26:36

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G270

AQUIFER DATA

Saturated Thickness: 16.41 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G270

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.35 ft
Static Water Column Height: 16.41 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.79 ft
Total Well Penetration Depth: 16.41 ft

No. of Observations: 102

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.415	0.2566	3.017	2.069	1.715
0.003683	3.383	0.2747	3.	2.199	1.653
0.00735	3.366	0.2937	2.981	2.329	1.582
0.01102	3.347	0.3136	2.957	2.469	1.521
0.01857	3.338	0.3347	2.934	2.619	1.453
0.02223	3.333	0.3567	2.912	2.779	1.387
0.02595	3.325	0.3806	2.889	2.939	1.327
0.02962	3.297	0.4057	2.864	3.119	1.257
0.03803	3.298	0.4316	2.837	3.309	1.188
0.04172	3.29	0.4597	2.811	3.509	1.121
0.0454	3.291	0.4896	2.782	3.719	1.053
0.04907	3.236	0.5206	2.759	3.939	0.988
0.05722	3.262	0.5546	2.727	4.179	0.92

R001388

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06092	3.259	0.5897	2.696	4.429	0.861
0.06458	3.255	0.6267	2.662	4.689	0.799
0.06827	3.253	0.6666	2.628	4.969	0.735
0.07693	3.238	0.7087	2.594	5.269	0.682
0.08063	3.224	0.7527	2.557	5.579	0.625
0.08433	3.228	0.7996	2.52	5.919	0.57
0.08803	3.221	0.8497	2.484	6.269	0.516
0.09683	3.204	0.9026	2.443	6.639	0.467
0.1006	3.197	0.9587	2.397	7.039	0.421
0.1089	3.196	1.019	2.357	7.459	0.377
0.1167	3.184	1.079	2.315	7.899	0.339
0.1267	3.175	1.149	2.264	8.369	0.303
0.1366	3.156	1.219	2.211	8.869	0.266
0.1467	3.146	1.289	2.169	9.399	0.24
0.1577	3.13	1.369	2.113	9.959	0.204
0.1697	3.116	1.459	2.059	10.56	0.173
0.1827	3.103	1.539	2.008	11.16	0.163
0.1956	3.087	1.639	1.95	11.86	0.148
0.2097	3.067	1.739	1.889	12.56	0.132
0.2246	3.051	1.839	1.835	13.26	0.119
0.2407	3.032	1.949	1.777	14.06	0.103

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00048	cm/sec
Ss	3.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.2401 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004785	5.292E-5	+/- 0.000105	9.043	cm/sec
Ss	3.353E-5	1.819E-5	+/- 3.61E-5	1.843	ft^{-1}
Kz/Kr	1.	1.096	+/- 2.175	0.912	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error

R001389

No estimation window

T = K*b = 0.2394 cm²/sec

Parameter Correlations

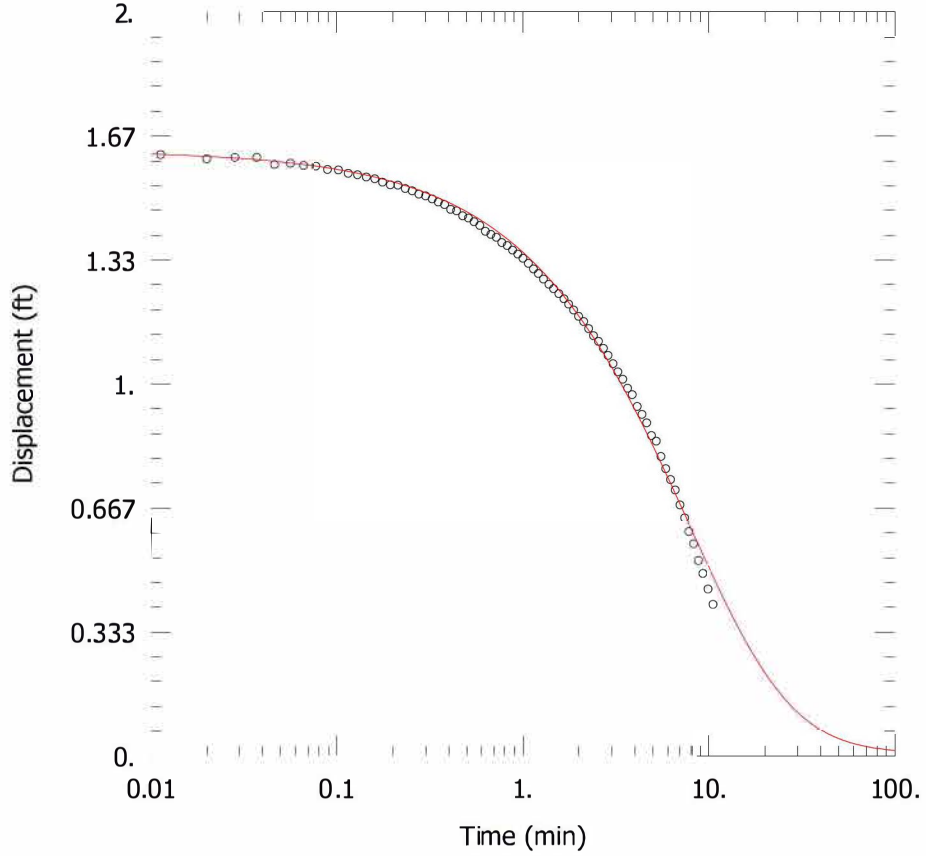
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01528 ft^2
Variance . . . . . 0.0001544 ft^2
Std. Deviation . . . . . 0.01242 ft
Mean. . . . . 0.001996 ft
No. of Residuals 102
No. of Estimates. 3

R001390



G271 @ GMF RECYCLE POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G271
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00016 cm/sec
Ss = 0.0007 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 7.36 ft

WELL DATA (G271)

Initial Displacement: 1.63 ft
Total Well Penetration Depth: 7.36 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 7.36 ft
Screen Length: 4.35 ft
Well Radius: 0.08333 ft

R001391

Diagnostic Statistics

Estimation complete! Parameter change criterion (ETOL) reached.

Aquifer Model: Confined
Solution Method: KGS Model

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.000162	1.925E-5	+/- 3.835E-5	8.418	cm/sec
Ss	0.0007608	0.0002807	+/- 0.0005592	2.71	ft^{-1}
Kz/Kr	1.	1.965	+/- 3.914	0.5089	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.03635 cm^2/sec

Parameter Correlations

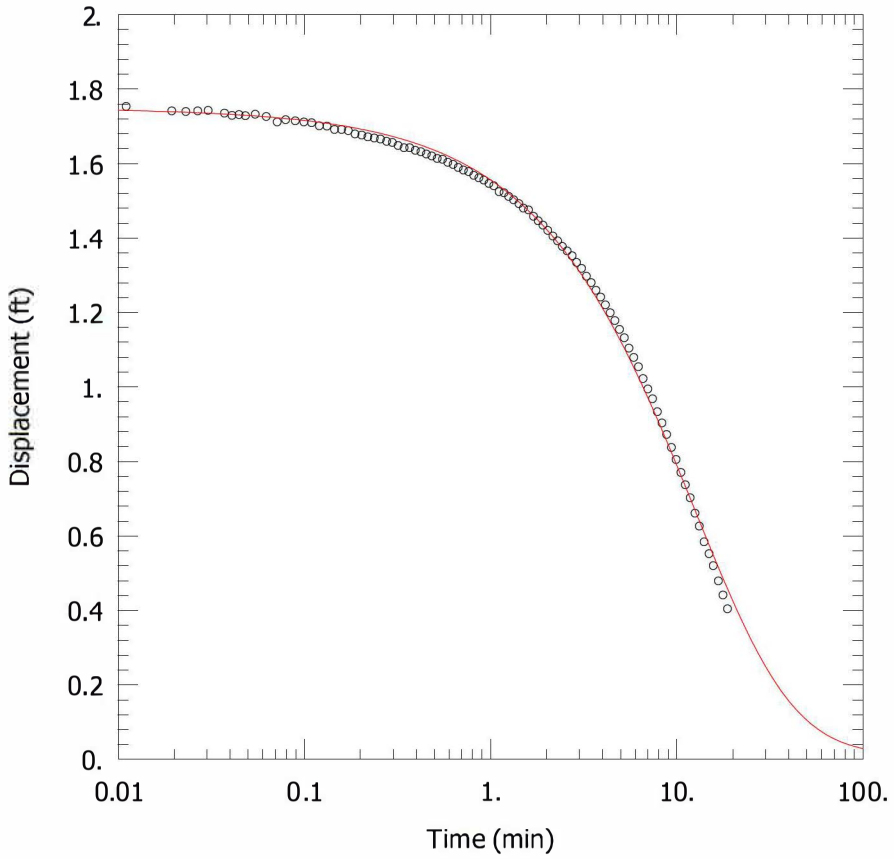
	Kr	Ss	Kz/Kr
Kr	1.00	-0.97	-0.97
Ss	-0.97	1.00	0.88
Kz/Kr	-0.97	0.88	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02832 ft^2
Variance . . . . . 0.0003726 ft^2
Std. Deviation . . . . . 0.0193 ft
Mean. . . . . -0.002737 ft
No. of Residuals 79
No. of Estimates. 3

R001392



G271 @ GMF RECYCLE POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G271
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00011 cm/sec
Ss = 0.0003 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 7.36 ft

WELL DATA (G271)

Initial Displacement: 1.75 ft
Total Well Penetration Depth: 7.36 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 7.36 ft
Screen Length: 4.35 ft
Well Radius: 0.08333 ft

R001393

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G271rh.aqt
Title: G271 @ GMF Recycle Pond – Rising Head Test
Date: 11/28/16
Time: 09:27:29

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G271

AQUIFER DATA

Saturated Thickness: 7.36 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G271

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.75 ft
Static Water Column Height: 7.36 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.35 ft
Total Well Penetration Depth: 7.36 ft

No. of Observations: 99

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.752	0.3685	1.642	2.902	1.334
0.003667	1.759	0.3945	1.635	3.082	1.318
0.00735	1.758	0.4225	1.631	3.272	1.297
0.01105	1.753	0.4525	1.625	3.471	1.28
0.01943	1.741	0.4835	1.62	3.682	1.259
0.02312	1.739	0.5175	1.613	3.902	1.241
0.02678	1.741	0.5525	1.611	4.141	1.22
0.03045	1.742	0.5895	1.603	4.391	1.199
0.03727	1.735	0.6295	1.597	4.652	1.178
0.04097	1.729	0.6715	1.589	4.931	1.154
0.04467	1.731	0.7155	1.582	5.231	1.132
0.04837	1.728	0.7625	1.578	5.542	1.104
0.0545	1.732	0.8125	1.568	5.882	1.079

R001394

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06252	1.726	0.8655	1.561	6.231	1.054
0.0715	1.711	0.9215	1.555	6.601	1.022
0.0795	1.717	0.9815	1.546	7.002	0.994
0.0895	1.714	1.042	1.54	7.422	0.968
0.09952	1.711	1.111	1.524	7.862	0.933
0.1095	1.709	1.182	1.521	8.332	0.903
0.1205	1.701	1.252	1.511	8.832	0.872
0.1325	1.7	1.331	1.502	9.361	0.837
0.1455	1.691	1.422	1.492	9.922	0.805
0.1585	1.691	1.502	1.48	10.52	0.77
0.1725	1.688	1.601	1.475	11.13	0.737
0.1875	1.679	1.702	1.458	11.82	0.702
0.2035	1.676	1.802	1.446	12.52	0.661
0.2195	1.671	1.912	1.434	13.22	0.626
0.2375	1.668	2.031	1.42	14.02	0.584
0.2565	1.665	2.162	1.405	14.92	0.552
0.2765	1.659	2.292	1.392	15.72	0.52
0.2975	1.656	2.432	1.377	16.72	0.479
0.3195	1.648	2.582	1.365	17.72	0.441
0.3435	1.642	2.741	1.352	18.72	0.404

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00011	cm/sec
Ss	0.0003	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02468 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0001097	2.066E-5	+/- 4.102E-5	5.308	cm/sec
Ss	0.0002898	0.0001997	+/- 0.0003965	1.451	ft^{-1}
Kz/Kr	1.	2.523	+/- 5.007	0.3964	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001395

T = K*b = 0.02461 cm²/sec

Parameter Correlations

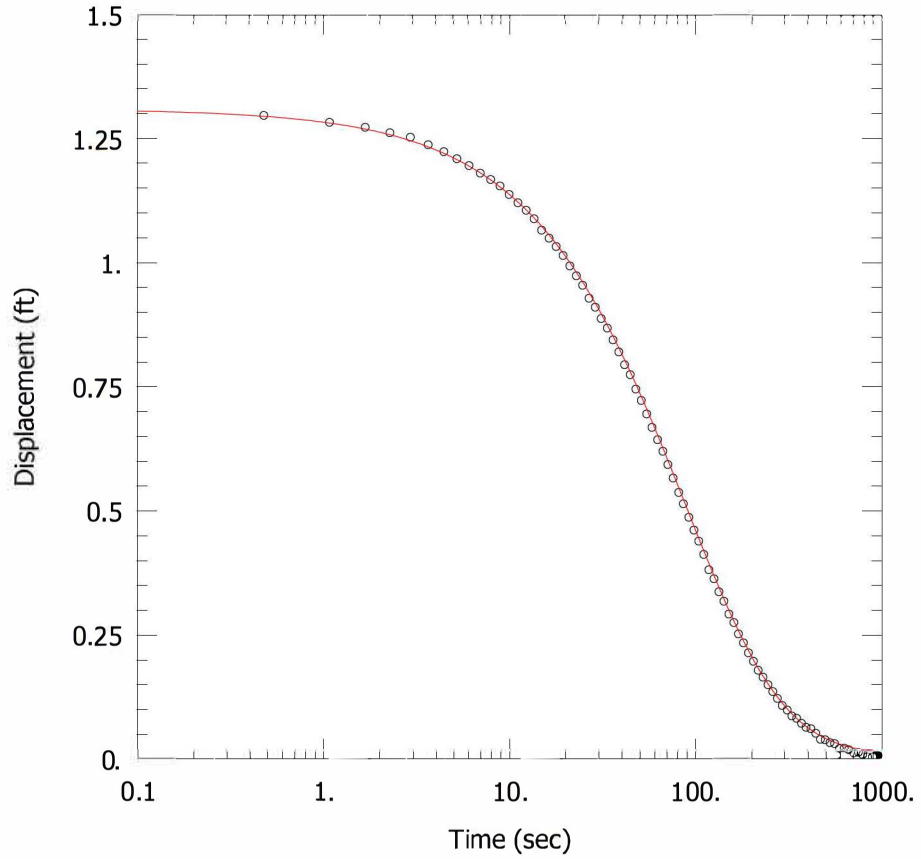
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.97
Kz/Kr	-0.99	0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02807 ft^2
Variance . . . . . 0.0002924 ft^2
Std. Deviation . . . . . 0.0171 ft
Mean. . . . . -0.003834 ft
No. of Residuals 99
No. of Estimates. 3

R001396



G273 @ GMF RECYCLE POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G273
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.001 cm/sec
Ss = 9.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 6.69 ft

WELL DATA (G273)

Initial Displacement: 1.31 ft
Total Well Penetration Depth: 6.69 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 6.69 ft
Screen Length: 4.48 ft
Well Radius: 0.08333 ft

R001397

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G273fh.aqt
Title: G273 @ GMF Recycle Pond – Falling Head Test
Date: 11/28/16
Time: 09:27:52

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G273

AQUIFER DATA

Saturated Thickness: 6.69 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G273

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.31 ft
Static Water Column Height: 6.69 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.48 ft
Total Well Penetration Depth: 6.69 ft

No. of Observations: 89

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
-3.499	1.386	22.86	0.973	169.8	0.252
-3.249	1.325	24.72	0.954	180.6	0.234
-2.85	1.405	26.76	0.928	192.	0.214
-2.639	1.363	28.86	0.91	204.	0.197
-2.279	1.387	31.08	0.887	216.6	0.179
-1.859	1.36	33.48	0.868	229.8	0.165
-1.439	1.343	36.	0.844	244.2	0.15
-1.02	1.331	38.64	0.82	259.2	0.136
0.	1.307	41.46	0.794	274.8	0.122
0.48	1.296	44.46	0.774	291.6	0.108
1.081	1.282	47.64	0.745	309.6	0.099
1.681	1.272	51.	0.722	328.2	0.087
2.281	1.261	54.6	0.695	348.6	0.082

R001398

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
2.94	1.252	58.2	0.668	369.6	0.072
3.66	1.237	62.4	0.643	391.8	0.064
4.44	1.223	66.6	0.62	415.8	0.061
5.22	1.209	70.8	0.593	441.	0.052
6.061	1.195	75.65	0.566	467.4	0.04
6.96	1.18	81.	0.537	495.6	0.039
7.92	1.167	85.8	0.514	525.6	0.033
8.88	1.154	91.8	0.487	557.4	0.031
9.96	1.137	97.8	0.461	591.	0.021
11.1	1.12	103.8	0.439	627.	0.022
12.3	1.105	110.4	0.412	663.	0.019
13.56	1.088	117.6	0.381	705.	0.012
14.88	1.065	125.4	0.363	747.	0.013
16.32	1.049	133.2	0.337	789.	0.009
17.82	1.032	141.6	0.318	837.	0.004
19.38	1.014	150.6	0.292	891.	0.004
21.06	0.993	160.2	0.275		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.001	cm/sec
Ss	9.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.2039 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.001024	0.0001056	+/- 0.0002099	9.693	cm/sec
Ss	8.684E-5	3.541E-5	+/- 7.039E-5	2.452	ft^{-1}
Kz/Kr	1.	2.292	+/- 4.557	0.4362	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.2087 cm^2/sec

R001399

Parameter Correlations

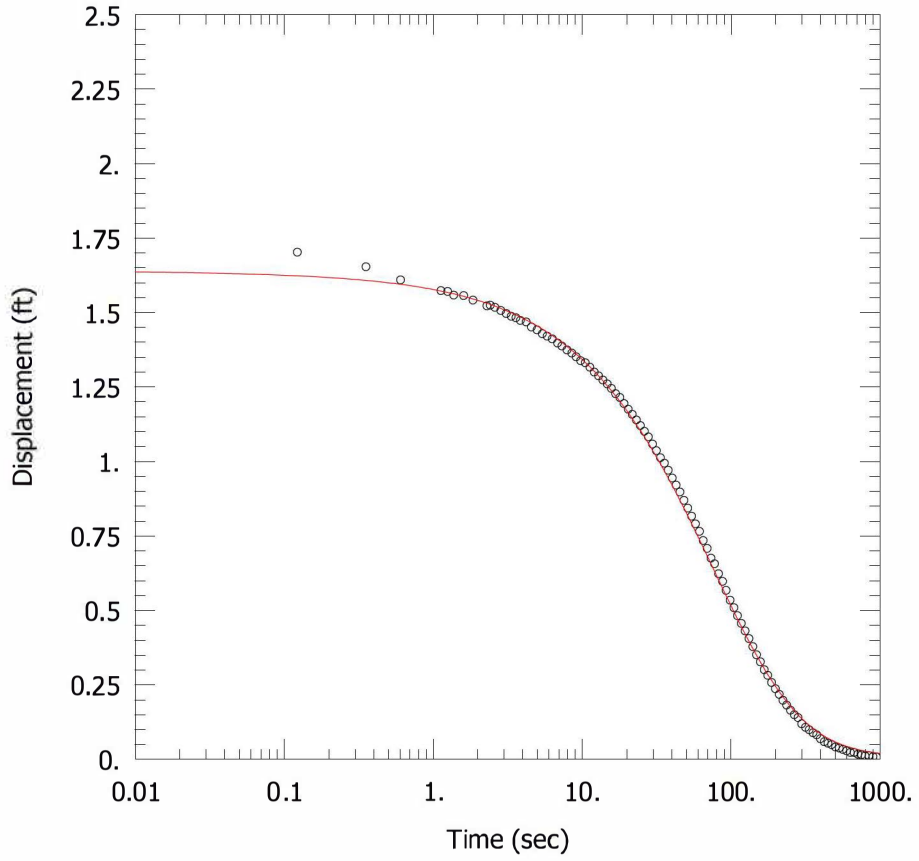
	Kr	Ss	Kz/Kr
Kr	1.00	-0.47	-0.92
Ss	-0.47	1.00	0.11
Kz/Kr	-0.92	0.11	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02896 ft^2
Variance . . . . . 0.0003367 ft^2
Std. Deviation . . . . . 0.01835 ft
Mean. . . . . 0.004437 ft
No. of Residuals 89
No. of Estimates. 3

R001400



G273 @ GMF RECYCLE POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G273
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00083 cm/sec
Ss = 0.0015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 6.69 ft

WELL DATA (G273)

Initial Displacement: 1.64 ft
Total Well Penetration Depth: 6.69 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 6.69 ft
Screen Length: 4.48 ft
Well Radius: 0.08333 ft

R001401

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G273rh.aqt
Title: G273 @ GMF Recycle Pond – Rising Head Test
Date: 11/28/16
Time: 09:28:15

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: G273

AQUIFER DATA

Saturated Thickness: 6.69 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G273

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.64 ft
Static Water Column Height: 6.69 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.48 ft
Total Well Penetration Depth: 6.69 ft

No. of Observations: 105

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.692	15.73	1.245	132.3	0.405
0.123	1.702	16.82	1.227	140.1	0.378
0.355	1.653	17.95	1.214	148.5	0.351
0.605	1.609	19.16	1.194	157.5	0.327
1.131	1.573	20.41	1.175	167.1	0.301
1.254	1.57	21.73	1.158	176.7	0.282
1.377	1.558	23.18	1.139	187.5	0.258
1.605	1.556	24.68	1.12	198.9	0.237
1.855	1.541	26.23	1.101	210.9	0.218
2.298	1.522	27.91	1.082	223.5	0.198
2.421	1.524	29.73	1.058	236.7	0.182
2.605	1.517	31.57	1.036	251.1	0.165
2.855	1.506	33.62	1.012	266.1	0.15

R001402

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
3.105	1.496	35.72	0.994	281.7	0.14
3.355	1.487	37.94	0.97	298.5	0.119
3.605	1.482	40.34	0.944	316.5	0.107
3.855	1.473	42.85	0.92	335.1	0.099
4.215	1.468	45.49	0.897	355.5	0.089
4.575	1.451	48.31	0.869	376.5	0.082
4.995	1.441	51.31	0.843	398.7	0.069
5.415	1.428	54.49	0.816	422.7	0.059
5.835	1.42	57.85	0.79	447.9	0.054
6.315	1.411	61.45	0.765	474.3	0.049
6.855	1.397	65.06	0.734	502.5	0.041
7.335	1.387	69.25	0.708	532.5	0.038
7.935	1.374	73.45	0.675	564.3	0.033
8.535	1.363	77.66	0.656	597.9	0.028
9.136	1.351	82.45	0.623	633.9	0.023
9.795	1.338	87.86	0.597	669.9	0.023
10.52	1.331	92.66	0.567	711.9	0.017
11.3	1.316	98.66	0.534	753.9	0.015
12.07	1.3	104.7	0.509	795.9	0.011
12.91	1.287	110.7	0.482	843.9	0.012
13.82	1.273	117.3	0.456	897.9	0.009
14.78	1.26	124.5	0.431	945.9	0.008

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00083	cm/sec
Ss	0.0015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1692 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0008319	7.881E-5	+/- 0.0001563	10.56	cm/sec
Ss	0.001271	0.0003781	+/- 0.0007497	3.362	ft^{-1}
Kz/Kr	1.	1.63	+/- 3.232	0.6135	

C.I. is approximate 95% confidence interval for parameter

R001403

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1696 cm²/sec

Parameter Correlations

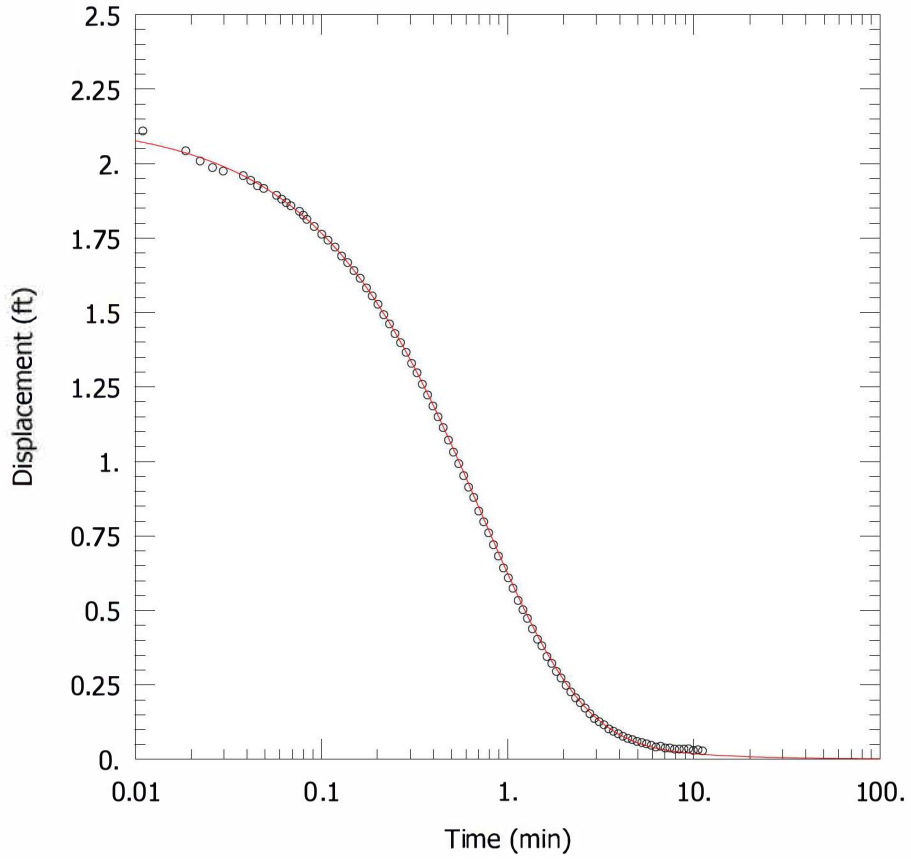
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.98
Ss	-0.99	1.00	0.95
Kz/Kr	-0.98	0.95	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02784 ft^2
Variance . . . . . 0.000273 ft^2
Std. Deviation . . . . . 0.01652 ft
Mean. . . . . -0.003839 ft
No. of Residuals 105
No. of Estimates. 3

R001404



G279 @ GMF RECYCLE POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G279
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0017 cm/sec
Ss = 0.0007 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 7. ft

WELL DATA (G279)

Initial Displacement: 2.15 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.08333 ft

Static Water Column Height: 7. ft
Screen Length: 4.39 ft
Well Radius: 0.08333 ft

R001405

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G279fh.aqt
Title: G279 @ GMF Recycle Pond – Falling Head Test
Date: 11/28/16
Time: 09:28:43

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G279

AQUIFER DATA

Saturated Thickness: 7. ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G279

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.15 ft
Static Water Column Height: 7. ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.39 ft
Total Well Penetration Depth: 7. ft

No. of Observations: 96

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.068	0.2487	1.429	1.831	0.295
0.003683	2.003	0.2667	1.398	1.941	0.273
0.00735	2.023	0.2857	1.366	2.061	0.248
0.011	2.109	0.3057	1.329	2.191	0.226
0.0187	2.042	0.3267	1.297	2.321	0.206
0.02238	2.008	0.3487	1.259	2.461	0.19
0.02607	1.986	0.3727	1.223	2.611	0.172
0.02973	1.974	0.3977	1.186	2.771	0.153
0.0381	1.959	0.4237	1.149	2.931	0.137
0.0418	1.943	0.4517	1.113	3.111	0.126
0.04547	1.925	0.4817	1.071	3.301	0.116
0.04915	1.916	0.5127	1.031	3.501	0.102
0.05758	1.893	0.5467	0.992	3.711	0.094

R001406

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06127	1.88	0.5817	0.952	3.931	0.086
0.06497	1.868	0.6187	0.913	4.171	0.077
0.06865	1.858	0.6587	0.879	4.421	0.07
0.07633	1.839	0.7007	0.833	4.681	0.066
0.08003	1.826	0.7447	0.797	4.961	0.06
0.08372	1.812	0.7917	0.76	5.261	0.056
0.09167	1.788	0.8417	0.72	5.571	0.052
0.1007	1.762	0.8947	0.682	5.911	0.047
0.1087	1.742	0.9507	0.642	6.261	0.041
0.1187	1.719	1.011	0.609	6.631	0.044
0.1287	1.689	1.071	0.574	7.031	0.038
0.1387	1.667	1.141	0.533	7.451	0.038
0.1497	1.64	1.211	0.502	7.891	0.034
0.1617	1.614	1.281	0.473	8.361	0.034
0.1747	1.582	1.361	0.438	8.861	0.034
0.1877	1.555	1.451	0.403	9.391	0.035
0.2017	1.527	1.531	0.381	9.951	0.03
0.2167	1.492	1.631	0.345	10.55	0.032
0.2327	1.461	1.731	0.322	11.15	0.028

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0017	cm/sec
Ss	0.0007	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.3627 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.001719	0.0001754	+/- 0.0003483	9.798	cm/sec
Ss	0.0007021	0.0002498	+/- 0.000496	2.811	ft^{-1}
Kz/Kr	1.	1.488	+/- 2.955	0.672	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001407

T = K*b = 0.3667 cm²/sec

Parameter Correlations

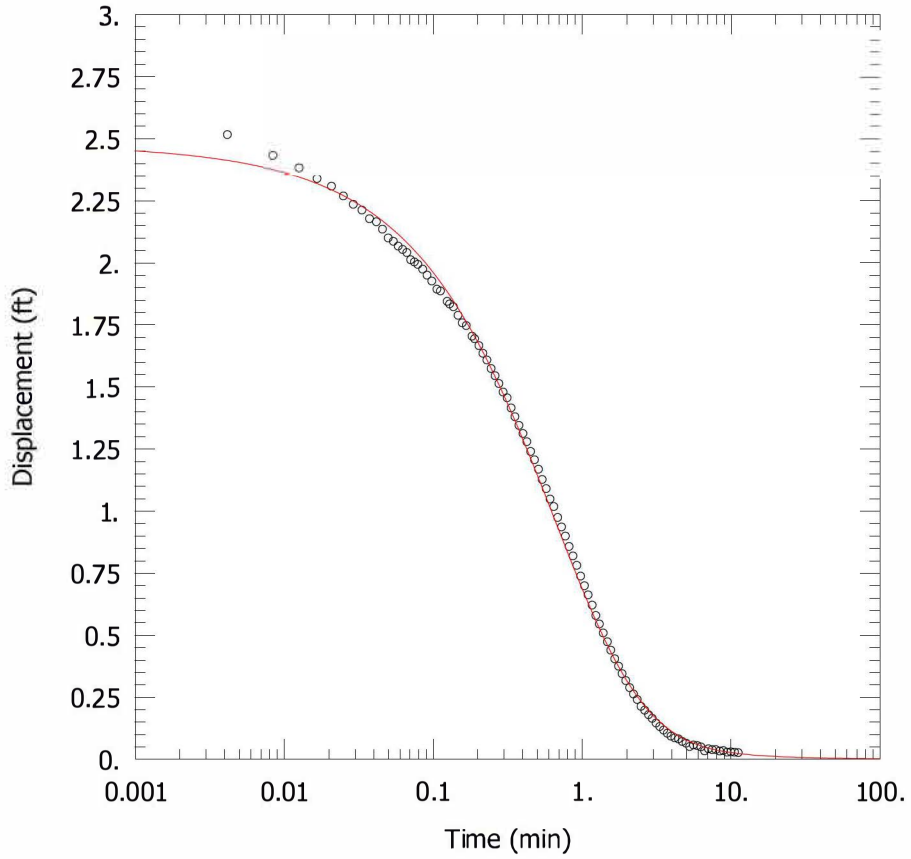
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.97
Kz/Kr	-0.99	0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02749 ft^2
Variance . . . . . 0.0002956 ft^2
Std. Deviation . . . . . 0.01719 ft
Mean. . . . . -0.0009089 ft
No. of Residuals 96
No. of Estimates. 3

R001408



G279 @ GMF RECYCLE POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G279
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0015 cm/sec
Ss = 0.0025 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 7. ft

WELL DATA (G279)

Initial Displacement: 2.48 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.08333 ft

Static Water Column Height: 7. ft
Screen Length: 4.39 ft
Well Radius: 0.08333 ft

R001409

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G279rh.aqt
Title: G279 @ GMF Recycle Pond – Rising Head Test
Date: 11/28/16
Time: 10:43:04

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: G279

AQUIFER DATA

Saturated Thickness: 7. ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G279

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.48 ft
Static Water Column Height: 7. ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.39 ft
Total Well Penetration Depth: 7. ft

No. of Observations: 102

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.581	0.2162	1.635	1.659	0.405
0.004167	2.516	0.2302	1.608	1.759	0.375
0.008333	2.433	0.2452	1.574	1.859	0.345
0.0125	2.383	0.2612	1.545	1.969	0.317
0.01667	2.339	0.2772	1.513	2.089	0.289
0.02083	2.308	0.2952	1.479	2.219	0.263
0.025	2.269	0.3142	1.456	2.349	0.241
0.02917	2.235	0.3342	1.415	2.489	0.213
0.03333	2.212	0.3552	1.38	2.639	0.198
0.0375	2.177	0.3772	1.345	2.799	0.18
0.04167	2.165	0.4012	1.312	2.959	0.165
0.04583	2.135	0.4262	1.279	3.139	0.146
0.05	2.1	0.4522	1.24	3.329	0.132

R001410

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05417	2.086	0.4802	1.206	3.529	0.118
0.05833	2.067	0.5102	1.168	3.739	0.105
0.0625	2.053	0.5412	1.127	3.959	0.093
0.06667	2.041	0.5752	1.09	4.199	0.086
0.07083	2.012	0.6102	1.048	4.449	0.082
0.075	2.003	0.6472	1.018	4.709	0.072
0.07917	1.993	0.6872	0.974	4.989	0.065
0.08517	1.974	0.7292	0.936	5.291	0.051
0.09117	1.95	0.7732	0.899	5.599	0.058
0.09817	1.926	0.8202	0.857	5.939	0.055
0.1062	1.893	0.8702	0.819	6.289	0.05
0.1122	1.886	0.9232	0.781	6.659	0.034
0.1245	1.844	0.9792	0.738	7.059	0.042
0.1292	1.834	1.039	0.699	7.479	0.039
0.1372	1.822	1.099	0.662	7.919	0.039
0.1472	1.788	1.169	0.621	8.389	0.033
0.1572	1.758	1.239	0.579	8.889	0.035
0.1672	1.747	1.309	0.545	9.419	0.029
0.1829	1.704	1.389	0.509	9.979	0.03
0.1902	1.694	1.479	0.473	10.58	0.029
0.2032	1.666	1.559	0.44	11.18	0.027

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0015	cm/sec
Ss	0.0025	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.32 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.001475	0.0001155	+/- 0.0002292	12.77	cm/sec
Ss	0.00256	0.0005911	+/- 0.001173	4.331	ft^{-1}
Kz/Kr	1.	1.448	+/- 2.872	0.6908	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error

R001411

No estimation window

T = K*b = 0.3147 cm²/sec

Parameter Correlations

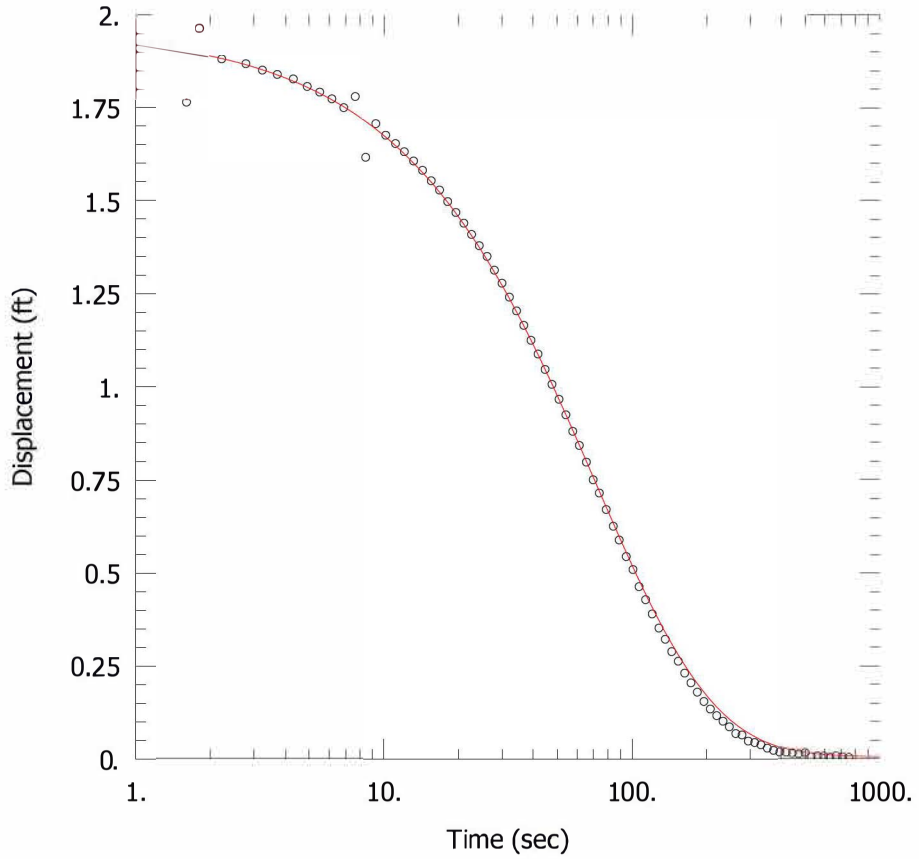
	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.96
Ss	-0.98	1.00	0.91
Kz/Kr	-0.96	0.91	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.08946 ft^2
Variance . . . . . 0.0009036 ft^2
Std. Deviation . . . . . 0.03006 ft
Mean. . . . . -0.004822 ft
No. of Residuals 102
No. of Estimates. 3

R001412



G280 @ GMF RECYCLE POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G280
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00125 cm/sec
Ss = 2.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 15.26 ft

WELL DATA (G280)

Initial Displacement: 1.96 ft
Total Well Penetration Depth: 15.26 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.26 ft
Screen Length: 4.84 ft
Well Radius: 0.08333 ft

R001413

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G280fh.aqt
Title: G280 @ GMF Recycle Pond – Falling Head Test
Date: 11/28/16
Time: 09:29:18

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G280

AQUIFER DATA

Saturated Thickness: 15.26 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G280

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.96 ft
Static Water Column Height: 15.26 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.84 ft
Total Well Penetration Depth: 15.26 ft

No. of Observations: 86

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.974	24.31	1.378	153.8	0.263
0.417	1.933	26.11	1.349	163.4	0.231
0.61	1.928	27.97	1.312	173.1	0.205
0.971	1.913	30.01	1.277	183.8	0.18
1.607	1.763	32.11	1.24	195.3	0.155
1.81	1.964	34.33	1.203	207.3	0.135
2.23	1.879	36.73	1.164	219.8	0.117
2.789	1.866	39.25	1.124	233.1	0.102
3.25	1.849	41.89	1.087	247.4	0.087
3.73	1.837	44.71	1.046	262.4	0.069
4.33	1.825	47.71	1.006	278.	0.065
4.93	1.805	50.89	0.966	294.8	0.049
5.53	1.79	54.25	0.924	312.8	0.045

R001414

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
6.19	1.772	57.85	0.88	331.4	0.039
6.91	1.748	61.45	0.842	351.8	0.03
7.69	1.778	65.65	0.797	372.8	0.024
8.47	1.615	69.85	0.75	395.	0.019
9.31	1.705	74.05	0.714	419.	0.018
10.21	1.674	78.85	0.67	444.3	0.016
11.17	1.652	84.25	0.625	470.6	0.014
12.13	1.63	89.05	0.588	499.	0.017
13.21	1.605	95.05	0.544	528.8	0.006
14.35	1.58	101.1	0.509	560.6	0.008
15.55	1.552	107.1	0.463	594.2	0.007
16.81	1.527	113.6	0.428	630.4	0.004
18.13	1.496	120.8	0.39	666.2	0.008
19.57	1.467	128.7	0.352	708.2	0.006
21.07	1.438	136.4	0.322	750.2	0.004
22.63	1.408	144.8	0.289		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

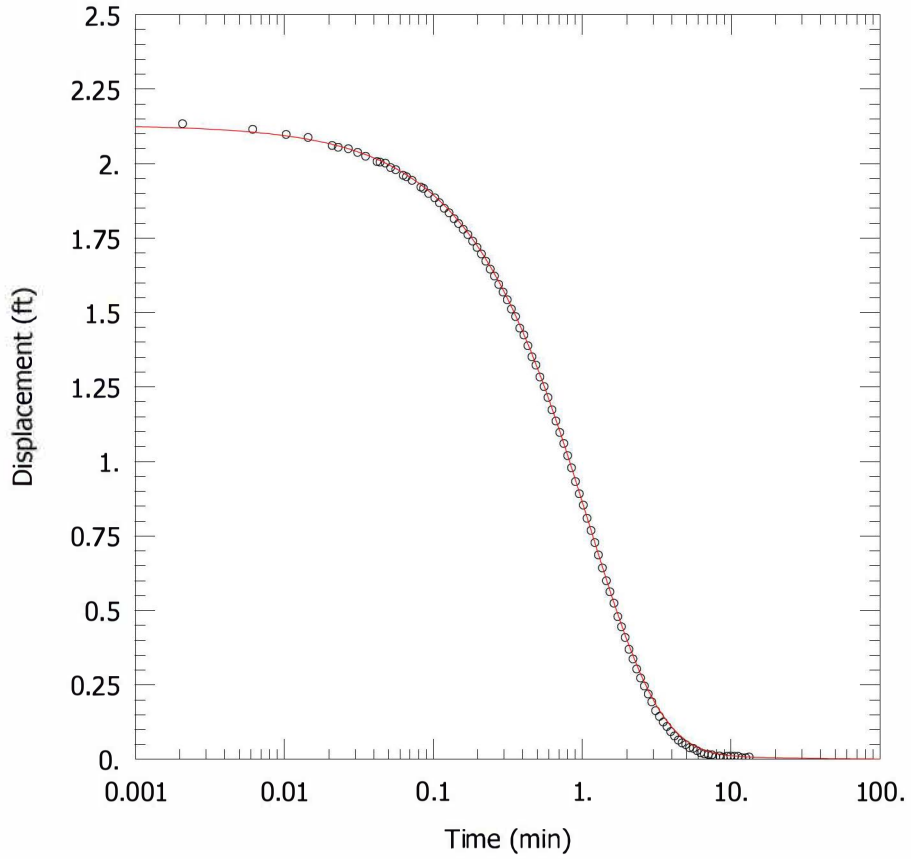
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00125	cm/sec
Ss	2.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.5814 cm^2/sec

R001415



G280 @ GMF RECYCLE POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G280
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0013 cm/sec
Ss = 6.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 15.26 ft

WELL DATA (G280)

Initial Displacement: 2.13 ft
Total Well Penetration Depth: 15.26 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.26 ft
Screen Length: 4.84 ft
Well Radius: 0.08333 ft

R001416

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G280rh.aqt
Title: G280 @ GMF Recycle Pond – Rising Head Test
Date: 11/28/16
Time: 09:29:41

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G280

AQUIFER DATA

Saturated Thickness: 15.26 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G280

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.13 ft
Static Water Column Height: 15.26 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.84 ft
Total Well Penetration Depth: 15.26 ft

No. of Observations: 101

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.135	0.2583	1.622	2.07	0.369
0.002083	2.133	0.2763	1.594	2.2	0.337
0.006167	2.114	0.2953	1.568	2.33	0.303
0.01033	2.097	0.3153	1.542	2.47	0.273
0.0145	2.087	0.3363	1.511	2.62	0.246
0.02105	2.06	0.3583	1.486	2.78	0.219
0.0231	2.054	0.3823	1.447	2.94	0.193
0.027	2.049	0.4073	1.424	3.12	0.163
0.03117	2.037	0.4333	1.388	3.31	0.144
0.03533	2.024	0.4613	1.351	3.51	0.125
0.04208	2.006	0.4913	1.323	3.72	0.11
0.04413	2.004	0.5223	1.283	3.94	0.093
0.04783	2.001	0.5563	1.251	4.18	0.078

R001417

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.052	1.986	0.5913	1.214	4.43	0.064
0.05617	1.979	0.6283	1.173	4.69	0.055
0.0631	1.96	0.6683	1.135	4.97	0.049
0.06633	1.955	0.7103	1.097	5.27	0.039
0.07235	1.943	0.7543	1.06	5.58	0.037
0.08297	1.92	0.8013	1.019	5.921	0.029
0.08633	1.916	0.8513	0.978	6.27	0.022
0.09333	1.899	0.9043	0.932	6.64	0.018
0.103	1.884	0.9603	0.891	7.04	0.016
0.1103	1.868	1.02	0.853	7.46	0.015
0.1191	1.849	1.08	0.809	7.9	0.008
0.1283	1.834	1.15	0.768	8.37	0.011
0.1383	1.814	1.22	0.727	8.87	0.007
0.1483	1.798	1.29	0.686	9.4	0.01
0.1593	1.779	1.37	0.642	9.96	0.011
0.1713	1.761	1.46	0.599	10.56	0.01
0.1843	1.739	1.54	0.562	11.16	0.01
0.1973	1.718	1.64	0.524	11.86	0.005
0.2113	1.696	1.74	0.479	12.56	0.005
0.2263	1.672	1.84	0.445	13.26	0.008
0.2423	1.645	1.95	0.409		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0013	cm/sec
Ss	6.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.6047 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.001322	0.0001102	+/- 0.0002187	11.99	cm/sec
Ss	5.714E-5	2.337E-5	+/- 4.636E-5	2.445	ft^{-1}
Kz/Kr	1.	0.8362	+/- 1.659	1.196	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error

R001418

No estimation window

T = K*b = 0.6148 cm²/sec

Parameter Correlations

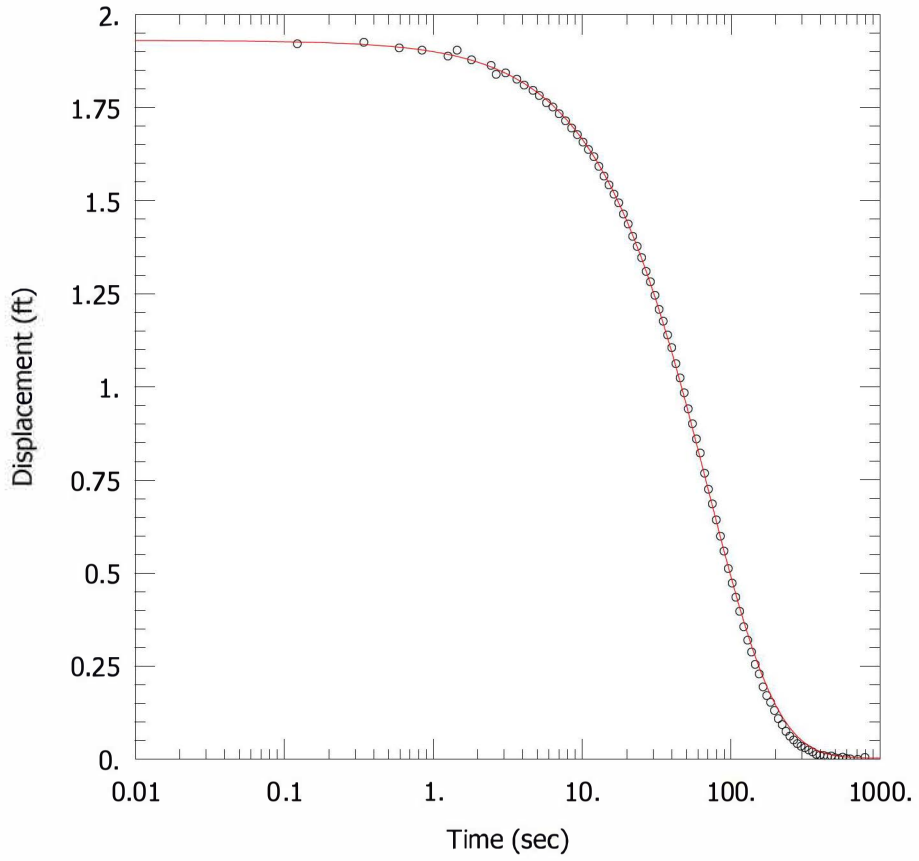
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.005558 ft^2
Variance . . . . . 5.672E-5 ft^2
Std. Deviation . . . . . 0.007531 ft
Mean. . . . . -0.002476 ft
No. of Residuals 101
No. of Estimates. 3

R001419



G281 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G281
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0021 cm/sec
Ss = 2.0E-12 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 15.8 ft

WELL DATA (G281)

Initial Displacement: 1.93 ft
Total Well Penetration Depth: 15.8 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.8 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001420

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G281fh.aqt
Title: G281 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 09:30:07

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G281

AQUIFER DATA

Saturated Thickness: 15.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G281

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.93 ft
Static Water Column Height: 15.8 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 15.8 ft

No. of Observations: 91

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.951	21.91	1.404	154.7	0.229
0.123	1.921	23.47	1.377	164.3	0.194
0.344	1.925	25.15	1.347	173.9	0.171
0.594	1.91	26.95	1.31	184.7	0.153
0.844	1.904	28.81	1.282	196.1	0.131
1.261	1.888	30.85	1.246	208.1	0.109
1.453	1.904	32.95	1.208	220.7	0.093
1.816	1.878	35.17	1.176	233.9	0.075
2.451	1.863	37.57	1.139	248.3	0.062
2.653	1.839	40.09	1.105	263.3	0.052
3.073	1.843	42.73	1.062	278.9	0.042
3.651	1.826	45.55	1.024	295.7	0.035
4.093	1.81	48.55	0.984	313.7	0.031

R001421

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
4.689	1.796	51.73	0.941	332.3	0.025
5.173	1.782	55.09	0.901	352.7	0.02
5.774	1.763	58.69	0.86	373.7	0.013
6.374	1.751	62.29	0.822	395.9	0.011
7.033	1.733	66.49	0.768	419.9	0.01
7.753	1.714	70.69	0.725	445.1	0.007
8.533	1.695	74.89	0.686	471.5	0.009
9.313	1.677	79.69	0.643	499.7	0.004
10.15	1.657	85.09	0.599	529.7	0.002
11.05	1.637	89.89	0.559	561.5	0.006
12.01	1.618	95.89	0.512	595.1	0.002
12.97	1.592	101.9	0.473	631.1	0.001
14.05	1.566	107.9	0.435	667.1	-0.001
15.19	1.542	114.5	0.397	709.1	0.
16.39	1.517	121.7	0.356	751.1	-0.003
17.65	1.494	129.5	0.32	793.2	0.005
18.97	1.464	137.3	0.288		
20.41	1.437	145.7	0.255		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0021	cm/sec
Ss	2.0E-12	ft^{-1}
Kz/Kr	1.	

T = K*b = 1.011 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.002112	0.0008403	+/- 0.00167	2.513	cm/sec
Ss	1.86E-12	9.133E-9	+/- 1.815E-8	0.0002036	ft^{-1}
Kz/Kr	1.	2098.5	+/- 4169.8	0.0004765	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 1.017 cm^2/sec

R001422

Parameter Correlations

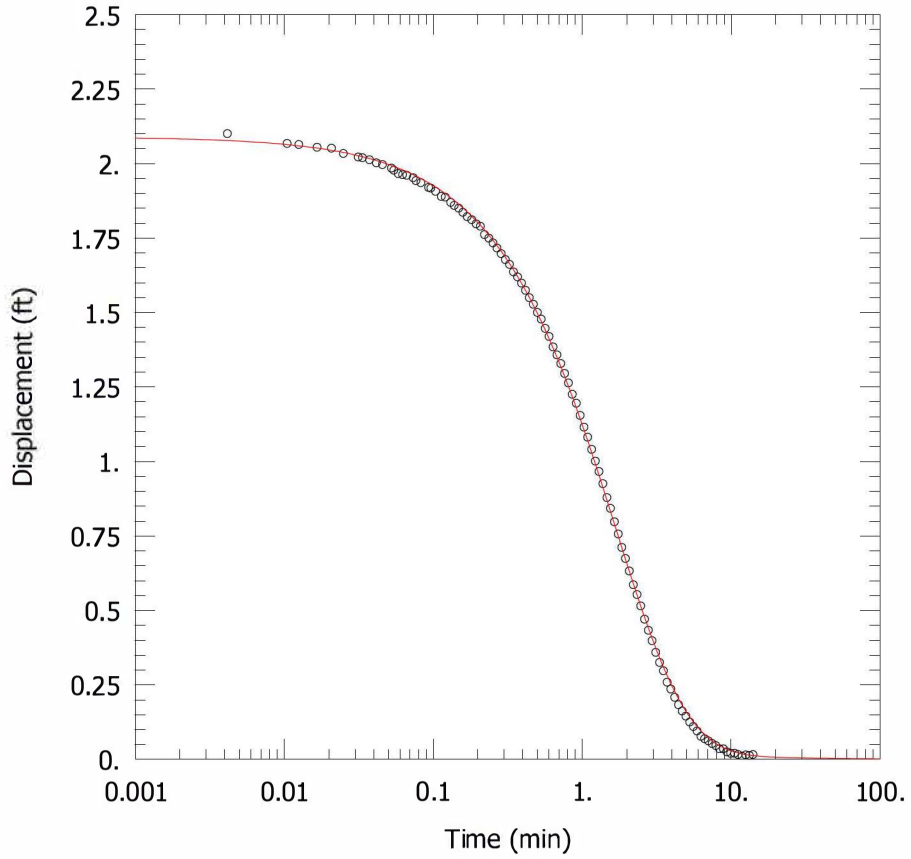
	Kr	Ss	Kz/Kr
Kr	1.00	-0.97	0.97
Ss	-0.97	1.00	-1.00
Kz/Kr	0.97	-1.00	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01011 ft^2
Variance . . . . . 0.0001149 ft^2
Std. Deviation . . . . . 0.01072 ft
Mean. . . . . -0.00248 ft
No. of Residuals 91
No. of Estimates. 3

R001423



G281 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G281
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00089 cm/sec
Ss = 6.2E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 15.8 ft

WELL DATA (G281)

Initial Displacement: 2.09 ft
Total Well Penetration Depth: 15.8 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 15.8 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001424

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G281rh.aqt
Title: G281 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 09:31:04

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G281

AQUIFER DATA

Saturated Thickness: 15.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G281

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.09 ft
Static Water Column Height: 15.8 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 15.8 ft

No. of Observations: 104

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.116	0.2528	1.733	2.081	0.632
0.004167	2.1	0.2688	1.716	2.211	0.586
0.0105	2.067	0.2868	1.697	2.341	0.553
0.01257	2.063	0.3058	1.677	2.481	0.515
0.01667	2.054	0.3258	1.661	2.631	0.47
0.02083	2.051	0.3468	1.636	2.791	0.433
0.025	2.033	0.3688	1.619	2.951	0.398
0.03152	2.021	0.3928	1.598	3.131	0.359
0.03358	2.019	0.4178	1.574	3.321	0.325
0.0375	2.012	0.4438	1.549	3.521	0.297
0.04167	2.002	0.4718	1.527	3.731	0.259
0.04583	1.996	0.5018	1.5	3.951	0.236
0.05258	1.984	0.5328	1.477	4.191	0.208

R001425

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05465	1.977	0.5668	1.446	4.441	0.183
0.05833	1.966	0.6018	1.419	4.701	0.162
0.0625	1.962	0.6388	1.384	4.981	0.145
0.06667	1.96	0.6788	1.357	5.281	0.125
0.07362	1.952	0.7208	1.328	5.591	0.11
0.07682	1.942	0.7648	1.295	5.931	0.095
0.08287	1.935	0.8118	1.263	6.281	0.077
0.09345	1.919	0.8618	1.225	6.651	0.069
0.09682	1.917	0.9148	1.195	7.051	0.062
0.1038	1.906	0.9708	1.154	7.471	0.053
0.1135	1.889	1.031	1.115	7.911	0.046
0.1208	1.887	1.091	1.081	8.381	0.035
0.1316	1.869	1.161	1.04	8.881	0.035
0.1388	1.859	1.231	1.001	9.411	0.025
0.1488	1.85	1.301	0.966	9.971	0.02
0.1588	1.836	1.381	0.925	10.57	0.02
0.1698	1.821	1.471	0.878	11.17	0.016
0.1818	1.811	1.551	0.842	11.87	0.01
0.1948	1.797	1.651	0.797	12.57	0.015
0.2078	1.789	1.751	0.756	13.27	0.013
0.2218	1.761	1.851	0.711	14.07	0.016
0.2368	1.749	1.961	0.674		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00089	cm/sec
Ss	6.2E-5	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.4286\ cm^2/sec$

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0008928	0.0001189	+/- 0.0002359	7.51	cm/sec
Ss	6.185E-5	4.021E-5	+/- 7.978E-5	1.538	ft^{-1}
Kz/Kr	1.	1.309	+/- 2.598	0.7637	

C.I. is approximate 95% confidence interval for parameter

R001426

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.4299 cm²/sec

Parameter Correlations

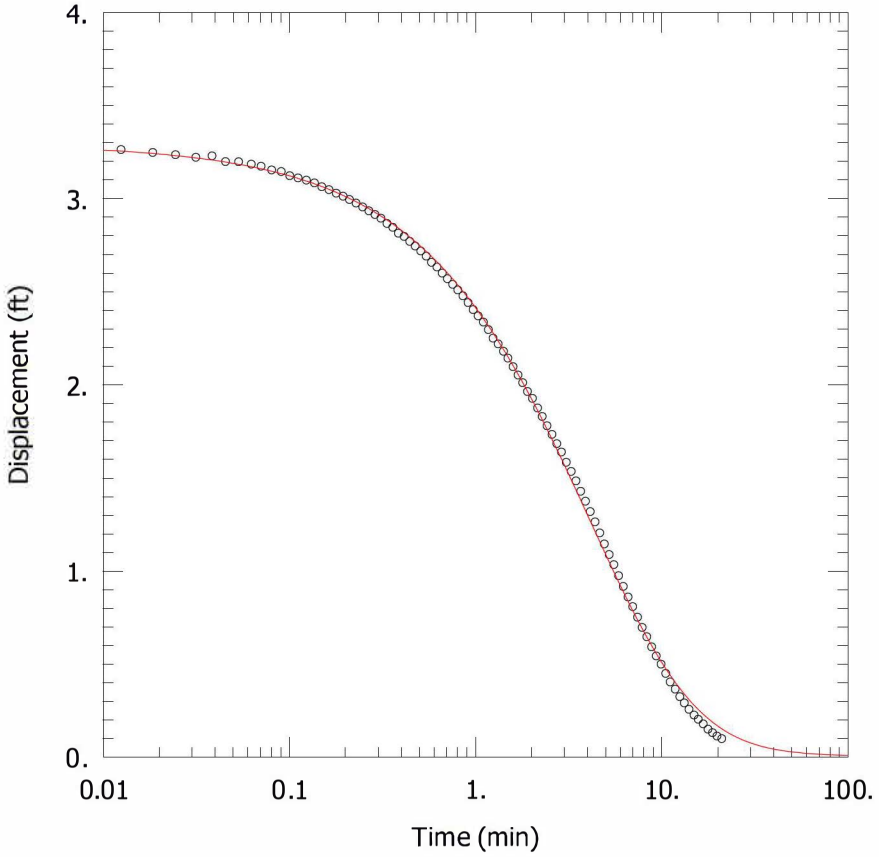
	Kr	Ss	Kz/Kr
Kr	1.00	-1.00	-1.00
Ss	-1.00	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01291 ft^2
Variance . . . . . 0.0001278 ft^2
Std. Deviation . . . . . 0.01131 ft
Mean. . . . . -0.003426 ft
No. of Residuals 104
No. of Estimates. 3

R001427



G301 @ ASH POND 1 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G301
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00027 cm/sec
Ss = 0.0009 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.82 ft

WELL DATA (G301)

Initial Displacement: 3.3 ft
Total Well Penetration Depth: 11.82 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.82 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001428

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G301fh.aqt
Title: G301 @ Ash Pond 1 – Falling Head Test
Date: 11/28/16
Time: 09:31:30

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G301

AQUIFER DATA

Saturated Thickness: 11.82 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G301

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.3 ft
Static Water Column Height: 11.82 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 11.82 ft

No. of Observations: 97

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.31	0.4745	2.745	3.672	1.428
0.004167	3.255	0.5085	2.719	3.893	1.375
0.008333	3.267	0.5435	2.691	4.133	1.319
0.0125	3.263	0.5805	2.658	4.383	1.264
0.0185	3.248	0.6205	2.633	4.643	1.205
0.02452	3.236	0.6625	2.6	4.923	1.145
0.0315	3.222	0.7065	2.57	5.223	1.089
0.0385	3.23	0.7535	2.54	5.532	1.034
0.0455	3.199	0.8035	2.51	5.872	0.975
0.0535	3.198	0.8565	2.478	6.223	0.917
0.0625	3.185	0.9125	2.442	6.593	0.861
0.0705	3.174	0.9725	2.404	6.992	0.809
0.0805	3.154	1.033	2.37	7.412	0.752

R001429

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.0905	3.145	1.103	2.337	7.853	0.697
0.1005	3.123	1.173	2.296	8.322	0.647
0.1115	3.111	1.242	2.251	8.822	0.593
0.1235	3.099	1.323	2.22	9.352	0.544
0.1365	3.084	1.413	2.18	9.912	0.5
0.1495	3.064	1.492	2.143	10.51	0.45
0.1635	3.048	1.593	2.098	11.11	0.405
0.1785	3.029	1.692	2.053	11.81	0.366
0.1945	3.013	1.793	2.012	12.51	0.326
0.2105	2.995	1.903	1.964	13.21	0.292
0.2285	2.976	2.023	1.927	14.01	0.258
0.2475	2.955	2.152	1.876	14.91	0.227
0.2675	2.935	2.283	1.83	15.71	0.204
0.2885	2.915	2.422	1.78	16.71	0.179
0.3105	2.895	2.572	1.734	17.72	0.151
0.3345	2.867	2.732	1.684	18.72	0.132
0.3595	2.846	2.893	1.639	19.81	0.114
0.3855	2.814	3.072	1.584	21.01	0.1
0.4135	2.797	3.263	1.535		
0.4435	2.77	3.462	1.484		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00027	cm/sec
Ss	0.0009	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.09727 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0002698	1.629E-5	+/- 3.234E-5	16.56	cm/sec
Ss	0.0008799	0.0001922	+/- 0.0003815	4.579	ft^{-1}
Kz/Kr	1.	0.8564	+/- 1.7	1.168	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001430

T = K*b = 0.09719 cm²/sec

Parameter Correlations

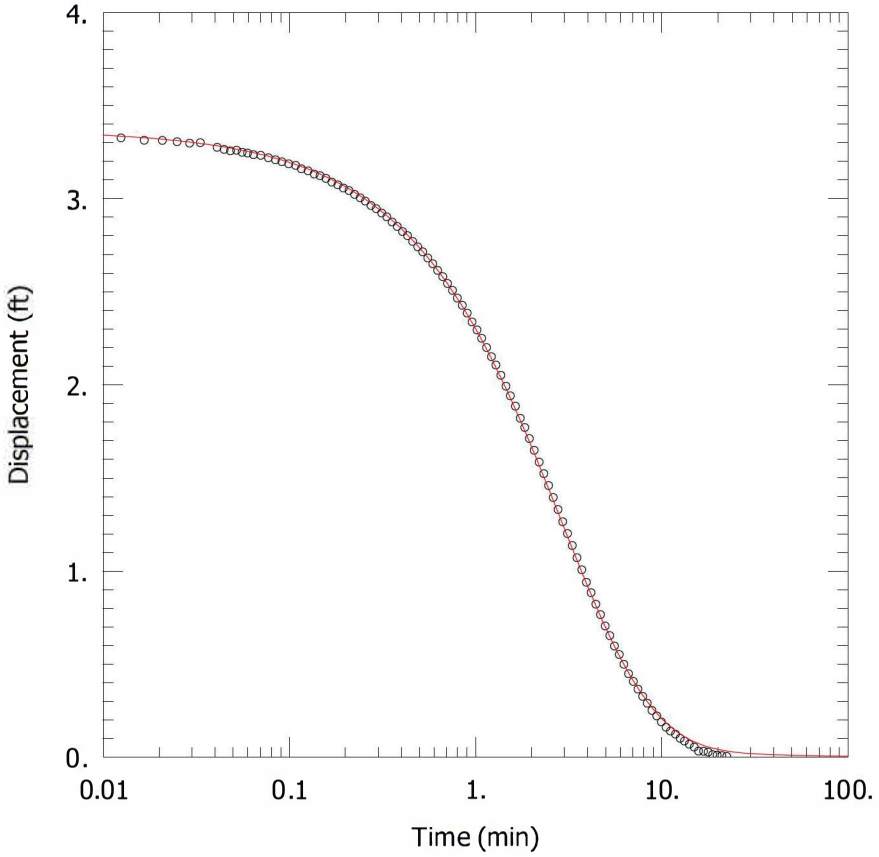
	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.97
Ss	-0.98	1.00	0.93
Kz/Kr	-0.97	0.93	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.07757 ft^2
Variance . . . . . 0.0008252 ft^2
Std. Deviation . . . . . 0.02873 ft
Mean. . . . . -0.006371 ft
No. of Residuals 97
No. of Estimates. 3

R001431



G301 @ ASH POND 1 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G301
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0005 cm/sec
Ss = 9.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.82 ft

WELL DATA (G301)

Initial Displacement: 3.37 ft
Total Well Penetration Depth: 11.82 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.82 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001432

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G301rh.aqt
Title: G301 @ Ash Pond 1 – Rising Head Test
Date: 11/28/16
Time: 09:32:12

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G301

AQUIFER DATA

Saturated Thickness: 11.82 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G301

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.37 ft
Static Water Column Height: 11.82 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 11.82 ft

No. of Observations: 112

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.02083	3.462	0.2933	2.946	2.938	1.265
-0.01667	3.446	0.3133	2.923	3.118	1.201
-0.0125	3.401	0.3343	2.902	3.308	1.137
0.	3.35	0.3563	2.874	3.508	1.071
0.004167	3.343	0.3803	2.85	3.718	1.007
0.008333	3.341	0.4053	2.823	3.938	0.94
0.0125	3.326	0.4313	2.801	4.178	0.884
0.01667	3.313	0.4593	2.77	4.428	0.822
0.02083	3.312	0.4893	2.741	4.688	0.766
0.025	3.305	0.5203	2.714	4.968	0.705
0.02917	3.298	0.5543	2.681	5.268	0.653
0.03333	3.3	0.5893	2.65	5.578	0.597
0.04102	3.275	0.6263	2.615	5.918	0.552

R001433

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.04472	3.264	0.6663	2.581	6.268	0.499
0.04838	3.256	0.7083	2.544	6.638	0.449
0.05208	3.26	0.7523	2.507	7.038	0.407
0.0559	3.249	0.7993	2.466	7.465	0.366
0.05975	3.244	0.8493	2.427	7.898	0.327
0.06433	3.236	0.9023	2.385	8.368	0.29
0.07033	3.232	0.9583	2.338	8.868	0.252
0.07733	3.219	1.018	2.295	9.398	0.222
0.08433	3.208	1.078	2.25	9.958	0.19
0.09133	3.198	1.148	2.2	10.56	0.161
0.09933	3.187	1.218	2.151	11.16	0.141
0.1083	3.178	1.288	2.106	11.86	0.124
0.1163	3.16	1.368	2.051	12.56	0.102
0.1263	3.149	1.458	1.993	13.26	0.087
0.1363	3.132	1.538	1.941	14.06	0.07
0.1463	3.123	1.638	1.885	14.96	0.055
0.1573	3.108	1.738	1.821	15.76	0.033
0.1693	3.089	1.838	1.771	16.76	0.032
0.1823	3.074	1.948	1.711	17.76	0.028
0.1953	3.057	2.068	1.649	18.76	0.014
0.2093	3.043	2.198	1.585	19.86	0.012
0.2243	3.022	2.328	1.523	21.06	0.009
0.2403	3.004	2.468	1.459	22.36	0.005
0.2563	2.986	2.618	1.395		
0.2743	2.963	2.778	1.33		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0005	cm/sec
Ss	9.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1801 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004957	5.04E-5	+/- 9.988E-5	9.836	cm/sec
Ss	9.396E-5	4.339E-5	+/- 8.599E-5	2.166	ft^{-1}

Kz/Kr	1.	1.072	+/- 2.124	0.933

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.1786 cm²/sec

Parameter Correlations

	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.98
Kz/Kr	-1.00	0.98	1.00

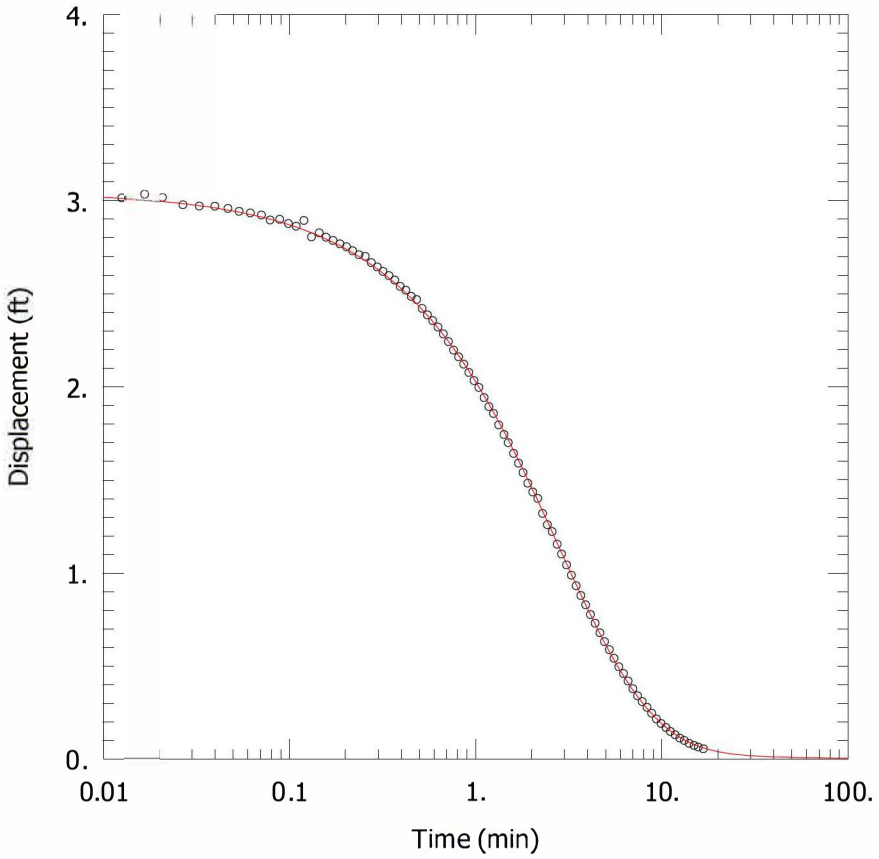
Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.03615 ft^2
Variance . . . . . 0.0003317 ft^2
Std. Deviation . . . . . 0.01821 ft
Mean. . . . . -0.004631 ft
No. of Residuals 112
No. of Estimates 3

R001434

R001435



G302 @ ASH POND 1 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G302
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00049 cm/sec
Ss = 0.0002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.37 ft

WELL DATA (G302)

Initial Displacement: 3.05 ft
Total Well Penetration Depth: 11.37 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.37 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001436

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G302fh.aqt
Title: G302 @ Ash Pond 1 – Falling Head Test
Date: 11/28/16
Time: 09:32:35

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G302

AQUIFER DATA

Saturated Thickness: 11.37 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G302

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.05 ft
Static Water Column Height: 11.37 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 11.37 ft

No. of Observations: 95

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.007	0.3938	2.54	2.901	1.102
0.004167	2.93	0.4218	2.519	3.081	1.044
0.008333	2.962	0.4518	2.486	3.271	0.989
0.0125	3.015	0.4828	2.468	3.471	0.932
0.01667	3.036	0.5168	2.421	3.681	0.88
0.02083	3.017	0.5518	2.387	3.901	0.83
0.02683	2.978	0.5888	2.356	4.141	0.777
0.03283	2.971	0.6288	2.321	4.391	0.731
0.03983	2.97	0.6708	2.284	4.651	0.679
0.04683	2.958	0.7148	2.243	4.931	0.632
0.05382	2.942	0.7618	2.197	5.231	0.589
0.06183	2.934	0.8118	2.161	5.541	0.542
0.07083	2.923	0.8648	2.122	5.881	0.497

R001437

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.07883	2.896	0.9208	2.077	6.231	0.461
0.08883	2.899	0.9808	2.034	6.601	0.42
0.09883	2.877	1.041	1.997	7.001	0.379
0.1088	2.862	1.111	1.942	7.421	0.341
0.1198	2.893	1.181	1.894	7.861	0.31
0.1318	2.805	1.251	1.857	8.331	0.279
0.1448	2.827	1.331	1.796	8.831	0.247
0.1578	2.803	1.421	1.744	9.361	0.216
0.1718	2.786	1.501	1.7	9.921	0.192
0.1868	2.768	1.601	1.643	10.52	0.171
0.2028	2.752	1.701	1.59	11.12	0.149
0.2188	2.731	1.801	1.539	11.82	0.131
0.2368	2.709	1.911	1.483	12.52	0.114
0.2558	2.701	2.031	1.435	13.22	0.101
0.2758	2.667	2.161	1.401	14.02	0.086
0.2968	2.644	2.291	1.32	14.92	0.074
0.3188	2.62	2.431	1.26	15.72	0.066
0.3428	2.597	2.581	1.223	16.72	0.056
0.3678	2.573	2.741	1.155		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00049	cm/sec
Ss	0.0002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1698 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0004933	4.307E-5	+/- 8.553E-5	11.45	cm/sec
Ss	0.0001891	7.368E-5	+/- 0.0001463	2.566	ft^{-1}
Kz/Kr	1.	0.9375	+/- 1.862	1.067	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

R001438

T = K*b = 0.171 cm²/sec

Parameter Correlations

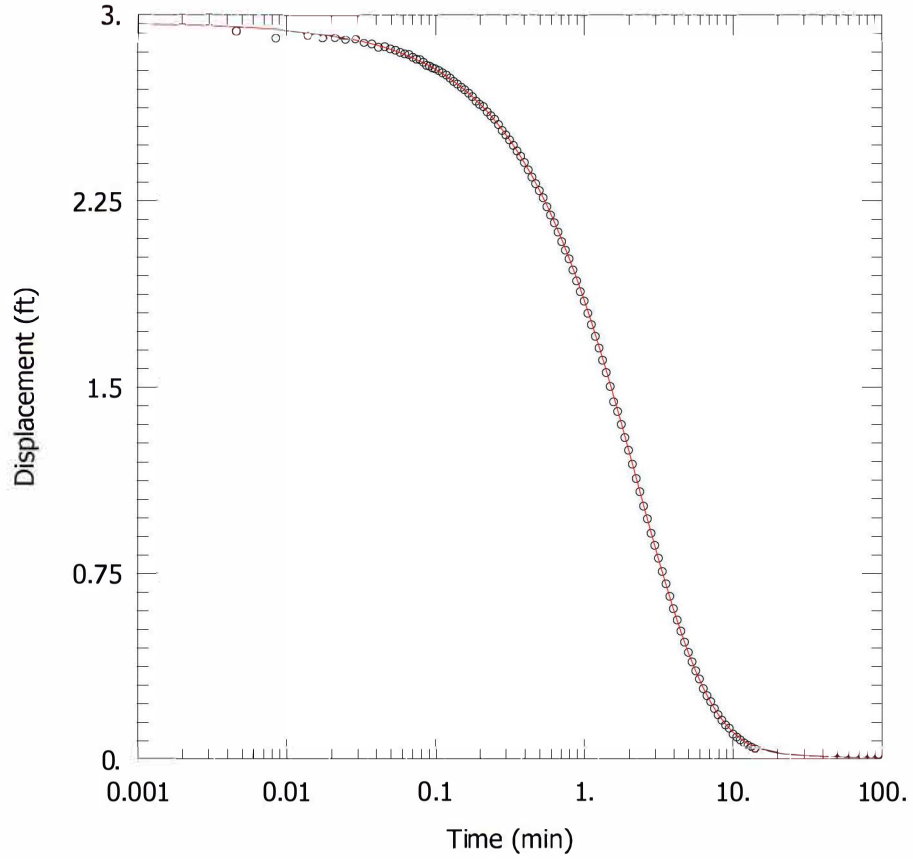
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.98
Kz/Kr	-1.00	0.98	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.02827 ft^2
Variance . . . . . 0.0003073 ft^2
Std. Deviation . . . . . 0.01753 ft
Mean. . . . . 0.0006103 ft
No. of Residuals 95
No. of Estimates. 3

R001439



G302 @ ASH POND 1 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G302
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00063 cm/sec
Ss = 0.0001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.37 ft

WELL DATA (G302)

Initial Displacement: 2.97 ft
Total Well Penetration Depth: 11.37 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.37 ft
Screen Length: 4.65 ft
Well Radius: 0.08333 ft

R001440

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G302rh.aqt
Title: G302 @ Ash Pond 1 – Rising Head Test
Date: 11/28/16
Time: 09:32:58

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G302

AQUIFER DATA

Saturated Thickness: 11.37 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G302

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.97 ft
Static Water Column Height: 11.37 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.65 ft
Total Well Penetration Depth: 11.37 ft

No. of Observations: 110

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.004617	2.935	0.224	2.609	1.88	1.297
0.0084	2.907	0.237	2.593	1.99	1.246
0.01393	2.92	0.251	2.579	2.11	1.19
0.01758	2.907	0.266	2.558	2.24	1.132
0.02123	2.908	0.282	2.534	2.37	1.079
0.02502	2.901	0.298	2.516	2.511	1.021
0.02918	2.903	0.316	2.496	2.66	0.97
0.03335	2.889	0.335	2.474	2.82	0.912
0.03752	2.882	0.355	2.451	2.98	0.863
0.04168	2.869	0.376	2.43	3.16	0.811
0.04585	2.871	0.398	2.405	3.35	0.758
0.05002	2.862	0.422	2.375	3.55	0.708
0.05418	2.857	0.447	2.346	3.763	0.658

R001441

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05835	2.848	0.473	2.32	3.98	0.608
0.06252	2.842	0.501	2.292	4.22	0.562
0.06668	2.84	0.531	2.263	4.47	0.518
0.07085	2.829	0.562	2.227	4.73	0.473
0.07502	2.821	0.596	2.193	5.015	0.432
0.07918	2.819	0.631	2.162	5.31	0.394
0.08335	2.809	0.668	2.125	5.62	0.358
0.08752	2.796	0.708	2.086	5.96	0.325
0.09168	2.793	0.75	2.052	6.31	0.286
0.09585	2.786	0.794	2.017	6.684	0.258
0.1	2.782	0.841	1.972	7.08	0.234
0.106	2.775	0.891	1.928	7.5	0.206
0.112	2.766	0.944	1.885	7.94	0.181
0.119	2.757	1.	1.847	8.41	0.159
0.126	2.745	1.06	1.798	8.91	0.14
0.133	2.731	1.12	1.752	9.44	0.127
0.141	2.721	1.19	1.705	10.	0.103
0.15	2.708	1.26	1.658	10.6	0.091
0.158	2.698	1.33	1.609	11.2	0.08
0.168	2.684	1.41	1.559	11.9	0.067
0.178	2.67	1.5	1.503	12.6	0.058
0.188	2.652	1.58	1.441	13.3	0.05
0.199	2.639	1.68	1.402	14.1	0.043
0.211	2.63	1.78	1.35		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00063	cm/sec
Ss	0.0001	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.2183\ cm^2/sec$

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.00063	2.361E-5	+/- 4.679E-5	26.69	cm/sec
Ss	0.0001057	1.773E-5	+/- 3.513E-5	5.966	ft^{-1}
Kz/Kr	1.	0.4005	+/- 0.7939	2.497	

R001442

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.2183 cm²/sec

Parameter Correlations

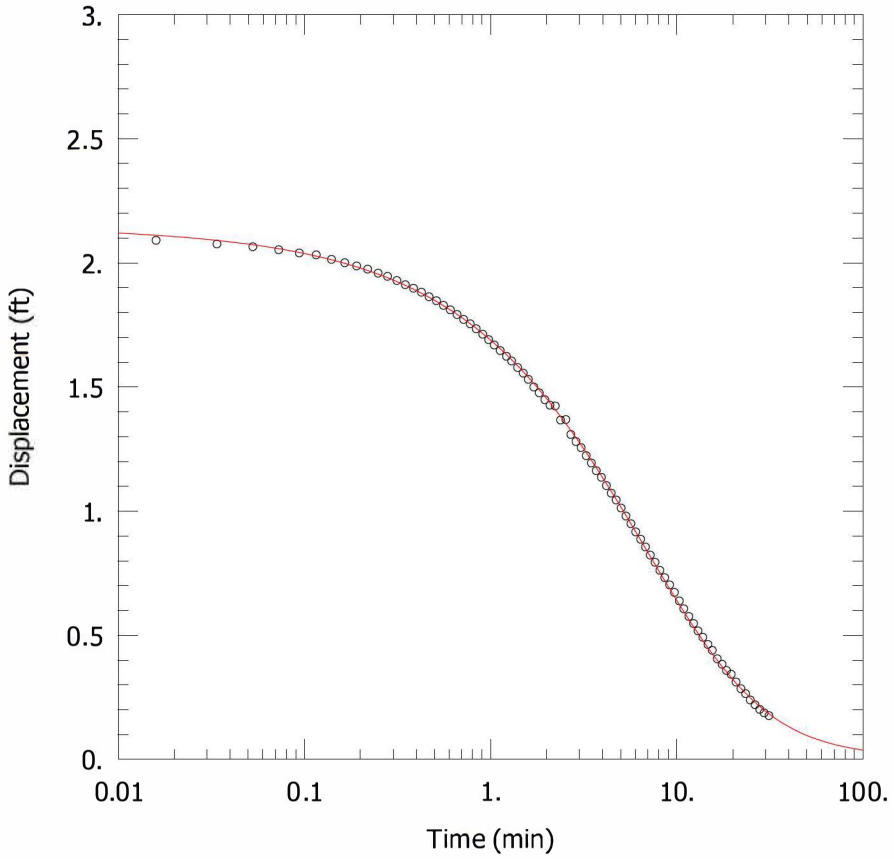
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-1.00
Ss	-0.99	1.00	0.99
Kz/Kr	-1.00	0.99	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.00378 ft^2
Variance . . . . . 3.532E-5 ft^2
Std. Deviation . . . . . 0.005943 ft
Mean. . . . . -0.0002972 ft
No. of Residuals 110
No. of Estimates. 3

R001443



G303 @ ASH POND 1 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G303
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 5.6E-5 cm/sec
Ss = 0.002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 17.03 ft

WELL DATA (G303)

Initial Displacement: 2.15 ft
Total Well Penetration Depth: 17.03 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 17.03 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001444

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G303fh.aqt
Title: G303 @ Ash Pond 1 – Falling Head Test
Date: 11/28/16
Time: 09:33:23

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G303

AQUIFER DATA

Saturated Thickness: 17.03 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G303

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.15 ft
Static Water Column Height: 17.03 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 17.03 ft

No. of Observations: 103

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.1886	2.358	0.386	1.897	4.728	1.044
-0.185	2.423	0.426	1.881	5.028	1.012
-0.1813	2.411	0.468	1.863	5.338	0.98
-0.176	2.312	0.512	1.847	5.678	0.949
-0.17	2.203	0.559	1.828	6.028	0.916
-0.163	2.162	0.609	1.81	6.398	0.886
-0.156	2.193	0.662	1.791	6.798	0.855
-0.149	2.224	0.718	1.771	7.218	0.822
-0.141	2.219	0.778	1.754	7.658	0.793
-0.132	2.193	0.838	1.734	8.128	0.761
-0.124	2.178	0.908	1.712	8.628	0.731
-0.114	2.174	0.978	1.69	9.158	0.702
-0.104	2.174	1.048	1.669	9.718	0.672

R001445

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.09402	2.163	1.128	1.646	10.32	0.638
-0.08302	2.151	1.218	1.623	10.92	0.606
-0.07102	2.147	1.298	1.604	11.62	0.575
-0.05802	2.138	1.398	1.578	12.32	0.547
-0.04502	2.124	1.498	1.555	13.02	0.517
-0.03102	2.118	1.598	1.53	13.82	0.491
-0.016	2.111	1.708	1.499	14.72	0.462
0.	2.094	1.828	1.476	15.52	0.439
0.016	2.09	1.958	1.448	16.52	0.405
0.034	2.075	2.088	1.426	17.52	0.383
0.053	2.064	2.228	1.423	18.52	0.358
0.073	2.052	2.378	1.366	19.62	0.342
0.09398	2.039	2.538	1.368	20.82	0.311
0.116	2.031	2.698	1.308	22.12	0.284
0.14	2.013	2.878	1.28	23.42	0.264
0.165	2.	3.068	1.255	24.82	0.239
0.191	1.987	3.268	1.223	26.32	0.22
0.219	1.974	3.478	1.193	27.92	0.201
0.249	1.958	3.698	1.162	29.52	0.187
0.28	1.945	3.938	1.136	31.32	0.176
0.314	1.928	4.188	1.102		
0.349	1.911	4.448	1.072		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	5.6E-5	cm/sec
Ss	0.002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02907 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	5.383E-5	3.02E-6	+/- 5.993E-6	17.82	cm/sec
Ss	0.002308	0.0004271	+/- 0.0008474	5.403	ft^{-1}
Kz/Kr	1.	1.674	+/- 3.321	0.5974	

C.I. is approximate 95% confidence interval for parameter

R001446

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.02794 cm²/sec

Parameter Correlations

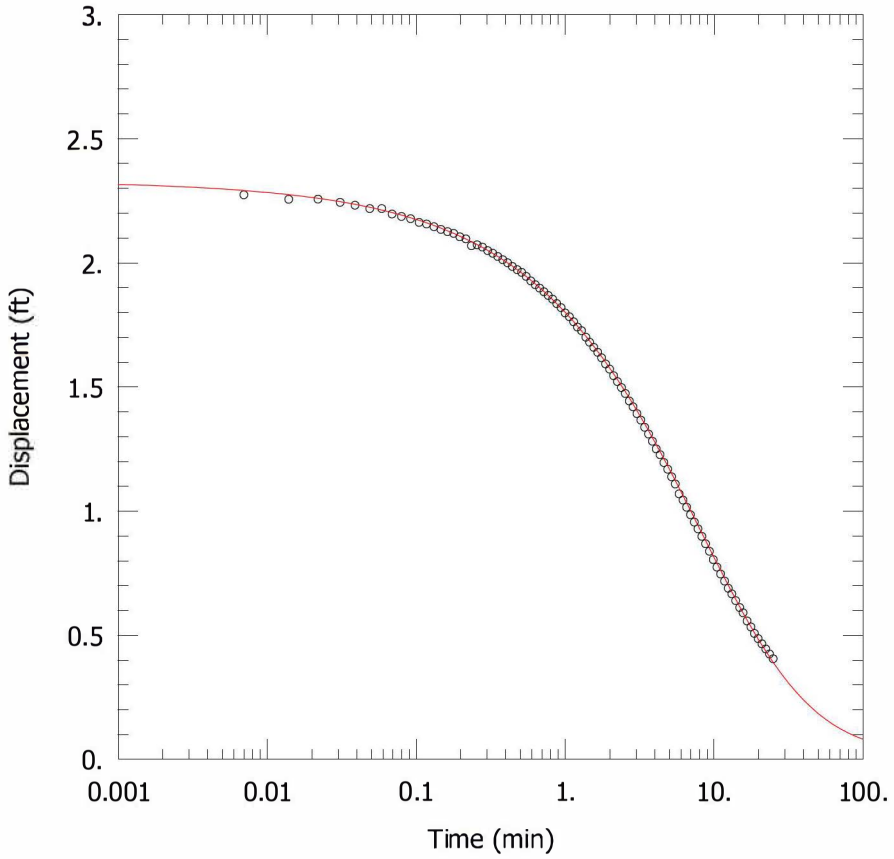
	Kr	Ss	Kz/Kr
Kr	1.00	-0.94	-0.51
Ss	-0.94	1.00	0.32
Kz/Kr	-0.51	0.32	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.2436 ft^2
Variance . . . . . 0.002436 ft^2
Std. Deviation . . . . . 0.04936 ft
Mean. . . . . 0.01078 ft
No. of Residuals 103
No. of Estimates. 3

R001447



G303 @ ASH POND 1 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G303
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 3.1E-5 cm/sec
Ss = 0.0085 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 17.03 ft

WELL DATA (G303)

Initial Displacement: 2.33 ft
Total Well Penetration Depth: 17.03 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 17.03 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001448

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G303rh.aqt
Title: G303 @ Ash Pond 1 – Rising Head Test
Date: 11/28/16
Time: 09:33:48

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G303

AQUIFER DATA

Saturated Thickness: 17.03 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G303

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.33 ft
Static Water Column Height: 17.03 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 17.03 ft

No. of Observations: 100

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.0315	2.324	0.477	1.972	4.101	1.25
-0.02733	2.297	0.512	1.961	4.351	1.227
-0.02317	2.301	0.549	1.945	4.611	1.195
-0.019	2.32	0.589	1.927	4.891	1.168
-0.013	2.313	0.631	1.911	5.191	1.138
-0.007	2.282	0.675	1.898	5.501	1.109
0.	2.279	0.722	1.883	5.841	1.069
0.007	2.273	0.772	1.868	6.191	1.044
0.014	2.255	0.825	1.853	6.561	1.015
0.022	2.256	0.881	1.835	6.961	0.985
0.031	2.243	0.941	1.819	7.381	0.955
0.039	2.231	1.001	1.798	7.821	0.928
0.049	2.218	1.071	1.782	8.291	0.898

R001449

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.059	2.218	1.141	1.762	8.791	0.868
0.069	2.196	1.211	1.741	9.321	0.838
0.08	2.186	1.291	1.726	9.881	0.804
0.092	2.177	1.381	1.7	10.48	0.774
0.105	2.162	1.461	1.68	11.08	0.746
0.118	2.156	1.561	1.659	11.78	0.718
0.132	2.145	1.661	1.639	12.48	0.689
0.147	2.134	1.761	1.617	13.18	0.666
0.163	2.125	1.871	1.592	13.98	0.639
0.179	2.118	1.991	1.571	14.88	0.611
0.197	2.104	2.121	1.545	15.68	0.59
0.216	2.096	2.251	1.521	16.68	0.557
0.236	2.068	2.391	1.497	17.68	0.533
0.257	2.072	2.541	1.473	18.68	0.507
0.279	2.063	2.701	1.443	19.78	0.486
0.303	2.049	2.861	1.42	20.98	0.465
0.328	2.038	3.041	1.392	22.28	0.444
0.354	2.025	3.231	1.366	23.58	0.424
0.382	2.012	3.431	1.337	24.98	0.405
0.412	2.	3.641	1.31		
0.443	1.985	3.861	1.281		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	3.1E-5	cm/sec
Ss	0.0085	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.01609 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	3.152E-5	1.915E-6	+/- 3.801E-6	16.46	cm/sec
Ss	0.008559	0.0008401	+/- 0.001668	10.19	ft^{-1}
Kz/Kr	1.	7.083	+/- 14.06	0.1412	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error

R001450

No estimation window

T = K*b = 0.01636 cm²/sec

Parameter Correlations

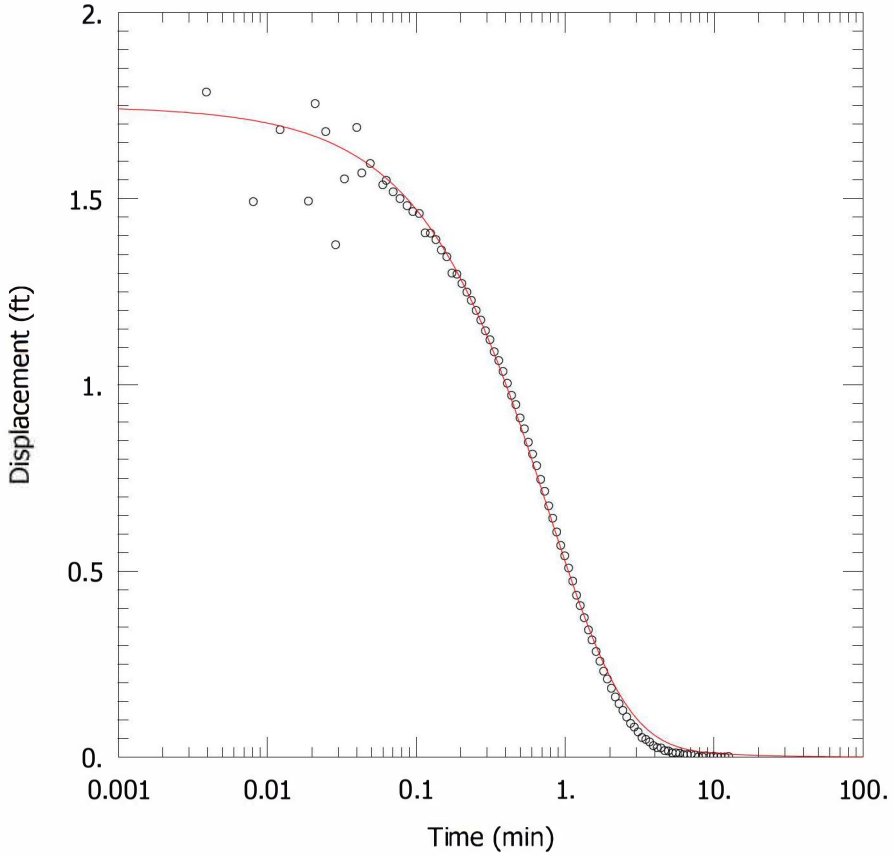
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.98
Ss	-0.99	1.00	0.96
Kz/Kr	-0.98	0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01115 ft^2
Variance . . . . . 0.0001149 ft^2
Std. Deviation . . . . . 0.01072 ft
Mean. . . . . -0.001744 ft
No. of Residuals 100
No. of Estimates. 3

R001451



G304 @ ASH POND 1 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G304
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00089 cm/sec
Ss = 7.0E-5 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 18.81 ft

WELL DATA (G304)

Initial Displacement: 1.75 ft
Total Well Penetration Depth: 18.81 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 18.81 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001452

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G304fh.aqt
Title: G304 @ Ash Pond 1 – Falling Head Test
Date: 11/28/16
Time: 09:40:21

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G304

AQUIFER DATA

Saturated Thickness: 18.81 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G304

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.75 ft
Static Water Column Height: 18.81 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 18.81 ft

No. of Observations: 95

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.867	0.3132	1.121	2.307	0.144
0.003917	1.786	0.3352	1.089	2.447	0.126
0.008083	1.492	0.3592	1.065	2.597	0.108
0.01225	1.685	0.3842	1.036	2.757	0.091
0.01897	1.493	0.4102	1.004	2.917	0.081
0.02103	1.755	0.4382	0.972	3.097	0.068
0.02475	1.68	0.4682	0.947	3.287	0.053
0.02892	1.376	0.4992	0.911	3.487	0.048
0.03308	1.553	0.5332	0.882	3.697	0.041
0.04002	1.691	0.5682	0.846	3.917	0.031
0.04323	1.569	0.6052	0.814	4.157	0.026
0.04927	1.594	0.6452	0.783	4.407	0.025
0.05982	1.537	0.6872	0.746	4.667	0.018

R001453

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06323	1.549	0.7312	0.714	4.947	0.017
0.07023	1.518	0.7782	0.675	5.247	0.012
0.07825	1.5	0.8282	0.642	5.557	0.012
0.08723	1.481	0.8812	0.605	5.897	0.011
0.09523	1.465	0.9372	0.569	6.247	0.007
0.1052	1.46	0.9972	0.541	6.617	0.007
0.1152	1.408	1.057	0.508	7.017	0.009
0.1252	1.407	1.127	0.473	7.437	0.006
0.1362	1.39	1.197	0.435	7.877	0.001
0.1482	1.362	1.267	0.407	8.347	0.002
0.1612	1.344	1.347	0.375	8.847	0.004
0.1742	1.3	1.437	0.342	9.377	0.002
0.1882	1.297	1.517	0.315	9.937	0.003
0.2032	1.272	1.617	0.284	10.54	0.001
0.2192	1.249	1.717	0.258	11.14	0.001
0.2352	1.227	1.817	0.231	11.84	0.001
0.2532	1.2	1.927	0.21	12.54	0.002
0.2722	1.174	2.047	0.185	13.24	-0.002
0.2922	1.145	2.177	0.162		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

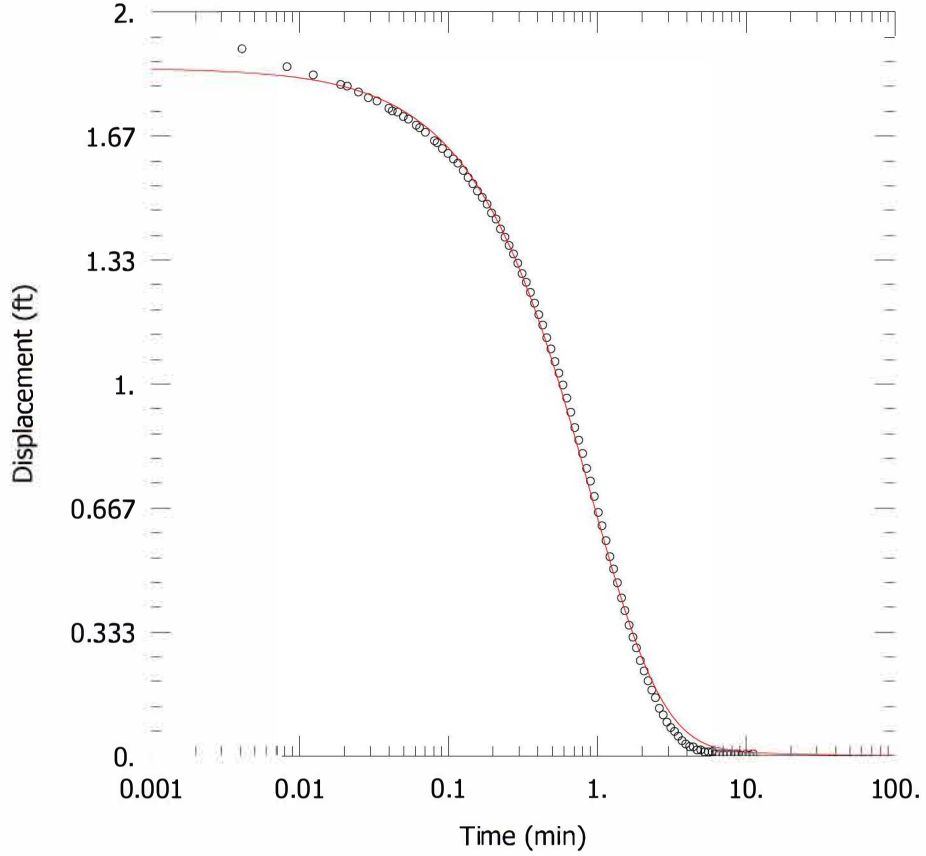
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00089	cm/sec
Ss	7.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.5103 cm^2/sec

R001454



G304 @ ASH POND 1 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G304
Test Date: 17 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.001 cm/sec
Ss = 1.0E-6 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 18.81 ft

WELL DATA (G304)

Initial Displacement: 1.85 ft
Total Well Penetration Depth: 18.81 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 18.81 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001455

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G304rh.aqt
Title: G304 @ Ash Pond 1 – Rising Head Test
Date: 11/28/16
Time: 09:40:55

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 17 Jun 2016
Test Well: G304

AQUIFER DATA

Saturated Thickness: 18.81 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G304

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.85 ft
Static Water Column Height: 18.81 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 18.81 ft

No. of Observations: 97

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.977	0.2563	1.372	1.948	0.257
0.0041	1.901	0.2743	1.349	2.068	0.229
0.008267	1.852	0.2933	1.324	2.198	0.203
0.01243	1.83	0.3133	1.296	2.328	0.178
0.01895	1.804	0.3343	1.273	2.468	0.157
0.02102	1.8	0.3563	1.246	2.618	0.129
0.02493	1.784	0.3803	1.217	2.778	0.111
0.0291	1.769	0.4053	1.186	2.938	0.092
0.03327	1.76	0.4313	1.158	3.118	0.077
0.04	1.74	0.4593	1.124	3.308	0.067
0.04207	1.733	0.4893	1.094	3.508	0.054
0.04577	1.73	0.5203	1.06	3.718	0.042
0.04993	1.718	0.5543	1.029	3.938	0.033

R001456

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.0541	1.711	0.5893	0.997	4.178	0.026
0.06107	1.695	0.6263	0.962	4.428	0.025
0.06427	1.688	0.6663	0.924	4.688	0.017
0.07027	1.676	0.7083	0.883	4.968	0.017
0.08085	1.653	0.7523	0.849	5.268	0.012
0.08427	1.648	0.7993	0.813	5.578	0.012
0.09127	1.632	0.8493	0.773	5.918	0.012
0.09967	1.619	0.9023	0.739	6.268	0.005
0.1083	1.604	0.9583	0.698	6.638	0.004
0.1163	1.593	1.018	0.655	7.038	0.004
0.1263	1.573	1.078	0.619	7.458	0.005
0.1363	1.554	1.148	0.579	7.898	0.005
0.1463	1.538	1.218	0.536	8.368	0.004
0.1573	1.518	1.288	0.503	8.868	0.005
0.1693	1.501	1.368	0.466	9.398	0.001
0.1823	1.483	1.458	0.425	9.958	0.004
0.1953	1.459	1.538	0.391	10.56	0.003
0.2093	1.443	1.638	0.352	11.16	0.006
0.2243	1.416	1.738	0.32		
0.2403	1.394	1.838	0.291		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

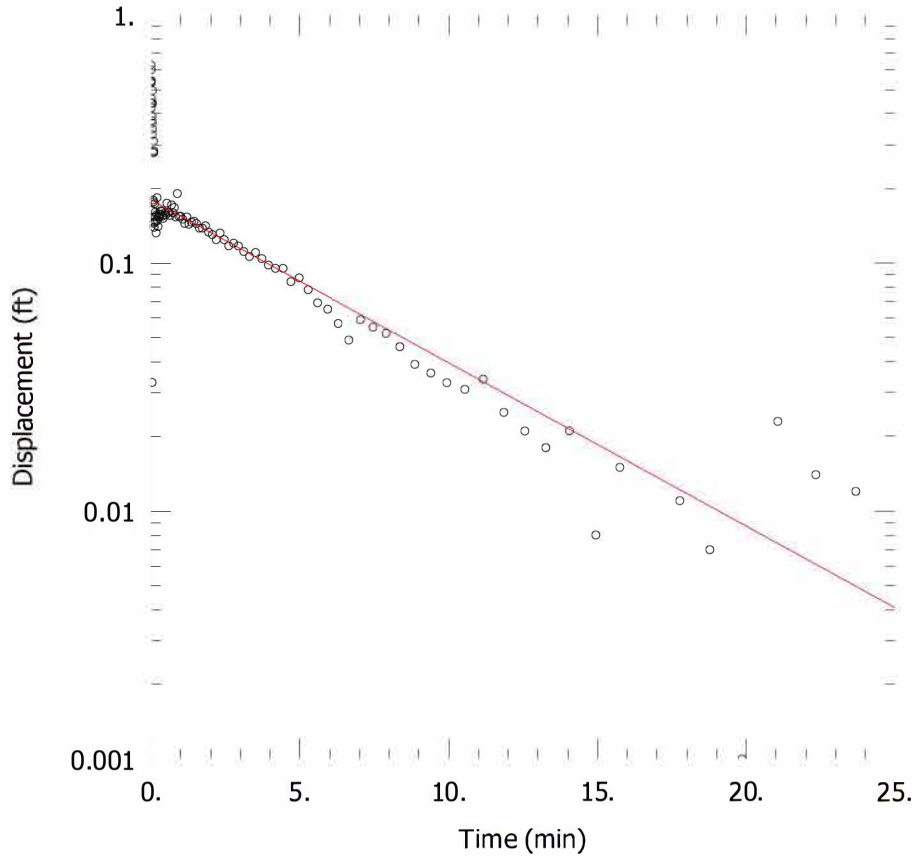
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.001	cm/sec
Ss	1.0E-6	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.5733 cm^2/sec

R001457



G401 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G401
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.00018 cm/sec
y0 = 0.18 ft

AQUIFER DATA

Saturated Thickness: 4.92 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G401)

Initial Displacement: 0.6 ft
Total Well Penetration Depth: 4.92 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 4.92 ft
Screen Length: 4.63 ft
Well Radius: 0.08333 ft

R001458

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G401fh.aqt
Title: G401 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 10:44:18

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G401

AQUIFER DATA

Saturated Thickness: 4.92 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G401

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.6 ft
Static Water Column Height: 4.92 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.63 ft
Total Well Penetration Depth: 4.92 ft

No. of Observations: 112

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	0.629	0.3217	0.157	3.127	0.111
0.00417	0.537	0.3427	0.157	3.317	0.106
0.00834	0.531	0.3647	0.162	3.517	0.11
0.0125	0.441	0.3887	0.161	3.727	0.104
0.01667	0.542	0.4137	0.154	3.947	0.098
0.02084	0.422	0.4397	0.151	4.187	0.095
0.025	0.44	0.4677	0.156	4.437	0.095
0.02917	0.459	0.4977	0.159	4.697	0.084
0.03334	0.375	0.5287	0.156	4.977	0.087
0.0375	0.391	0.5627	0.174	5.277	0.078
0.04167	0.329	0.5977	0.16	5.587	0.069
0.04584	0.366	0.6347	0.16	5.927	0.065
0.05	0.346	0.6747	0.155	6.277	0.057

R001459

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05417	0.441	0.7167	0.171	6.651	0.049
0.05834	0.495	0.7607	0.159	7.047	0.059
0.0625	-0.542	0.8077	0.167	7.467	0.055
0.06667	0.033	0.8577	0.153	7.907	0.052
0.07267	0.28	0.9107	0.19	8.377	0.046
0.07867	0.163	0.9667	0.154	8.877	0.039
0.08567	0.31	1.027	0.154	9.407	0.036
0.09267	0.278	1.087	0.15	9.967	0.033
0.09967	0.283	1.157	0.144	10.57	0.031
0.1077	0.179	1.227	0.153	11.17	0.034
0.1167	0.176	1.297	0.143	11.87	0.025
0.1247	0.144	1.377	0.146	12.57	0.021
0.1347	0.139	1.467	0.147	13.27	0.018
0.1447	0.146	1.547	0.144	14.07	0.021
0.1547	0.173	1.647	0.138	14.97	0.008
0.1657	0.153	1.747	0.138	15.77	0.015
0.1777	0.16	1.847	0.141	16.77	0.
0.1907	0.147	1.957	0.133	17.77	0.011
0.2037	0.132	2.077	0.13	18.77	0.007
0.2177	0.156	2.207	0.124	19.87	0.001
0.2327	0.183	2.337	0.132	21.07	0.023
0.2487	0.148	2.477	0.124	22.37	0.014
0.2647	0.14	2.627	0.117	23.67	0.012
0.2827	0.154	2.787	0.12		
0.3017	0.153	2.947	0.117		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 3.118

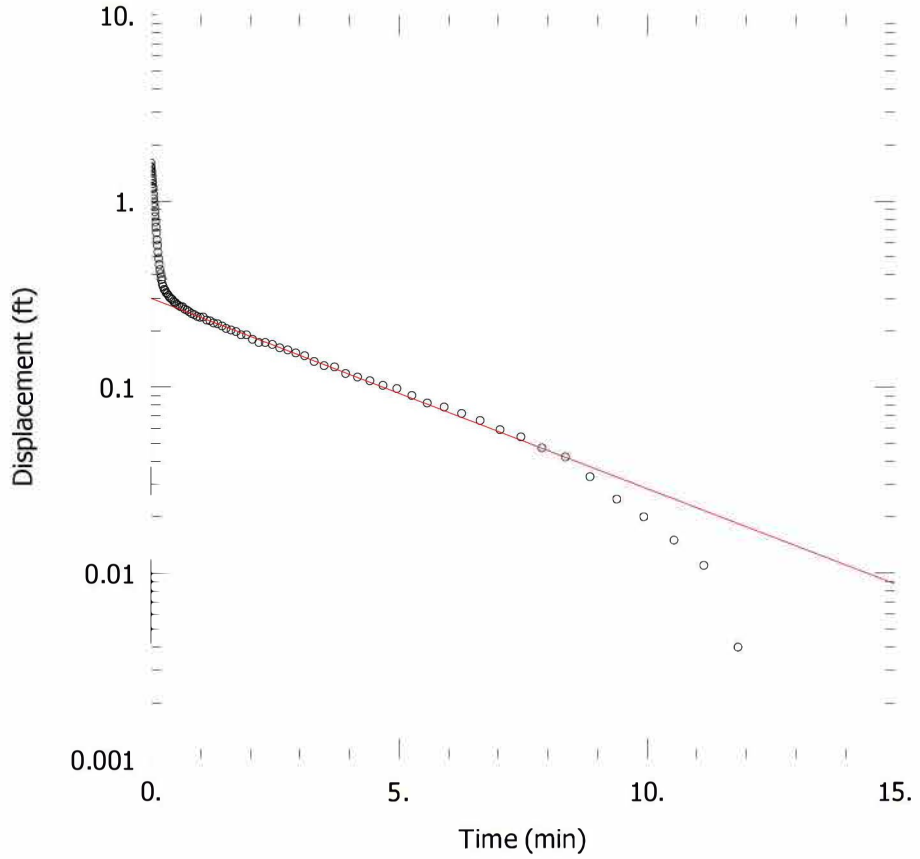
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00018	cm/sec
y0	0.18	ft

T = K*b = 0.02699 cm²/sec

R001460



G401 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G401
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.00028 cm/sec
y0 = 0.3 ft

AQUIFER DATA

Saturated Thickness: 4.92 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G401)

Initial Displacement: 1.6 ft
Total Well Penetration Depth: 4.92 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 4.92 ft
Screen Length: 4.63 ft
Well Radius: 0.08333 ft

R001461

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G401rh.aqt
Title: G401 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 10:45:18

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G401

AQUIFER DATA

Saturated Thickness: 4.92 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G401

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.6 ft
Static Water Column Height: 4.92 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.63 ft
Total Well Penetration Depth: 4.92 ft

No. of Observations: 96

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.532	0.2808	0.333	2.056	0.18
0.004167	1.512	0.3008	0.33	2.187	0.173
0.008333	1.479	0.3218	0.32	2.316	0.173
0.0125	1.44	0.3438	0.316	2.456	0.169
0.01667	1.414	0.3678	0.309	2.606	0.162
0.02083	1.362	0.3928	0.302	2.766	0.158
0.025	1.322	0.4188	0.298	2.926	0.152
0.02917	1.28	0.4468	0.294	3.106	0.147
0.03333	1.237	0.4768	0.286	3.296	0.137
0.0375	1.191	0.5078	0.283	3.496	0.13
0.04167	1.182	0.5418	0.277	3.706	0.128
0.04583	1.161	0.5768	0.273	3.926	0.118
0.05183	1.085	0.6138	0.269	4.166	0.113

R001462

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05783	1.029	0.6538	0.269	4.416	0.108
0.06483	0.977	0.6958	0.261	4.676	0.102
0.07183	0.928	0.7398	0.258	4.956	0.098
0.07883	0.874	0.7868	0.253	5.256	0.09
0.08683	0.824	0.8368	0.247	5.566	0.082
0.09583	0.771	0.8898	0.244	5.906	0.078
0.1038	0.722	0.9458	0.239	6.256	0.072
0.1138	0.673	1.006	0.236	6.626	0.066
0.1238	0.618	1.066	0.237	7.026	0.059
0.1338	0.576	1.136	0.228	7.446	0.054
0.1448	0.531	1.206	0.226	7.886	0.047
0.1568	0.49	1.276	0.22	8.356	0.042
0.1698	0.455	1.356	0.218	8.856	0.033
0.1828	0.427	1.446	0.212	9.39	0.025
0.1968	0.406	1.526	0.206	9.946	0.02
0.2118	0.389	1.626	0.202	10.55	0.015
0.2278	0.376	1.726	0.198	11.15	0.011
0.2438	0.357	1.826	0.19	11.85	0.004
0.2618	0.345	1.936	0.19	12.55	0.

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 3.118

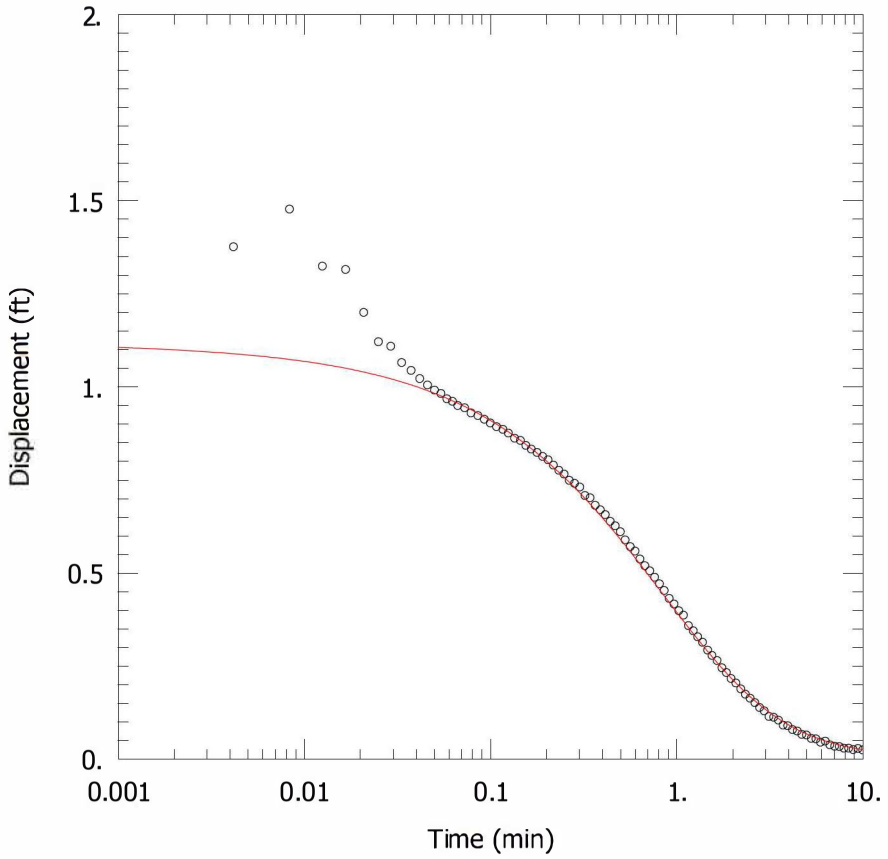
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00028	cm/sec
y0	0.3	ft

T = K*b = 0.04199 cm²/sec

R001463



G402 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G402
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00045 cm/sec
Ss = 0.002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.25 ft

WELL DATA (G402)

Initial Displacement: 1.12 ft
Total Well Penetration Depth: 13.25 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.25 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001464

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G402fh.aqt
Title: G402 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 09:41:35

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G402

AQUIFER DATA

Saturated Thickness: 13.25 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G402

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.12 ft
Static Water Column Height: 13.25 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 13.25 ft

No. of Observations: 97

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.302	0.2327	0.776	1.747	0.246
0.004167	1.376	0.2487	0.766	1.847	0.233
0.008333	1.477	0.2647	0.749	1.957	0.217
0.0125	1.324	0.2827	0.741	2.077	0.205
0.01667	1.315	0.3017	0.731	2.207	0.189
0.02083	1.2	0.3217	0.708	2.337	0.175
0.025	1.121	0.3427	0.702	2.477	0.164
0.02917	1.109	0.3646	0.682	2.627	0.152
0.03333	1.065	0.3887	0.67	2.787	0.139
0.0375	1.044	0.4137	0.657	2.947	0.13
0.04167	1.022	0.4396	0.639	3.127	0.115
0.04583	1.005	0.4677	0.627	3.317	0.113
0.05	0.991	0.4976	0.611	3.517	0.105

R001465

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05417	0.982	0.5287	0.589	3.727	0.092
0.05833	0.968	0.5627	0.571	3.947	0.09
0.0625	0.961	0.5977	0.559	4.187	0.08
0.06667	0.95	0.6347	0.538	4.437	0.076
0.07267	0.944	0.6747	0.52	4.697	0.067
0.07867	0.93	0.7167	0.506	4.977	0.065
0.08567	0.923	0.7607	0.489	5.277	0.056
0.09267	0.913	0.8077	0.471	5.587	0.055
0.09967	0.903	0.8577	0.453	5.927	0.046
0.1077	0.893	0.9106	0.432	6.277	0.049
0.1167	0.886	0.9667	0.417	6.647	0.039
0.1247	0.876	1.027	0.399	7.047	0.035
0.1347	0.862	1.087	0.387	7.467	0.034
0.1447	0.856	1.157	0.359	7.907	0.03
0.1547	0.843	1.227	0.345	8.377	0.03
0.1656	0.833	1.297	0.329	8.877	0.026
0.1777	0.824	1.377	0.314	9.407	0.029
0.1906	0.813	1.467	0.293	9.967	0.025
0.2037	0.804	1.547	0.279		
0.2177	0.79	1.647	0.265		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

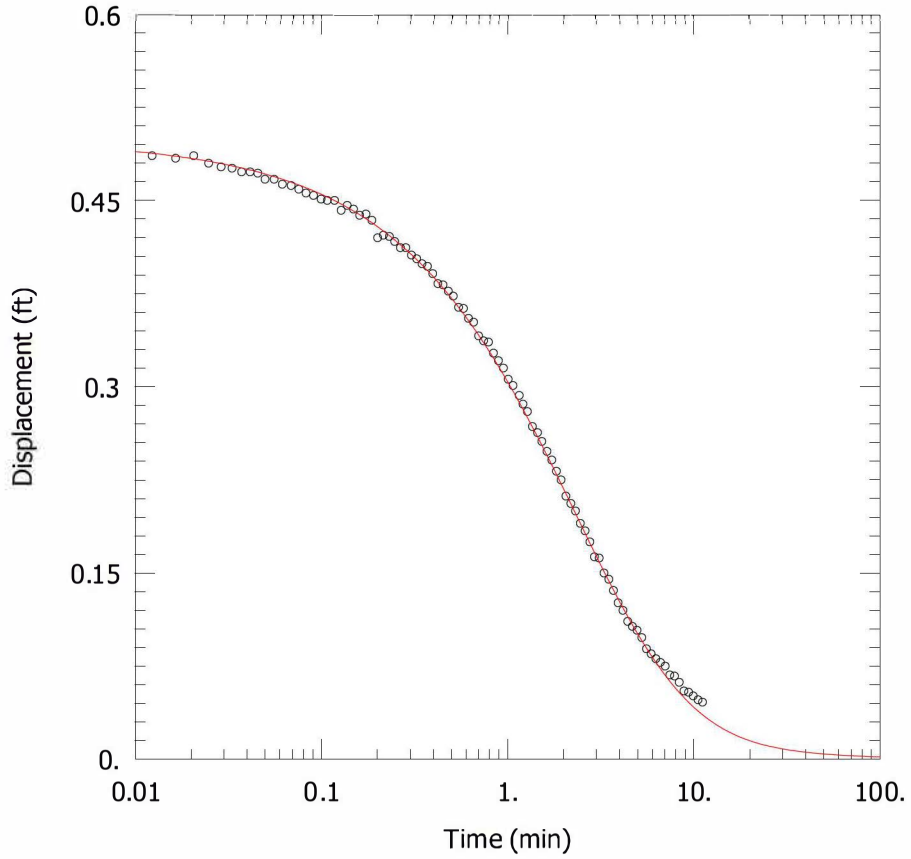
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00045	cm/sec
Ss	0.002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1817 cm^2/sec

R001466



G402 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G402
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00019 cm/sec
Ss = 0.001 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.25 ft

WELL DATA (G402)

Initial Displacement: 0.5 ft
Total Well Penetration Depth: 13.25 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.25 ft
Screen Length: 10. ft
Well Radius: 0.08333 ft

R001467

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G402rh.aqt
Title: G402 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 09:41:57

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G402

AQUIFER DATA

Saturated Thickness: 13.25 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G402

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.5 ft
Static Water Column Height: 13.25 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 10. ft
Total Well Penetration Depth: 13.25 ft

No. of Observations: 95

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.0001503	0.49	0.2658	0.412	1.94	0.225
0.004016	0.51	0.2848	0.412	2.06	0.212
0.009716	0.481	0.3049	0.406	2.19	0.206
0.01235	0.486	0.3258	0.403	2.32	0.2
0.01652	0.484	0.3478	0.399	2.46	0.19
0.02068	0.486	0.3719	0.397	2.61	0.184
0.02485	0.48	0.3968	0.391	2.77	0.175
0.02902	0.477	0.4228	0.383	2.93	0.163
0.03318	0.476	0.4508	0.382	3.11	0.162
0.03735	0.473	0.4808	0.377	3.3	0.15
0.04152	0.473	0.5119	0.373	3.5	0.145
0.04568	0.472	0.5458	0.364	3.71	0.136
0.04985	0.467	0.5808	0.363	3.93	0.126

R001468

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05585	0.467	0.6178	0.355	4.17	0.12
0.06185	0.463	0.6579	0.352	4.42	0.111
0.06885	0.462	0.6998	0.341	4.68	0.107
0.07585	0.459	0.7438	0.337	4.96	0.104
0.08285	0.456	0.7909	0.336	5.26	0.098
0.09085	0.454	0.8408	0.327	5.57	0.089
0.09985	0.451	0.8939	0.321	5.91	0.085
0.1079	0.45	0.9498	0.315	6.26	0.081
0.1179	0.45	1.01	0.306	6.63	0.078
0.1278	0.442	1.07	0.301	7.03	0.075
0.1379	0.446	1.157	0.293	7.45	0.068
0.1489	0.443	1.21	0.286	7.89	0.067
0.1608	0.438	1.28	0.28	8.36	0.062
0.1739	0.439	1.36	0.268	8.86	0.055
0.1868	0.434	1.45	0.263	9.39	0.054
0.2009	0.42	1.53	0.256	9.95	0.051
0.2158	0.422	1.63	0.248	10.55	0.048
0.2319	0.421	1.73	0.241	11.15	0.046
0.2478	0.417	1.83	0.232		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

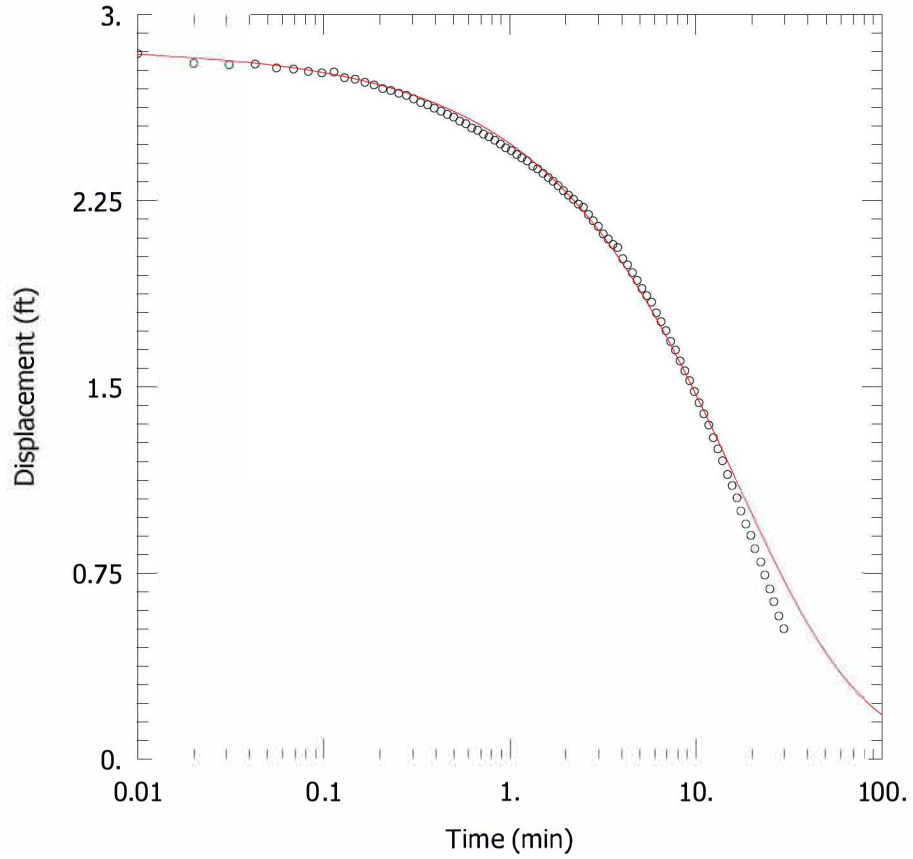
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00019	cm/sec
Ss	0.001	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.07673 cm^2/sec

R001469



G403 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G403
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 4.3E-5 cm/sec
Ss = 0.0075 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.99 ft

WELL DATA (G403)

Initial Displacement: 2.87 ft
Total Well Penetration Depth: 13.99 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.99 ft
Screen Length: 4.67 ft
Well Radius: 0.08333 ft

R001470

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G403fh.aqt
Title: G403 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 09:42:29

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G403

AQUIFER DATA

Saturated Thickness: 13.99 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G403

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.87 ft
Static Water Column Height: 13.99 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.67 ft
Total Well Penetration Depth: 13.99 ft

No. of Observations: 91

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.798	0.832	2.493	5.792	1.841
0.01	2.842	0.892	2.478	6.142	1.798
0.02	2.804	0.952	2.462	6.512	1.762
0.031	2.799	1.022	2.451	6.912	1.726
0.043	2.8	1.092	2.436	7.332	1.683
0.056	2.784	1.162	2.422	7.772	1.648
0.069	2.78	1.242	2.41	8.242	1.604
0.083	2.77	1.332	2.389	8.742	1.564
0.098	2.764	1.412	2.378	9.272	1.525
0.114	2.768	1.512	2.36	9.832	1.481
0.13	2.745	1.612	2.343	10.43	1.436
0.148	2.739	1.712	2.328	11.03	1.391
0.167	2.726	1.822	2.31	11.73	1.346

R001471

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.187	2.716	1.942	2.29	12.43	1.295
0.208	2.701	2.072	2.272	13.13	1.25
0.23	2.693	2.202	2.255	13.93	1.202
0.254	2.682	2.342	2.236	14.83	1.147
0.279	2.674	2.492	2.223	15.63	1.102
0.305	2.66	2.652	2.194	16.63	1.053
0.333	2.645	2.812	2.169	17.63	0.999
0.363	2.636	2.992	2.146	18.63	0.948
0.394	2.622	3.182	2.116	19.73	0.901
0.428	2.61	3.382	2.095	20.93	0.848
0.463	2.597	3.592	2.073	22.23	0.794
0.5	2.586	3.812	2.061	23.53	0.741
0.54	2.57	4.052	2.016	24.93	0.685
0.582	2.56	4.302	1.991	26.43	0.634
0.626	2.542	4.562	1.96	28.03	0.576
0.673	2.533	4.842	1.929	29.63	0.526
0.723	2.518	5.142	1.896		
0.776	2.507	5.452	1.867		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

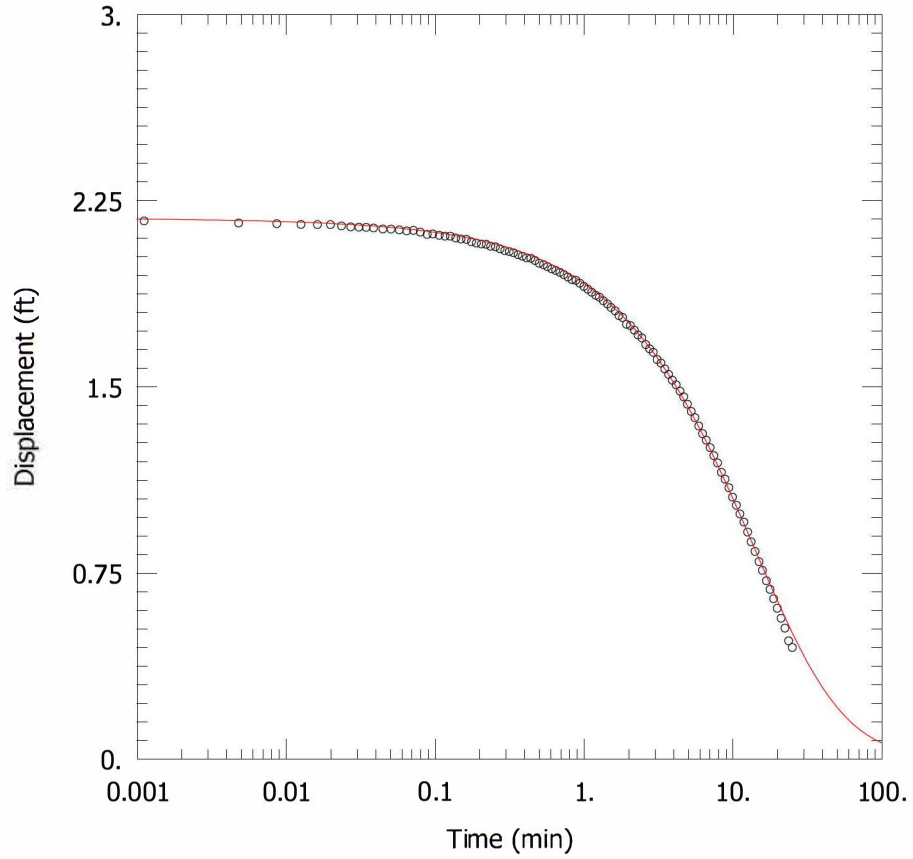
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.3E-5	cm/sec
Ss	0.0075	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.01834 cm^2/sec

R001472



G403 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G403
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 7.2E-5 cm/sec
Ss = 0.0015 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.99 ft

WELL DATA (G403)

Initial Displacement: 2.18 ft
Total Well Penetration Depth: 13.99 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.99 ft
Screen Length: 4.67 ft
Well Radius: 0.08333 ft

R001473

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G403rh.aqt
Title: G403 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 09:42:50

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G403

AQUIFER DATA

Saturated Thickness: 13.99 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G403

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.18 ft
Static Water Column Height: 13.99 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.67 ft
Total Well Penetration Depth: 13.99 ft

No. of Observations: 108

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	2.159	0.3607	2.032	3.289	1.596
0.001117	2.168	0.3857	2.026	3.489	1.572
0.004817	2.16	0.4117	2.02	3.699	1.55
0.008684	2.157	0.4397	2.018	3.919	1.527
0.0126	2.154	0.4697	2.009	4.159	1.508
0.01625	2.153	0.5007	1.998	4.409	1.483
0.0199	2.153	0.5347	1.992	4.669	1.46
0.02357	2.148	0.5697	1.984	4.949	1.43
0.02722	2.144	0.6067	1.975	5.249	1.401
0.03087	2.143	0.6467	1.969	5.559	1.376
0.03452	2.142	0.6887	1.961	5.899	1.342
0.03867	2.14	0.7327	1.952	6.249	1.311
0.04467	2.136	0.7797	1.942	6.619	1.285

R001474

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05067	2.135	0.8297	1.932	7.019	1.255
0.05767	2.132	0.8827	1.929	7.439	1.223
0.06467	2.128	0.9387	1.917	7.879	1.194
0.07167	2.13	0.9987	1.904	8.349	1.156
0.07967	2.123	1.059	1.893	8.849	1.128
0.08867	2.114	1.129	1.881	9.379	1.094
0.09667	2.116	1.199	1.869	9.939	1.056
0.1067	2.11	1.269	1.861	10.54	1.023
0.1167	2.107	1.349	1.847	11.14	0.988
0.1267	2.107	1.439	1.834	11.84	0.955
0.1377	2.1	1.519	1.82	12.54	0.915
0.1497	2.095	1.619	1.806	13.24	0.876
0.1627	2.094	1.719	1.787	14.04	0.837
0.1757	2.084	1.819	1.779	14.94	0.796
0.1897	2.079	1.931	1.752	15.74	0.761
0.2047	2.075	2.049	1.747	16.74	0.719
0.2207	2.074	2.179	1.728	17.74	0.684
0.2367	2.066	2.309	1.709	18.74	0.647
0.2547	2.064	2.449	1.697	19.84	0.608
0.2737	2.056	2.599	1.67	21.04	0.568
0.2937	2.049	2.759	1.653	22.34	0.528
0.3147	2.045	2.919	1.639	23.64	0.477
0.3367	2.04	3.099	1.61	25.04	0.45

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	7.2E-5	cm/sec
Ss	0.0015	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.0307 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	7.191E-5	5.079E-6	+/- 1.007E-5	14.16	cm/sec
Ss	0.001636	0.0003018	+/- 0.0005986	5.42	ft^{-1}
Kz/Kr	1.	1.686	+/- 3.343	0.5931	

R001475

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.03066 cm²/sec

Parameter Correlations

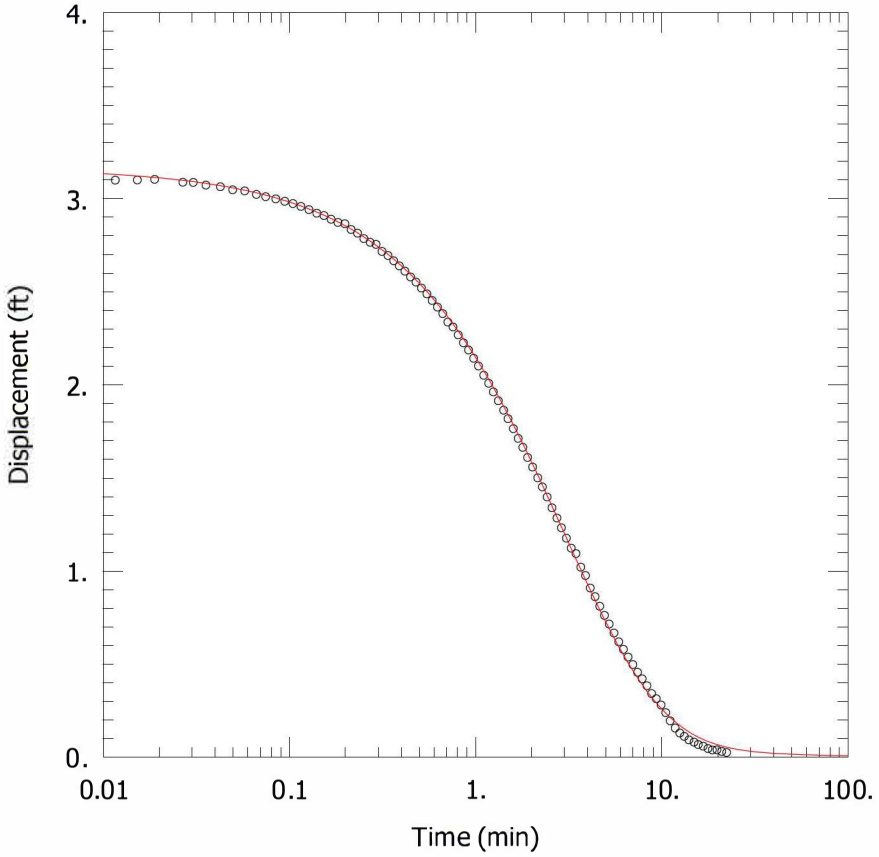
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.98
Ss	-0.99	1.00	0.94
Kz/Kr	-0.98	0.94	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01972 ft^2
Variance . . . . . 0.0001878 ft^2
Std. Deviation . . . . . 0.01371 ft
Mean. . . . . -0.004 ft
No. of Residuals 108
No. of Estimates. 3

R001476



G404 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G404
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00042 cm/sec
Ss = 0.00033 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 8.95 ft

WELL DATA (G404)

Initial Displacement: 3.17 ft
Total Well Penetration Depth: 8.95 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 8.95 ft
Screen Length: 4.75 ft
Well Radius: 0.08333 ft

R001477

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G404fh.aqt
Title: G404 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 09:43:12

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G404

AQUIFER DATA

Saturated Thickness: 8.95 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G404

X Location: 1. ft
Y Location: 0. ft

Initial Displacement: 3.17 ft
Static Water Column Height: 8.95 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.75 ft
Total Well Penetration Depth: 8.95 ft

No. of Observations: 99

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.136	0.4477	2.579	3.467	1.094
0.007967	3.119	0.4787	2.552	3.677	1.021
0.01163	3.099	0.5127	2.52	3.897	0.976
0.0153	3.1	0.5476	2.488	4.137	0.909
0.01895	3.103	0.5847	2.453	4.387	0.862
0.02685	3.088	0.6247	2.418	4.647	0.811
0.03055	3.087	0.6667	2.382	4.927	0.762
0.03567	3.072	0.7107	2.337	5.227	0.715
0.04267	3.064	0.7577	2.311	5.537	0.667
0.04967	3.047	0.8077	2.268	5.877	0.62
0.05767	3.041	0.8607	2.226	6.227	0.579
0.06667	3.022	0.9166	2.187	6.597	0.538
0.07467	3.01	0.9767	2.142	6.997	0.498

R001478

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.08467	2.998	1.037	2.101	7.417	0.456
0.09467	2.985	1.107	2.051	7.857	0.421
0.1047	2.973	1.177	2.008	8.327	0.384
0.1157	2.958	1.247	1.962	8.827	0.342
0.1277	2.941	1.327	1.914	9.357	0.314
0.1407	2.922	1.417	1.864	9.917	0.281
0.1537	2.909	1.497	1.818	10.52	0.24
0.1677	2.889	1.597	1.765	11.12	0.196
0.1827	2.872	1.697	1.712	11.82	0.157
0.1986	2.865	1.797	1.664	12.52	0.13
0.2147	2.834	1.907	1.61	13.22	0.112
0.2327	2.814	2.027	1.558	14.02	0.093
0.2517	2.785	2.157	1.501	14.93	0.081
0.2717	2.765	2.287	1.452	15.72	0.068
0.2927	2.754	2.427	1.397	16.72	0.06
0.3147	2.716	2.577	1.34	17.72	0.047
0.3387	2.695	2.737	1.285	18.72	0.039
0.3637	2.666	2.897	1.232	19.82	0.04
0.3897	2.639	3.077	1.176	21.02	0.031
0.4177	2.61	3.267	1.123	22.32	0.025

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

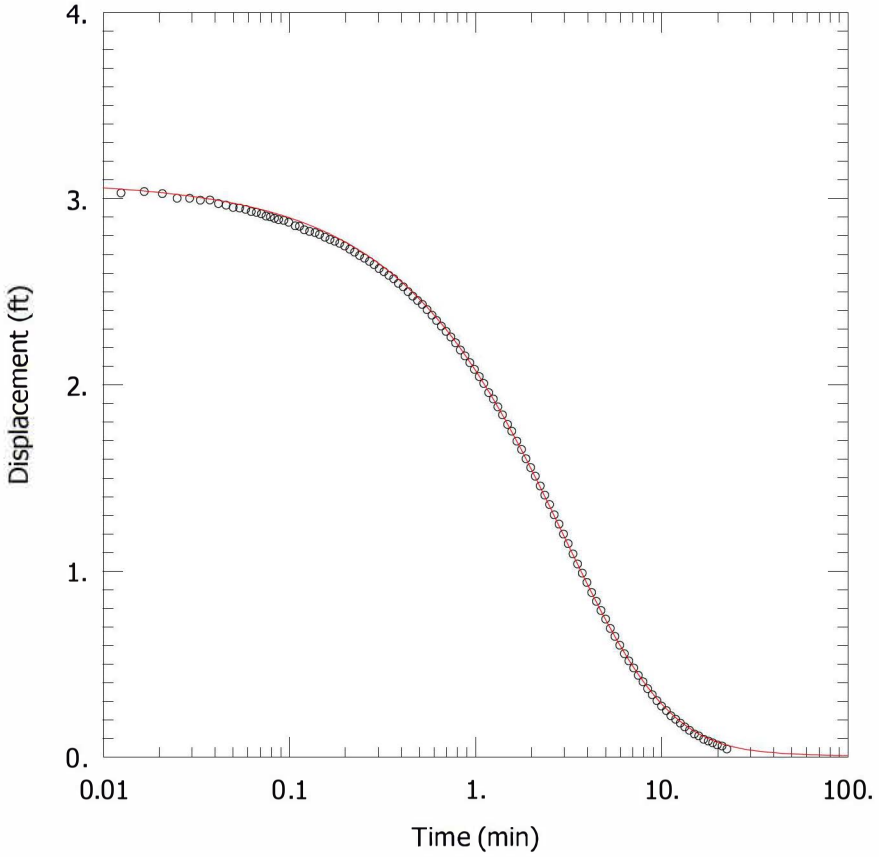
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00042	cm/sec
Ss	0.00033	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1146 cm^2/sec

R001479



G404 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G404
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00038 cm/sec
Ss = 0.0007 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 8.95 ft

WELL DATA (G404)

Initial Displacement: 3.1 ft
Total Well Penetration Depth: 8.95 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 8.95 ft
Screen Length: 4.75 ft
Well Radius: 0.08333 ft

R001480

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G404rh.aqt
Title: G404 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 09:43:34

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G404

AQUIFER DATA

Saturated Thickness: 8.95 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G404

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.1 ft
Static Water Column Height: 8.95 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.75 ft
Total Well Penetration Depth: 8.95 ft

No. of Observations: 116

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.022	0.2695	2.663	2.648	1.302
0.004167	3.042	0.2855	2.646	2.807	1.252
0.008333	3.052	0.3035	2.624	2.967	1.199
0.0125	3.03	0.3225	2.608	3.147	1.147
0.01667	3.038	0.3425	2.588	3.337	1.092
0.02083	3.027	0.3635	2.57	3.537	1.038
0.025	3.002	0.3855	2.545	3.747	0.989
0.02917	3.002	0.4095	2.526	3.967	0.939
0.03333	2.991	0.4345	2.5	4.207	0.885
0.0375	2.992	0.4605	2.476	4.457	0.837
0.04167	2.973	0.4885	2.453	4.717	0.788
0.04583	2.965	0.5185	2.431	4.997	0.742
0.05	2.953	0.5495	2.404	5.297	0.692

R001481

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05417	2.949	0.5835	2.374	5.607	0.649
0.05833	2.942	0.6185	2.345	5.947	0.602
0.0625	2.93	0.6555	2.315	6.297	0.556
0.06667	2.926	0.6955	2.287	6.667	0.517
0.07083	2.918	0.7375	2.257	7.067	0.48
0.075	2.906	0.7815	2.226	7.487	0.44
0.07917	2.902	0.8285	2.187	7.927	0.406
0.08333	2.894	0.8785	2.155	8.397	0.369
0.0875	2.887	0.9315	2.119	8.897	0.336
0.0935	2.883	0.9875	2.083	9.428	0.304
0.0995	2.873	1.047	2.044	9.987	0.275
0.1075	2.854	1.107	2.007	10.59	0.251
0.1135	2.851	1.178	1.958	11.19	0.223
0.1205	2.832	1.247	1.924	11.89	0.204
0.1286	2.824	1.317	1.882	12.59	0.184
0.1375	2.818	1.397	1.839	13.29	0.163
0.1455	2.807	1.488	1.787	14.09	0.145
0.1555	2.793	1.567	1.751	14.99	0.125
0.1655	2.781	1.668	1.698	15.79	0.115
0.1755	2.771	1.767	1.653	16.79	0.097
0.1865	2.76	1.867	1.603	17.79	0.087
0.1985	2.745	1.978	1.556	18.79	0.078
0.2115	2.728	2.097	1.509	19.89	0.067
0.2245	2.713	2.227	1.457	21.09	0.061
0.2385	2.695	2.357	1.408	22.39	0.044
0.2535	2.68	2.498	1.357		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

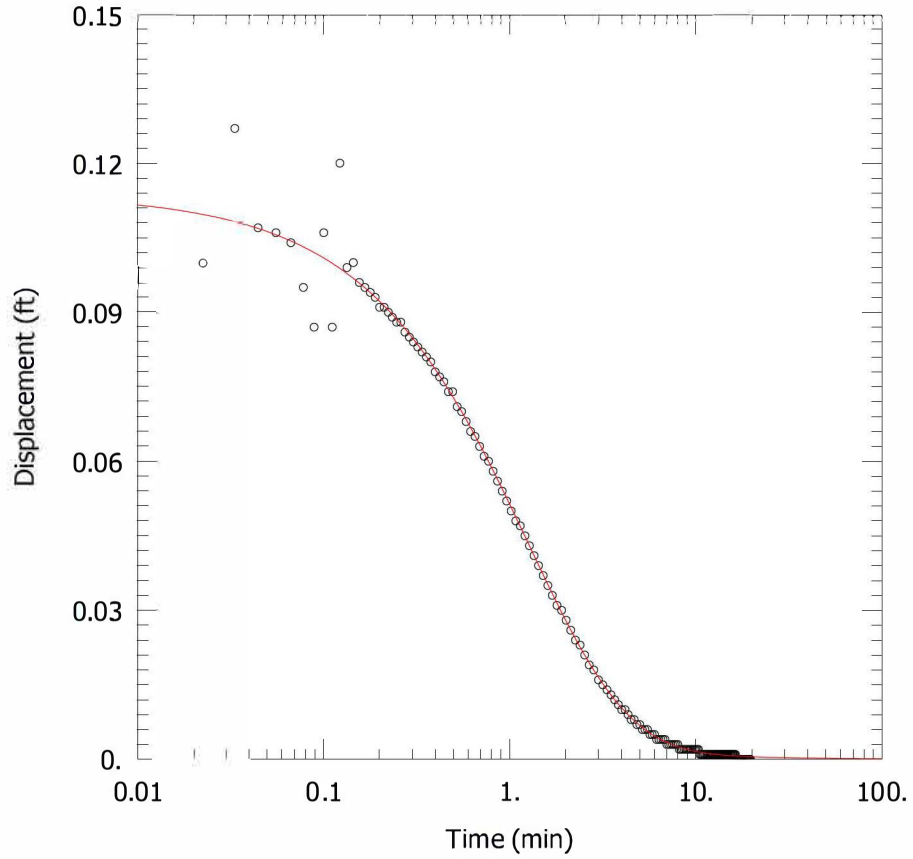
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00038	cm/sec
Ss	0.0007	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1037 cm^2/sec

R001482



G405 @ ASH POND 2 – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G405
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00098 cm/sec
Ss = 0.00037 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.12 ft

WELL DATA (G405)

Initial Displacement: 0.114 ft
Total Well Penetration Depth: 11.12 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.12 ft
Screen Length: 4.75 ft
Well Radius: 0.08333 ft

R001483

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G405fh2.aqt
Title: G405 @ Ash Pond 2 – Falling Head Test
Date: 11/28/16
Time: 09:43:55

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G405

AQUIFER DATA

Saturated Thickness: 11.12 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G405

X Location: 1. ft
Y Location: 0. ft

Initial Displacement: 0.114 ft
Static Water Column Height: 11.12 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.75 ft
Total Well Penetration Depth: 11.12 ft

No. of Observations: 166

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.0223	0.1	1.799	0.031	10.84	0.001
0.0335	0.127	1.904	0.03	11.01	0.001
0.0447	0.107	2.016	0.028	11.17	0.001
0.0558	0.106	2.134	0.026	11.34	0.001
0.067	0.104	2.259	0.024	11.51	0.001
0.0782	0.095	2.392	0.023	11.67	0.001
0.0893	0.087	2.532	0.021	11.84	0.001
0.1005	0.106	2.681	0.019	12.01	0.001
0.1117	0.087	2.838	0.018	12.17	0.001
0.1228	0.12	3.005	0.016	12.34	0.001
0.134	0.099	3.172	0.015	12.51	0.001
0.1452	0.1	3.338	0.014	12.67	0.001
0.1563	0.096	3.505	0.013	12.84	0.001

R001484

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.1675	0.095	3.672	0.012	13.01	0.001
0.1787	0.094	3.838	0.011	13.17	0.001
0.1898	0.093	4.005	0.01	13.34	0.001
0.201	0.091	4.172	0.01	13.51	0.001
0.2122	0.091	4.338	0.009	13.67	0.001
0.2233	0.09	4.505	0.008	13.84	0.001
0.235	0.089	4.672	0.008	14.01	0.001
0.2475	0.088	4.838	0.007	14.17	0.001
0.2607	0.088	5.005	0.007	14.34	0.001
0.2747	0.086	5.172	0.006	14.51	0.001
0.2895	0.085	5.338	0.006	14.67	0.001
0.3052	0.084	5.505	0.006	14.84	0.001
0.3218	0.083	5.672	0.005	15.01	0.001
0.3395	0.082	5.838	0.005	15.17	0.001
0.3582	0.081	6.005	0.005	15.34	0.001
0.378	0.08	6.172	0.004	15.51	0.001
0.399	0.078	6.338	0.004	15.67	0.001
0.4212	0.077	6.505	0.004	15.84	0.001
0.4447	0.076	6.672	0.004	16.	0.001
0.4695	0.074	6.838	0.004	16.17	0.001
0.4958	0.074	7.005	0.003	16.34	0.001
0.5238	0.071	7.172	0.003	16.5	0.
0.5535	0.07	7.338	0.003	16.67	0.
0.5848	0.068	7.505	0.003	16.84	0.
0.618	0.066	7.672	0.003	17.	0.
0.6532	0.065	7.838	0.003	17.17	0.
0.6905	0.063	8.005	0.003	17.34	0.
0.73	0.061	8.172	0.002	17.5	0.
0.7718	0.06	8.338	0.002	17.67	0.
0.8162	0.058	8.505	0.002	17.84	0.
0.8632	0.056	8.672	0.002	18.	0.
0.913	0.054	8.838	0.002	18.17	0.
0.9657	0.052	9.005	0.002	18.34	0.
1.022	0.05	9.172	0.002	18.5	0.
1.081	0.048	9.338	0.002	18.67	0.
1.143	0.047	9.505	0.002	18.84	0.
1.21	0.045	9.672	0.002	19.	0.
1.28	0.043	9.838	0.002	19.17	0.
1.355	0.041	10.01	0.002	19.34	0.
1.434	0.039	10.17	0.002	19.5	0.
1.517	0.037	10.34	0.002	19.67	0.
1.606	0.035	10.51	0.001		
1.7	0.033	10.67	0.001		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

R001485

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00098	cm/sec
Ss	0.00037	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.3322 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0009828	0.0002457	+/- 0.0004853	4.	cm/sec
Ss	0.0003762	0.0004077	+/- 0.0008052	0.9227	ft^{-1}
Kz/Kr	1.	2.807	+/- 5.544	0.3562	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.3331 cm^2/sec

Parameter Correlations

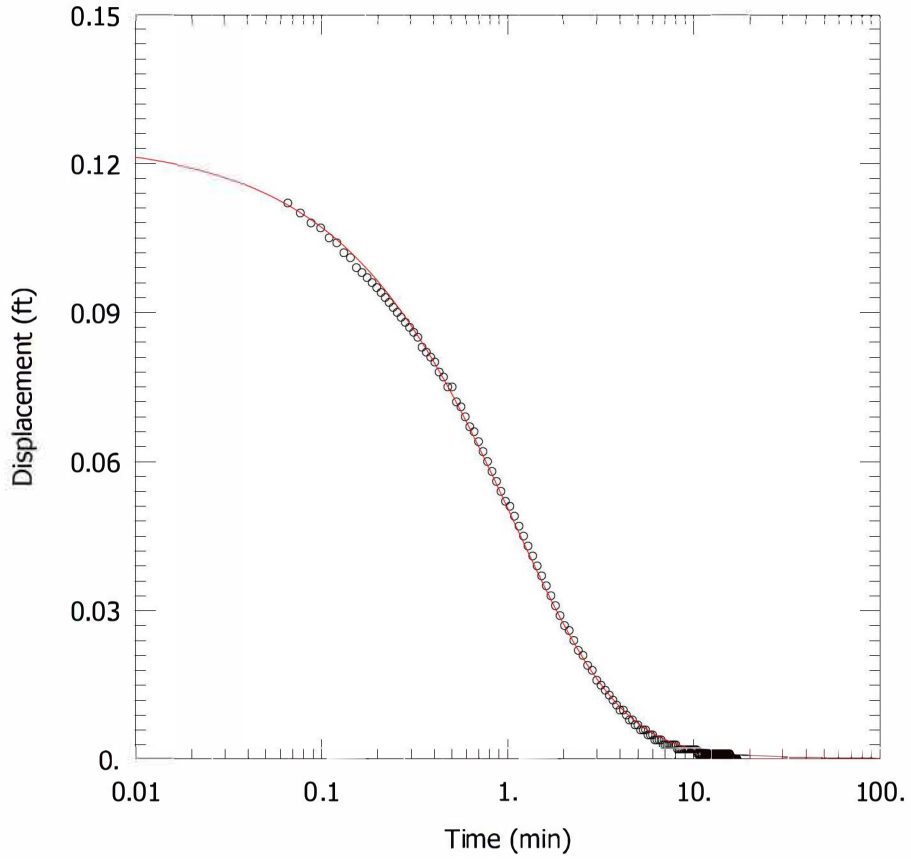
	Kr	Ss	Kz/Kr
Kr	1.00	-0.99	-0.99
Ss	-0.99	1.00	0.97
Kz/Kr	-0.99	0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.001412 ft^2
Variance . . . . . 8.661E-6 ft^2
Std. Deviation . . . . . 0.002943 ft
Mean. . . . . -3.208E-5 ft
No. of Residuals 166
No. of Estimates. 3

R001486



G405 @ ASH POND 2 – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G405
Test Date: 13 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00097 cm/sec
Ss = 0.0012 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 11.12 ft

WELL DATA (G405)

Initial Displacement: 0.125 ft
Total Well Penetration Depth: 11.12 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11.12 ft
Screen Length: 4.75 ft
Well Radius: 0.08333 ft

R001487

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\G405rh2.aqt
Title: G405 @ Ash Pond 2 – Rising Head Test
Date: 11/28/16
Time: 09:44:19

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 13 Jun 2016
Test Well: G405

AQUIFER DATA

Saturated Thickness: 11.12 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G405

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.125 ft
Static Water Column Height: 11.12 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.75 ft
Total Well Penetration Depth: 11.12 ft

No. of Observations: 147

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.066	0.112	1.441	0.039	9.013	0.002
0.077	0.11	1.525	0.037	9.179	0.002
0.088	0.108	1.613	0.035	9.346	0.002
0.099	0.107	1.707	0.033	9.513	0.002
0.11	0.105	1.807	0.031	9.679	0.002
0.121	0.104	1.912	0.029	9.846	0.002
0.132	0.102	2.023	0.027	10.01	0.002
0.143	0.101	2.142	0.026	10.18	0.002
0.154	0.099	2.267	0.024	10.35	0.002
0.165	0.098	2.399	0.022	10.51	0.001
0.176	0.097	2.54	0.021	10.68	0.001
0.187	0.096	2.688	0.019	10.85	0.001
0.198	0.095	2.846	0.018	11.01	0.001

R001488

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.094	3.013	0.016	11.18	0.001
0.22	0.093	3.179	0.015	11.35	0.001
0.231	0.092	3.346	0.014	11.51	0.001
0.2427	0.091	3.513	0.013	11.68	0.001
0.2552	0.09	3.679	0.012	11.85	0.001
0.2683	0.089	3.846	0.011	12.01	0.001
0.2823	0.088	4.013	0.01	12.18	0.001
0.2972	0.087	4.179	0.01	12.35	0.001
0.3128	0.086	4.346	0.009	12.51	0.001
0.3295	0.085	4.513	0.008	12.68	0.001
0.3472	0.083	4.679	0.008	12.85	0.001
0.3658	0.082	4.846	0.007	13.01	0.001
0.3857	0.081	5.013	0.007	13.18	0.001
0.4067	0.08	5.179	0.006	13.35	0.001
0.4288	0.078	5.346	0.006	13.51	0.001
0.4523	0.077	5.513	0.006	13.68	0.001
0.4772	0.075	5.679	0.005	13.85	0.001
0.5035	0.075	5.846	0.005	14.01	0.001
0.5315	0.072	6.013	0.005	14.18	0.001
0.5612	0.071	6.179	0.004	14.35	0.001
0.5925	0.069	6.346	0.004	14.51	0.001
0.6257	0.067	6.513	0.004	14.68	0.001
0.6608	0.066	6.679	0.004	14.85	0.001
0.6982	0.064	6.846	0.003	15.01	0.001
0.7377	0.062	7.013	0.003	15.18	0.001
0.7795	0.06	7.179	0.003	15.35	0.001
0.8238	0.058	7.346	0.003	15.51	0.001
0.8708	0.056	7.513	0.003	15.68	0.
0.9207	0.054	7.679	0.003	15.85	0.
0.9733	0.052	7.846	0.003	16.01	0.
1.029	0.051	8.013	0.003	16.18	0.
1.088	0.049	8.179	0.002	16.35	0.
1.151	0.047	8.346	0.002	16.51	0.
1.217	0.045	8.513	0.002	16.68	0.
1.288	0.043	8.679	0.002	16.85	0.
1.362	0.041	8.846	0.002	17.01	0.

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00097	cm/sec
Ss	0.0012	ft^{-1}

R001489

Kz/Kr 1.

T = K*b = 0.3288 cm²/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0009567	3.216E-5	+/- 6.357E-5	29.75	cm/sec
Ss	0.001278	0.0001631	+/- 0.0003224	7.835	ft^{-1}
Kz/Kr	1.	0.4379	+/- 0.8657	2.284	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.3243 cm²/sec

Parameter Correlations

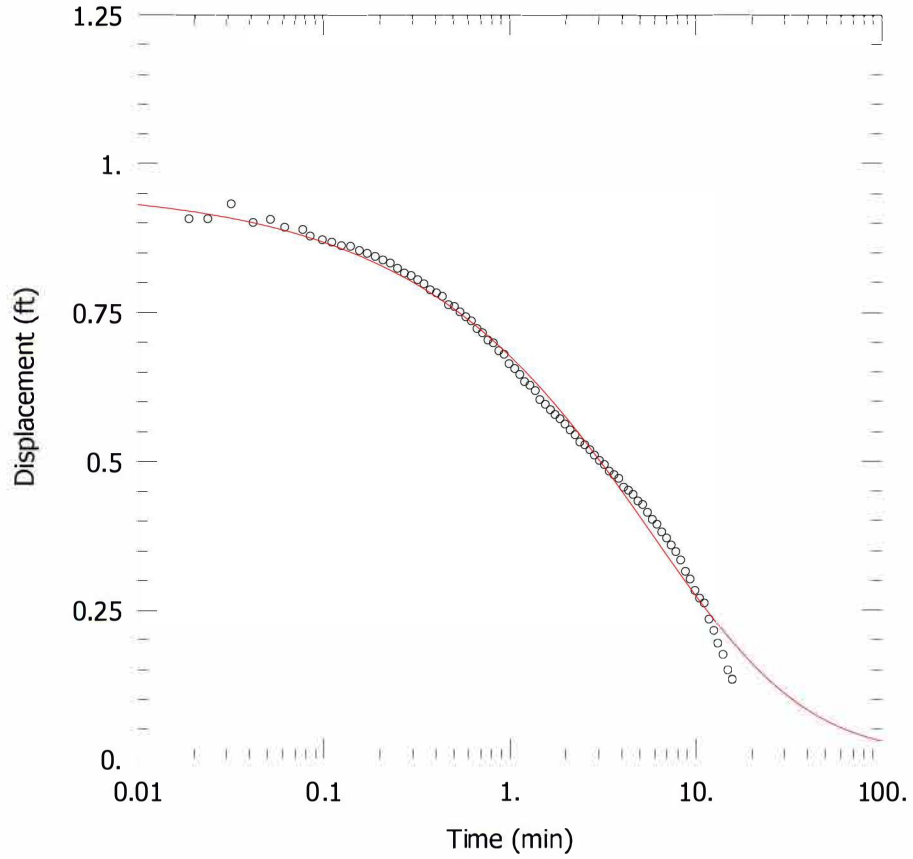
	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.96
Ss	-0.98	1.00	0.92
Kz/Kr	-0.96	0.92	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 9.007E-5 ft^2
Variance . . . . . 6.255E-7 ft^2
Std. Deviation . . . . . 0.0007909 ft
Mean. . . . . -0.0003511 ft
No. of Residuals 147
No. of Estimates. 3

R001490



R104 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: R104
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 7.0E-5 cm/sec
Ss = 0.045 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 14.17 ft

WELL DATA (R104)

Initial Displacement: 0.96 ft
Total Well Penetration Depth: 14.17 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.17 ft
Screen Length: 4.43 ft
Well Radius: 0.08333 ft

R001491

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\R104fh.aqt
Title: R104 @ CCR Landfill – Falling Head Test
Date: 11/28/16
Time: 10:46:31

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: R104

AQUIFER DATA

Saturated Thickness: 14.17 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: R104

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.96 ft
Static Water Column Height: 14.17 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.43 ft
Total Well Penetration Depth: 14.17 ft

No. of Observations: 91

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
-0.03432	1.004	0.405	0.783	3.034	0.502
-0.03015	0.97	0.436	0.777	3.224	0.495
-0.02598	0.932	0.47	0.763	3.424	0.484
-0.01998	0.905	0.505	0.76	3.634	0.478
-0.01398	0.897	0.542	0.751	3.854	0.472
-0.006983	0.913	0.582	0.743	4.094	0.457
0.	0.909	0.624	0.736	4.344	0.452
0.007	0.907	0.668	0.723	4.604	0.445
0.01902	0.907	0.715	0.716	4.884	0.434
0.024	0.907	0.765	0.704	5.184	0.428
0.032	0.932	0.818	0.699	5.494	0.415
0.04202	0.901	0.874	0.686	5.834	0.403
0.05202	0.906	0.934	0.68	6.184	0.395

R001492

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.062	0.893	0.994	0.664	6.554	0.382
0.07762	0.889	1.064	0.656	6.954	0.372
0.085	0.878	1.134	0.646	7.374	0.36
0.09885	0.872	1.204	0.634	7.814	0.349
0.111	0.868	1.284	0.628	8.284	0.335
0.125	0.862	1.374	0.619	8.784	0.316
0.14	0.861	1.454	0.604	9.314	0.303
0.156	0.854	1.554	0.596	9.874	0.284
0.172	0.849	1.654	0.587	10.47	0.271
0.19	0.844	1.754	0.579	11.07	0.263
0.209	0.838	1.864	0.572	11.77	0.236
0.229	0.833	1.984	0.563	12.47	0.216
0.25	0.824	2.114	0.553	13.17	0.195
0.2722	0.816	2.244	0.545	13.97	0.176
0.296	0.812	2.384	0.533	14.87	0.15
0.321	0.805	2.534	0.528	15.67	0.134
0.347	0.798	2.694	0.52		
0.375	0.788	2.854	0.511		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	7.0E-5	cm/sec
Ss	0.045	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.03023 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	6.961E-5	2.932E-5	+/- 5.826E-5	2.374	cm/sec
Ss	0.04481	0.0257	+/- 0.05106	1.744	ft^{-1}
Kz/Kr	1.	31.19	+/- 61.98	0.03206	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.03006 cm^2/sec

R001493

Parameter Correlations

	Kr	Ss	Kz/Kr
Kr	1.00	-1.00	-0.99
Ss	-1.00	1.00	0.97
Kz/Kr	-0.99	0.97	1.00

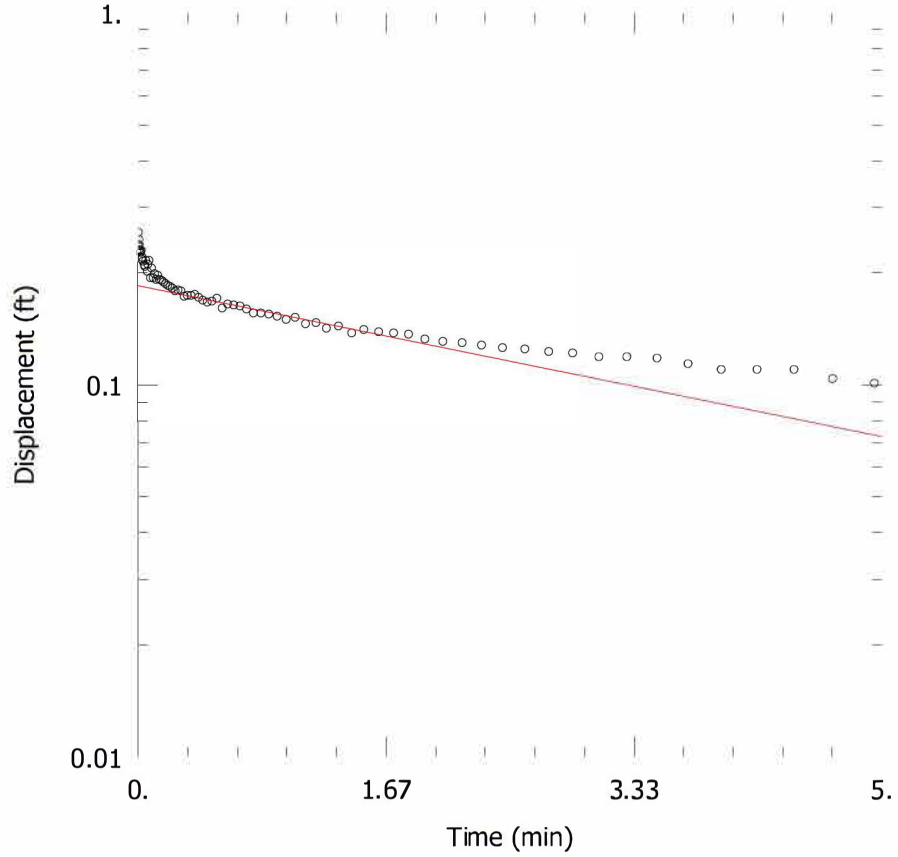
Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.04042 ft^2
Variance . . . . . 0.0004593 ft^2
Std. Deviation . . . . . 0.02143 ft
Mean. . . . . -0.002289 ft
No. of Residuals 91
No. of Estimates. 3

R001494

R104 @CCR LANDFILL – RISING HEAD TEST



PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: R104
Test Date: 15 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.00028 cm/sec
y0 = 0.185 ft

AQUIFER DATA

Saturated Thickness: 14.17 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (R104)

Initial Displacement: 0.23 ft
Total Well Penetration Depth: 14.17 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 14.17 ft
Screen Length: 4.43 ft
Well Radius: 0.08333 ft

R001495

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\R104rh.aqt
Title: R104 @CCR Landfill – Rising Head Test
Date: 12/01/16
Time: 09:05:00

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 15 Jun 2016
Test Well: R104

AQUIFER DATA

Saturated Thickness: 14.17 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: R104

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.23 ft
Static Water Column Height: 14.17 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.43 ft
Total Well Penetration Depth: 14.17 ft

No. of Observations: 93

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	0.239	0.2745	0.18	1.929	0.133
0.00365	0.257	0.2945	0.179	2.049	0.131
0.007317	0.246	0.3155	0.173	2.179	0.13
0.01098	0.237	0.3375	0.174	2.309	0.128
0.01465	0.231	0.3615	0.174	2.449	0.126
0.01863	0.229	0.3865	0.175	2.599	0.125
0.0228	0.227	0.4125	0.172	2.759	0.123
0.02697	0.229	0.4405	0.169	2.919	0.122
0.03113	0.218	0.4705	0.167	3.099	0.119
0.0353	0.22	0.5015	0.168	3.289	0.12
0.03947	0.215	0.5355	0.171	3.489	0.118
0.04867	0.21	0.5705	0.161	3.699	0.114
0.05237	0.208	0.6075	0.165	3.919	0.11

R001496

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.05847	0.216	0.6475	0.164	4.159	0.11
0.06835	0.202	0.6895	0.163	4.409	0.11
0.07247	0.211	0.7335	0.16	4.669	0.104
0.08047	0.216	0.7805	0.156	4.949	0.101
0.08947	0.194	0.8305	0.156	5.249	0.1
0.09748	0.206	0.8835	0.155	5.559	0.1
0.108	0.194	0.9395	0.153	5.899	0.096
0.1175	0.199	0.9995	0.15	6.249	0.093
0.1275	0.192	1.059	0.152	6.619	0.089
0.1385	0.197	1.129	0.146	7.019	0.086
0.1505	0.192	1.199	0.147	7.439	0.085
0.1635	0.191	1.269	0.142	7.879	0.076
0.1765	0.189	1.349	0.144	8.349	0.073
0.1905	0.187	1.439	0.138	8.849	0.072
0.2055	0.185	1.519	0.141	9.379	0.066
0.2215	0.184	1.619	0.139	9.939	0.059
0.2375	0.182	1.719	0.138	10.54	0.06
0.2555	0.179	1.819	0.137	11.14	0.051

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 3.761

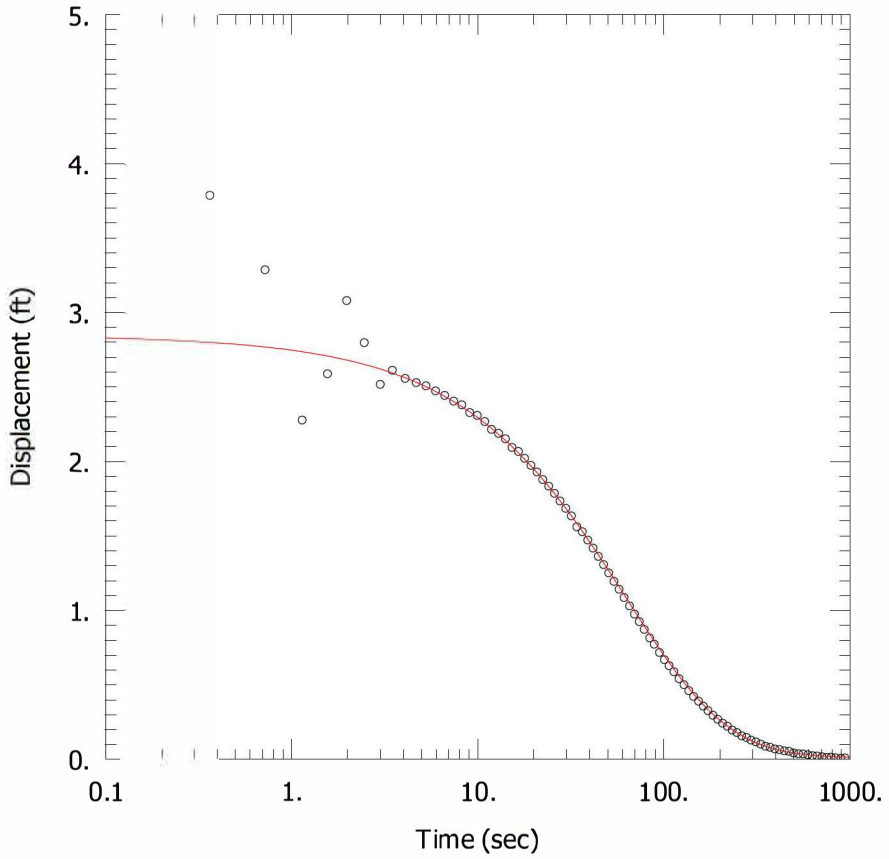
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00028	cm/sec
y0	0.185	ft

$T = K*b = 0.1209\ cm^2/sec$

R001497



T127 @ CCR LANDFILL – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T127
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0012 cm/sec
Ss = 0.0005 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.28 ft

WELL DATA (T127)

Initial Displacement: 2.85 ft
Total Well Penetration Depth: 10.28 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.28 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001498

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\T127fh.aqt
Title: T127 @ CCR Landfill – Falling Head Test
Date: 11/28/16
Time: 09:44:57

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: T127

AQUIFER DATA

Saturated Thickness: 10.28 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T127

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 2.85 ft
Static Water Column Height: 10.28 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 10.28 ft

No. of Observations: 89

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.12	27.72	1.734	183.6	0.295
0.36	3.789	29.76	1.684	195.	0.268
0.721	3.285	31.86	1.634	207.	0.242
1.141	2.277	34.08	1.561	219.6	0.222
1.56	2.588	36.48	1.527	232.8	0.196
1.98	3.079	39.	1.471	247.2	0.179
2.461	2.796	41.64	1.418	262.2	0.157
3.	2.517	44.46	1.362	278.	0.147
3.48	2.611	47.46	1.307	294.6	0.129
4.08	2.556	50.64	1.251	312.6	0.117
4.681	2.528	54.	1.194	331.2	0.102
5.28	2.507	57.6	1.141	351.6	0.088
5.94	2.473	61.2	1.086	372.6	0.08

R001499

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
6.66	2.442	65.4	1.03	394.8	0.069
7.44	2.404	69.6	0.975	418.8	0.065
8.22	2.379	73.8	0.924	444.	0.056
9.06	2.327	78.6	0.871	470.4	0.053
9.96	2.308	84.	0.815	498.6	0.042
10.92	2.267	88.8	0.773	528.6	0.037
11.88	2.214	94.8	0.717	560.4	0.036
12.96	2.188	100.8	0.668	594.	0.031
14.1	2.151	106.8	0.628	630.	0.024
15.3	2.093	113.4	0.588	666.	0.022
16.56	2.066	120.6	0.541	708.	0.017
17.88	2.02	128.4	0.501	750.	0.013
19.32	1.973	136.2	0.461	792.	0.015
20.82	1.928	144.6	0.422	840.	0.01
22.38	1.878	153.6	0.39	894.2	0.007
24.06	1.834	163.2	0.356	942.	0.009
25.86	1.786	172.8	0.326		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

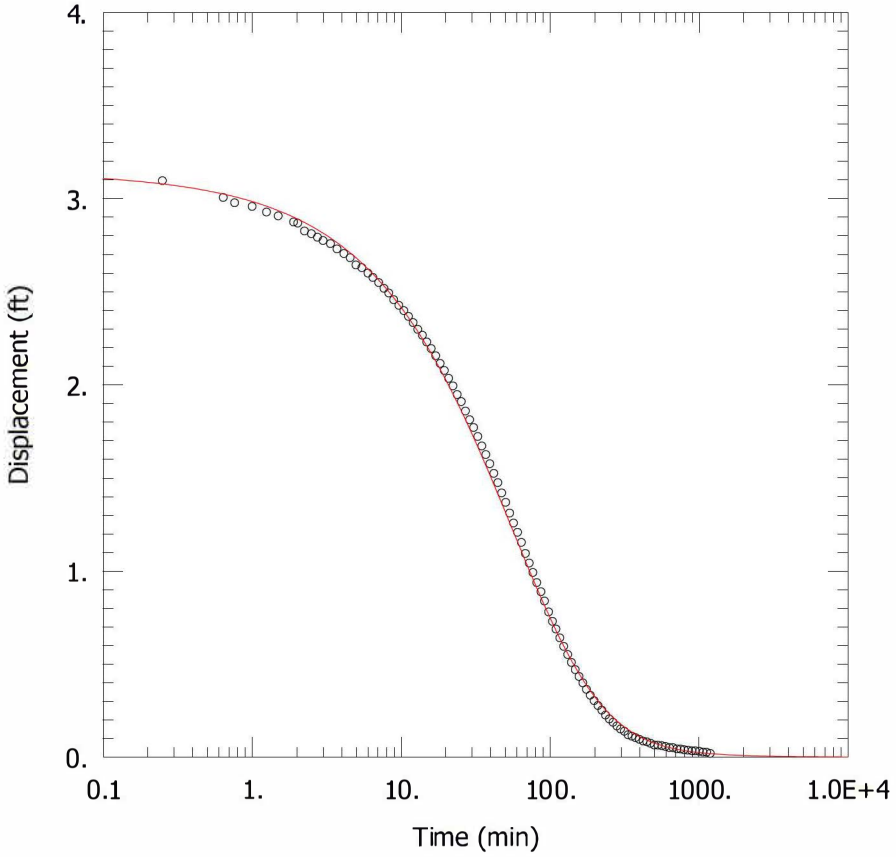
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.0012	cm/sec
Ss	0.0005	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.376 cm^2/sec

R001500



T127 @ CCR LANDFILL – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T127
Test Date: 14 Jun 2016

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 1.7E-5 cm/sec
Ss = 0.0025 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 10.28 ft

WELL DATA (T127)

Initial Displacement: 3.15 ft
Total Well Penetration Depth: 10.28 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 10.28 ft
Screen Length: 4.54 ft
Well Radius: 0.08333 ft

R001501

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\T127rh.aqt
Title: T127 @ CCR Landfill – Rising Head Test
Date: 11/28/16
Time: 09:45:21

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 14 Jun 2016
Test Well: T127

AQUIFER DATA

Saturated Thickness: 10.28 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T127

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 3.15 ft
Static Water Column Height: 10.28 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.54 ft
Total Well Penetration Depth: 10.28 ft

No. of Observations: 105

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	3.236	19.56	2.077	166.2	0.4
0.25	3.096	20.88	2.035	175.8	0.365
0.641	3.006	22.32	1.994	186.6	0.333
0.764	2.978	23.82	1.948	198.	0.304
1.	2.958	25.38	1.91	210.	0.278
1.25	2.928	27.06	1.859	222.6	0.253
1.5	2.907	28.86	1.813	235.8	0.227
1.903	2.874	30.72	1.771	250.2	0.206
2.027	2.868	32.76	1.723	265.2	0.188
2.25	2.826	34.86	1.672	280.8	0.168
2.5	2.812	37.08	1.625	297.6	0.152
2.75	2.793	39.48	1.576	315.6	0.14
3.	2.775	42.	1.525	334.2	0.121

R001502

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
3.36	2.758	44.64	1.475	354.8	0.113
3.72	2.73	47.46	1.42	375.6	0.105
4.14	2.705	50.46	1.369	397.8	0.097
4.56	2.683	53.64	1.311	421.8	0.087
4.98	2.644	57.	1.258	447.	0.083
5.46	2.629	60.6	1.208	473.4	0.075
6.	2.6	64.2	1.154	501.6	0.066
6.48	2.577	68.4	1.095	531.6	0.065
7.08	2.549	72.6	1.043	563.4	0.062
7.68	2.518	76.8	0.992	597.	0.058
8.28	2.493	81.6	0.938	633.	0.052
8.94	2.457	87.	0.889	669.	0.052
9.66	2.427	91.8	0.839	711.	0.045
10.44	2.399	97.8	0.781	753.	0.044
11.22	2.368	103.8	0.73	795.	0.041
12.06	2.334	109.8	0.689	843.	0.038
12.96	2.298	116.4	0.641	897.	0.035
13.92	2.266	123.6	0.596	945.	0.035
14.88	2.23	131.4	0.552	1005.	0.032
15.96	2.195	139.2	0.51	1065.	0.028
17.1	2.156	147.6	0.471	1125.	0.027
18.3	2.115	156.6	0.434	1191.	0.021

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

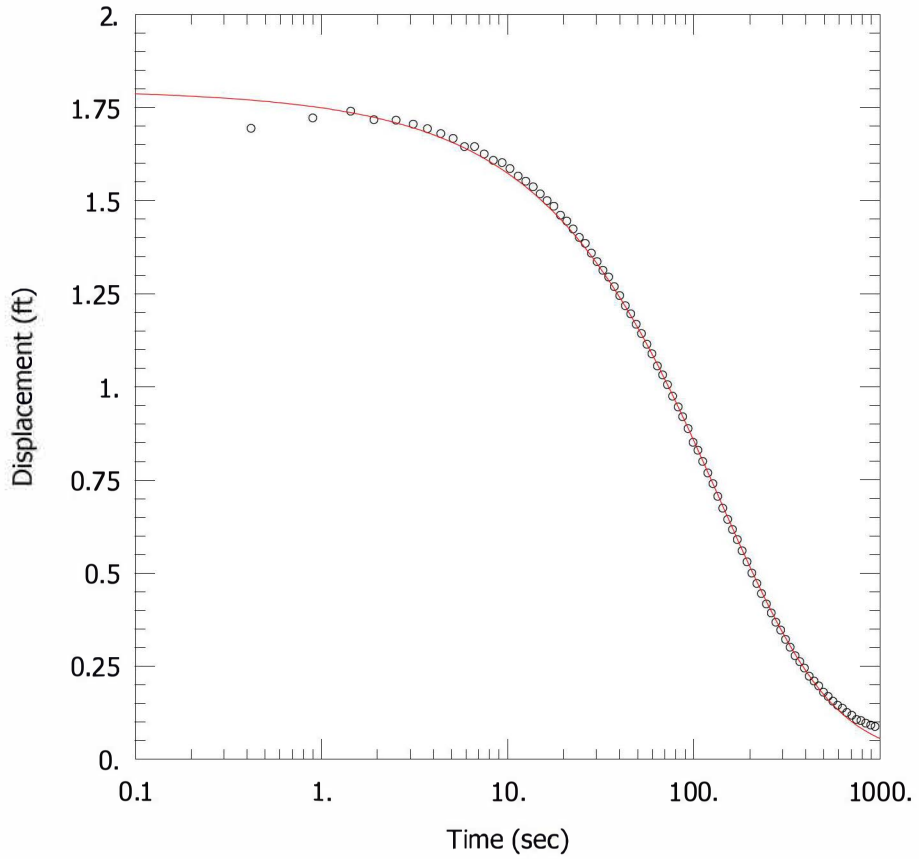
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	1.7E-5	cm/sec
Ss	0.0025	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.005327 cm^2/sec

R001503



T202 @ GMF GYPSUM POND – FALLING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T202
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00045 cm/sec
Ss = 0.002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.29 ft

WELL DATA (T202)

Initial Displacement: 1.8 ft
Total Well Penetration Depth: 13.29 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.29 ft
Screen Length: 4.38 ft
Well Radius: 0.08333 ft

R001504

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\T202fh.aqt
Title: T202 @ GMF Gypsum Pond – Falling Head Test
Date: 11/28/16
Time: 09:45:43

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: T202

AQUIFER DATA

Saturated Thickness: 13.29 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T202

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.8 ft
Static Water Column Height: 13.29 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.38 ft
Total Well Penetration Depth: 13.29 ft

No. of Observations: 89

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.742	34.92	1.295	231.2	0.445
0.42	1.694	37.44	1.269	245.6	0.417
0.9	1.722	40.08	1.245	260.6	0.393
1.44	1.74	42.9	1.218	276.2	0.368
1.92	1.717	45.9	1.196	293.	0.347
2.52	1.716	49.08	1.168	311.	0.322
3.12	1.705	52.44	1.143	329.6	0.301
3.72	1.693	56.04	1.114	350.	0.278
4.38	1.68	59.64	1.089	371.	0.262
5.1	1.667	63.84	1.056	393.2	0.245
5.88	1.645	68.04	1.032	417.2	0.223
6.66	1.645	72.24	1.006	442.4	0.21
7.5	1.625	77.04	0.975	468.8	0.197

R001505

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
8.4	1.608	82.44	0.946	497.	0.18
9.36	1.602	87.24	0.92	527.	0.169
10.32	1.586	93.24	0.888	558.8	0.156
11.4	1.566	99.24	0.851	592.4	0.145
12.54	1.552	105.2	0.83	628.4	0.137
13.74	1.537	111.8	0.8	664.4	0.126
15.	1.518	119.	0.769	706.4	0.118
16.32	1.5	126.8	0.74	748.4	0.107
17.76	1.485	134.6	0.706	790.4	0.104
19.26	1.461	143.	0.674	838.4	0.097
20.82	1.445	152.	0.644	892.4	0.092
22.5	1.424	161.6	0.617	940.6	0.088
24.3	1.401	171.2	0.59	1000.4	0.079
26.16	1.385	182.	0.56	1060.4	0.077
28.2	1.359	193.4	0.53	1120.4	0.07
30.3	1.336	205.4	0.5	1186.4	0.069
32.52	1.313	218.	0.472		

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

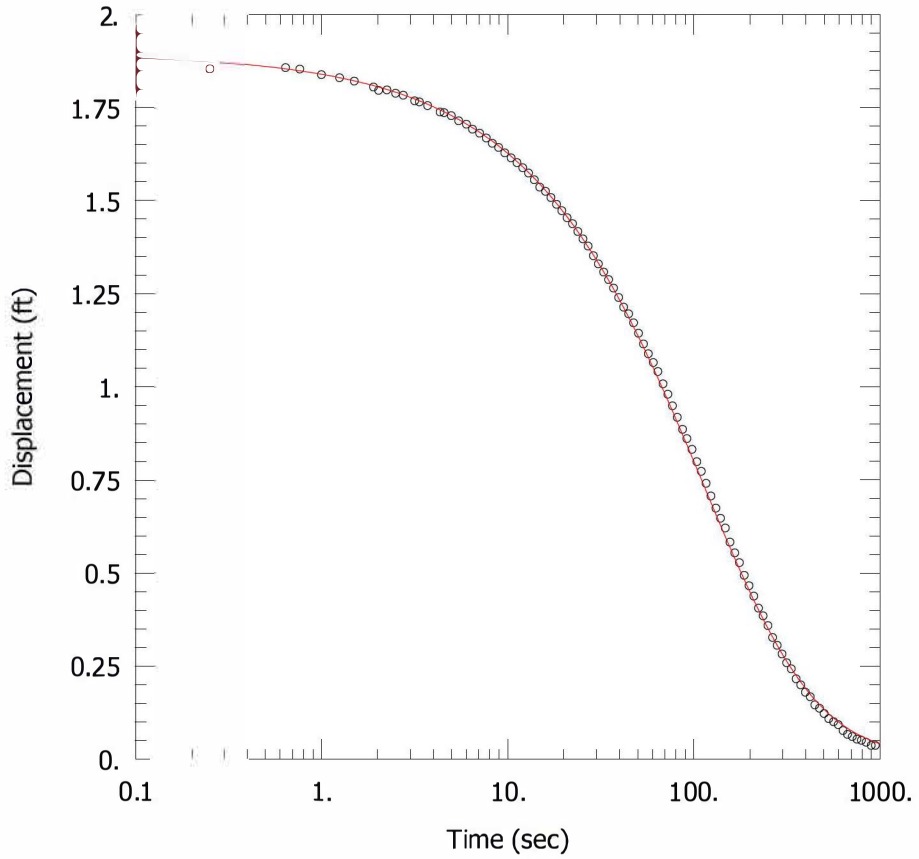
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00045	cm/sec
Ss	0.002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.1823 cm^2/sec

R001506



T202 @ GMF GYPSUM POND – RISING HEAD TEST

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T202
Test Date: 16 Jun 2016

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 0.00055 cm/sec
Ss = 0.002 ft^{-1}
Kz/Kr = 1.

AQUIFER DATA

Saturated Thickness: 13.29 ft

WELL DATA (T202)

Initial Displacement: 1.9 ft
Total Well Penetration Depth: 13.29 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 13.29 ft
Screen Length: 4.38 ft
Well Radius: 0.08333 ft

R001507

Data Set: C:\Users\ktheesfeld\AppData\Local\Temp\Temp1_CoffeenAqtesolvFiles.zip\T202rh.aqt
Title: T202 @ GMF Gypsum Pond – Rising Head Test
Date: 11/28/16
Time: 09:46:07

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 16 Jun 2016
Test Well: T202

AQUIFER DATA

Saturated Thickness: 13.29 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T202

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.9 ft
Static Water Column Height: 13.29 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.3333 ft
Screen Length: 4.38 ft
Total Well Penetration Depth: 13.29 ft

No. of Observations: 105

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.832	19.56	1.473	166.2	0.554
0.25	1.855	20.88	1.454	175.8	0.528
0.642	1.857	22.32	1.438	186.6	0.494
0.765	1.853	23.82	1.417	198.	0.466
1.	1.838	25.38	1.397	210.	0.438
1.25	1.83	27.06	1.378	222.6	0.406
1.5	1.821	28.86	1.352	235.8	0.385
1.903	1.805	30.72	1.33	250.2	0.359
2.027	1.796	32.76	1.308	265.2	0.327
2.25	1.797	34.86	1.288	280.8	0.306
2.5	1.788	37.08	1.265	297.6	0.283
2.75	1.783	39.48	1.24	315.6	0.259
3.167	1.768	42.	1.214	334.2	0.243

R001508

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
3.36	1.765	44.64	1.196	354.6	0.216
3.721	1.755	47.46	1.172	375.6	0.2
4.338	1.738	50.46	1.144	397.8	0.18
4.56	1.736	53.64	1.115	421.8	0.168
4.98	1.728	57.	1.089	447.	0.146
5.46	1.714	60.6	1.065	473.4	0.137
6.	1.705	64.2	1.041	501.6	0.123
6.48	1.692	68.4	1.008	531.6	0.109
7.08	1.681	72.6	0.98	563.4	0.101
7.68	1.668	76.8	0.949	597.	0.093
8.28	1.654	81.6	0.918	633.	0.077
8.94	1.643	87.	0.886	669.	0.067
9.66	1.628	91.8	0.861	711.	0.061
10.44	1.615	97.8	0.832	753.	0.054
11.22	1.602	103.8	0.799	795.	0.051
12.06	1.588	109.8	0.773	843.	0.046
12.96	1.574	116.4	0.741	897.	0.037
13.92	1.556	123.6	0.707	945.	0.037
14.88	1.536	131.4	0.674	1005.	0.031
15.96	1.525	139.2	0.647	1065.	0.026
17.1	1.508	147.6	0.621	1125.1	0.023
18.3	1.49	156.6	0.583	1191.	0.025

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	0.00055	cm/sec
Ss	0.002	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.2228 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	0.0005307	2.017E-5	+/- 4.0E-5	26.31	cm/sec
Ss	0.002349	0.0002737	+/- 0.0005428	8.581	ft^{-1}
Kz/Kr	1.	0.6606	+/- 1.31	1.514	

C.I. is approximate 95% confidence interval for parameter

R001509

t-ratio = estimate/std. error
No estimation window

T = K*b = 0.215 cm²/sec

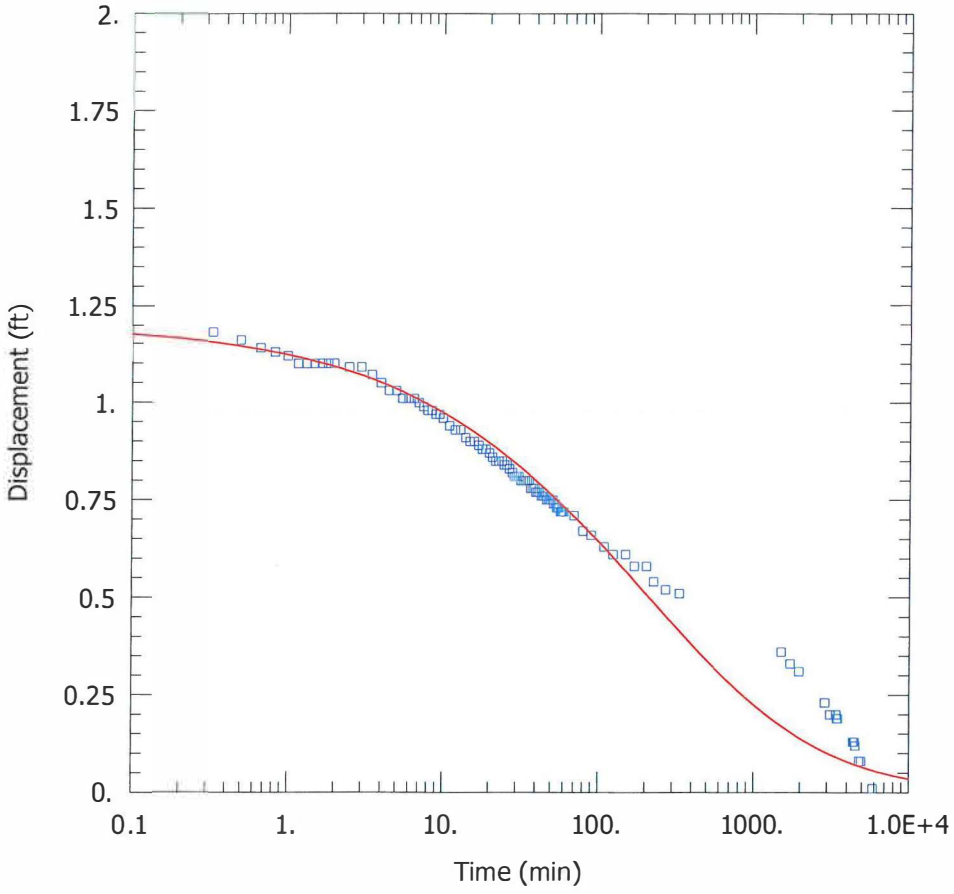
Parameter Correlations

	Kr	Ss	Kz/Kr
Kr	1.00	-0.98	-0.95
Ss	-0.98	1.00	0.89
Kz/Kr	-0.95	0.89	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.01824 ft^2
Variance . . . . . 0.0001788 ft^2
Std. Deviation . . . . . 0.01337 ft
Mean. . . . . -0.005597 ft
No. of Residuals 105
No. of Estimates. 3



G45D FALLING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G45D
Test Date: 29 Aug 2016

AQUIFER DATA

Saturated Thickness: 5.64 ft

WELL DATA (G45D)

Initial Displacement: 1.2 ft
Total Well Penetration Depth: 9.64 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 5.64 ft
Screen Length: 9.64 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 4.9E-7 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.2 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\G45D_fh1.aqt
Title: G45D Falling Head #1
Date: 09/27/16
Time: 14:28:20

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 29 Aug 2016
Test Well: G45D

AQUIFER DATA

Saturated Thickness: 5.64 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G45D

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.2 ft
Static Water Column Height: 5.64 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 9.64 ft
Total Well Penetration Depth: 9.64 ft

No. of Observations: 104

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.33	1.18	36.	0.8
0.5	1.16	37.13	0.78
0.67	1.14	38.27	0.78
0.83	1.13	39.2	0.78
1.	1.12	40.02	0.77
1.17	1.1	41.	0.77
1.33	1.1	42.	0.77
1.5	1.1	43.37	0.76
1.67	1.1	44.2	0.76
1.83	1.1	45.	0.76
2.	1.1	46.	0.76
2.5	1.09	47.	0.75
3.	1.09	48.	0.75
3.5	1.07	49.	0.75
4.	1.05	50.	0.75
4.5	1.03	51.23	0.75
5.	1.03	52.	0.74
5.5	1.01	53.07	0.74
6.	1.01	54.03	0.73

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
6.5	1.01	55.	0.73
7.	1.	56.05	0.73
7.5	0.99	57.32	0.72
8.	0.98	58.	0.72
8.5	0.98	59.	0.72
9.	0.97	60.	0.72
9.5	0.97	70.	0.71
10.	0.96	80.	0.67
11.	0.94	90.	0.66
12.	0.93	108.6	0.63
13.	0.93	123.8	0.61
14.	0.91	149.	0.61
15.	0.9	170.4	0.58
16.	0.9	204.4	0.58
17.13	0.89	226.	0.54
18.	0.88	270.9	0.52
19.	0.88	331.8	0.51
20.	0.87	1506.	0.36
21.	0.86	1722.	0.33
22.	0.85	1960.	0.31
23.03	0.85	2879.	0.23
24.23	0.85	3117.	0.2
25.	0.84	3380.	0.2
26.	0.84	3427.	0.19
27.	0.83	3464.	0.19
28.12	0.82	4328.	0.13
29.	0.81	4405.	0.13
30.	0.81	4431.	0.13
31.	0.81	4456.	0.13
32.	0.8	4499.	0.12
33.1	0.8	4775.	0.08
34.05	0.8	4899.	0.08
35.	0.8	5848.	0.01

SOLUTION

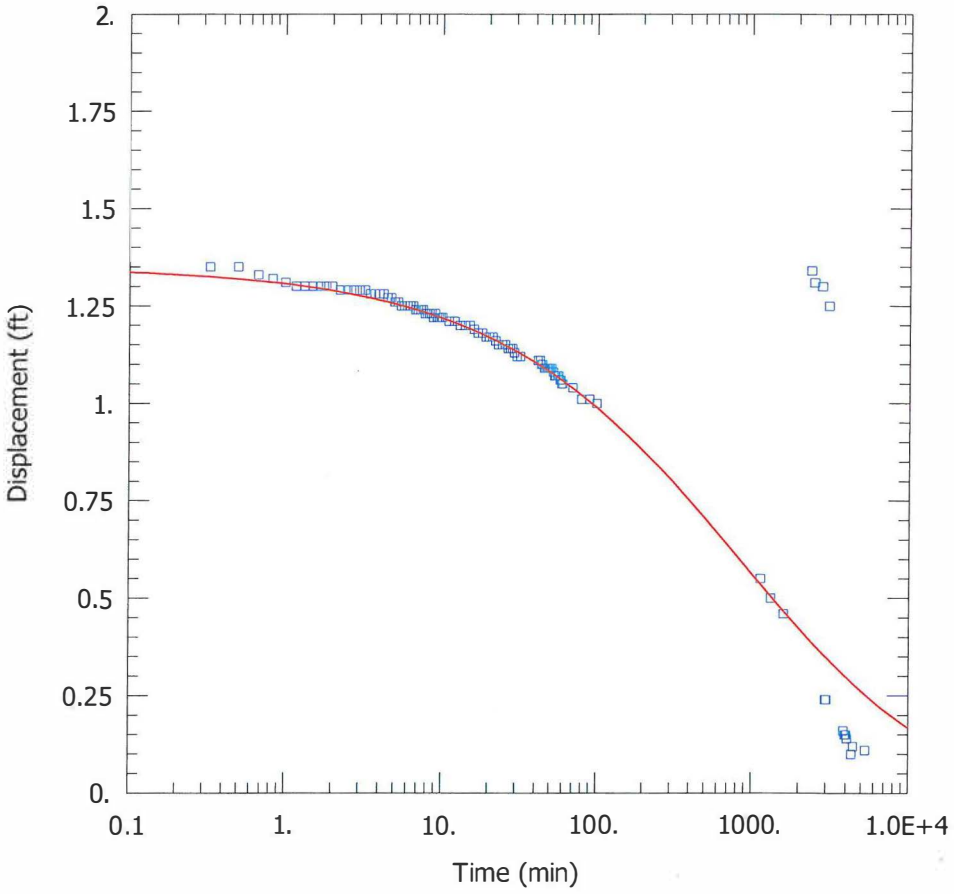
Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.9E-7	cm/sec
Ss	0.2	ft^{-1}
Kz/Kr	1.	

T = K*b = 8.423E-5 cm^2/sec



G46D FALLING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: G46D
Test Date: 29 Aug 2016

AQUIFER DATA

Saturated Thickness: 19.34 ft

WELL DATA (G46D)

Initial Displacement: 1.35 ft
Total Well Penetration Depth: 18.95 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 19.34 ft
Screen Length: 9.65 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 4.0E-8 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.2 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\G46D_fh1.aqt
Title: G46D Falling Head #1
Date: 09/27/16
Time: 14:28:21

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 29 Aug 2016
Test Well: G46D

AQUIFER DATA

Saturated Thickness: 19.34 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G46D

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.35 ft
Static Water Column Height: 19.34 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 9.65 ft
Total Well Penetration Depth: 18.95 ft

No. of Observations: 105

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.33	1.35	21.07	1.17
0.5	1.35	22.	1.16
0.67	1.33	23.	1.15
0.83	1.32	24.3	1.15
1.	1.31	25.35	1.15
1.17	1.3	26.47	1.14
1.33	1.3	27.33	1.14
1.5	1.3	28.28	1.14
1.67	1.3	29.13	1.13
1.83	1.3	30.25	1.12
2.	1.3	31.9	1.12
2.25	1.29	41.25	1.11
2.5	1.29	42.63	1.11
2.75	1.29	43.55	1.1
3.	1.29	44.42	1.1
3.25	1.29	45.33	1.09
3.5	1.28	46.18	1.09
3.75	1.28	47.12	1.09
4.	1.28	48.	1.09

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
4.25	1.28	49.	1.09
4.5	1.27	50.	1.09
4.75	1.27	51.	1.09
5.	1.26	52.05	1.08
5.25	1.26	53.23	1.07
5.5	1.25	54.	1.07
5.75	1.25	55.35	1.07
6.	1.25	56.57	1.07
6.25	1.25	57.48	1.06
6.5	1.25	58.28	1.06
6.75	1.24	59.	1.05
7.	1.24	60.	1.05
7.25	1.24	70.	1.04
7.5	1.24	80.	1.01
7.75	1.23	90.	1.01
8.	1.23	100.	1.
8.25	1.23	1143.	0.55
8.5	1.23	1332.	0.5
8.75	1.22	1607.	0.46
9.	1.23	2397.	1.34
9.25	1.22	2507.	1.31
9.5	1.22	2778.	1.3
9.75	1.22	2962.	0.24
10.	1.22	3001.	0.24
11.	1.21	3056.	1.25
12.	1.21	3856.	0.16
13.	1.2	3930.	0.15
14.	1.2	3975.	0.15
15.05	1.2	4012.	0.15
16.	1.19	4057.	0.14
17.	1.18	4337.	0.1
18.13	1.18	4445.	0.12
19.07	1.17	5325.	0.11
20.	1.17		

SOLUTION

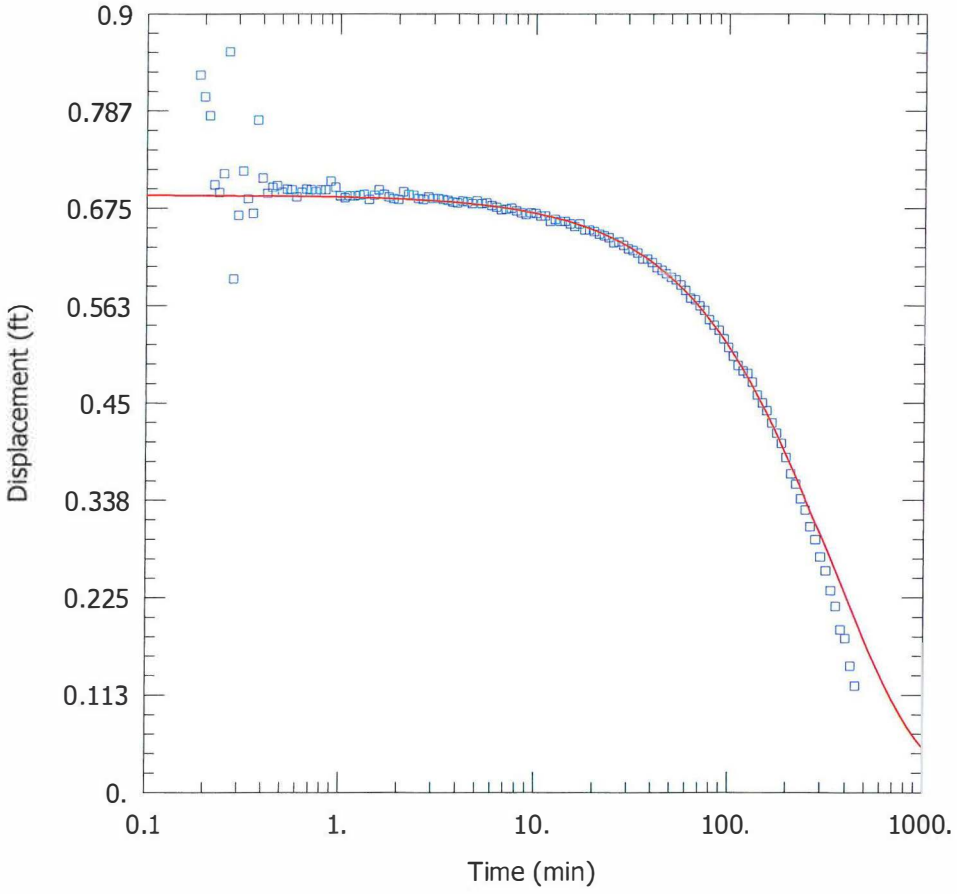
Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.0E-8	cm/sec
Ss	0.2	ft^{-1}
Kz/Kr	1.	

T = K*b = 2.358E-5 cm^2/sec



T408 FALLING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T408
Test Date: 1 Sept 2016

AQUIFER DATA

Saturated Thickness: 22.87 ft

WELL DATA (T408)

Initial Displacement: 0.69 ft
Total Well Penetration Depth: 22.44 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 22.87 ft
Screen Length: 4.83 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 4.7E-6 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 1.0E-7 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T408_fh1.aqt
Title: T408 Falling Head #1
Date: 09/27/16
Time: 14:28:22

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 1 Sept 2016
Test Well: T408

AQUIFER DATA

Saturated Thickness: 22.87 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T408

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.69 ft
Static Water Column Height: 22.87 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.83 ft
Total Well Penetration Depth: 22.44 ft

No. of Observations: 136

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.188	0.829	9.44	0.67
0.199	0.804	10.	0.669
0.211	0.782	10.6	0.666
0.224	0.702	11.2	0.666
0.237	0.693	11.9	0.66
0.251	0.715	12.6	0.662
0.266	0.856	13.3	0.66
0.282	0.593	14.1	0.66
0.298	0.667	15.	0.657
0.316	0.718	15.8	0.654
0.335	0.686	16.8	0.657
0.355	0.669	17.8	0.65
0.376	0.777	18.8	0.65
0.398	0.71	19.9	0.648
0.422	0.692	21.1	0.645
0.447	0.699	22.4	0.643
0.473	0.701	23.7	0.641
0.501	0.693	25.1	0.635
0.531	0.697	26.6	0.636

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.562	0.696	28.2	0.632
0.596	0.688	29.8	0.628
0.631	0.693	31.6	0.626
0.668	0.697	33.5	0.623
0.708	0.696	35.5	0.616
0.75	0.694	37.6	0.616
0.794	0.696	39.8	0.612
0.841	0.696	42.2	0.606
0.891	0.706	44.7	0.603
0.944	0.699	47.3	0.599
1.	0.689	50.1	0.595
1.06	0.687	53.1	0.592
1.12	0.689	56.2	0.586
1.19	0.689	59.6	0.58
1.26	0.69	63.1	0.571
1.33	0.691	66.8	0.569
1.41	0.685	70.8	0.562
1.5	0.69	75.	0.557
1.58	0.696	79.4	0.546
1.68	0.691	84.1	0.54
1.78	0.688	89.1	0.534
1.88	0.686	94.4	0.524
1.99	0.685	100.	0.514
2.11	0.694	106.	0.504
2.24	0.691	112.	0.493
2.37	0.69	119.	0.487
2.51	0.686	126.	0.484
2.66	0.685	133.	0.474
2.82	0.688	141.	0.459
2.98	0.686	150.	0.45
3.16	0.686	158.	0.441
3.35	0.685	168.	0.427
3.55	0.684	178.	0.415
3.76	0.682	188.	0.403
3.98	0.681	199.	0.387
4.22	0.683	211.	0.368
4.47	0.682	224.	0.356
4.73	0.68	237.	0.339
5.01	0.683	251.	0.326
5.31	0.68	266.	0.307
5.62	0.681	282.	0.292
5.96	0.678	298.	0.272
6.31	0.676	316.	0.256
6.68	0.673	335.	0.233
7.08	0.674	355.	0.215
7.5	0.675	376.	0.188
7.94	0.672	398.	0.178
8.41	0.67	422.	0.146
8.91	0.668	447.	0.123

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.7E-6	cm/sec
Ss	1.0E-7	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.003276 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	6.277E-6	7.768E-6	+/- 1.537E-5	0.8081	cm/sec
Ss	4.0E-12	2.586E-10	+/- 5.116E-10	0.01547	ft^{-1}
Kz/Kr	1.	not estimated			

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.004376 cm^2/sec

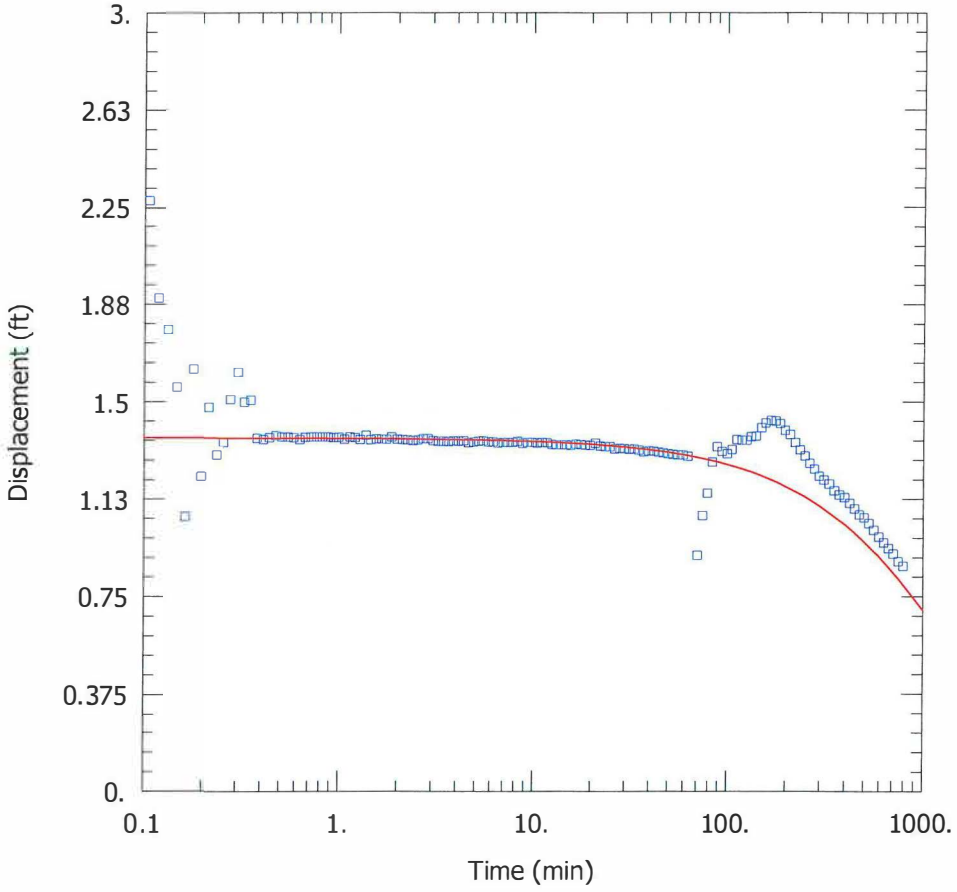
Parameter Correlations

	Kr	Ss
Kr	1.00	-1.00
Ss	-1.00	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 0.103 ft^2
Variance . . . . . 0.0007689 ft^2
Std. Deviation . . . . . 0.02773 ft
Mean. . . . . 0.006273 ft
No. of Residuals 136
No. of Estimates. 2



T408 FALLING HEAD #2

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T408
Test Date: 1 Sept 2016

AQUIFER DATA

Saturated Thickness: 22.74 ft

WELL DATA (T408)

Initial Displacement: 1.36 ft
Total Well Penetration Depth: 22.31 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 22.74 ft
Screen Length: 4.83 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 9.8E-7 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 1.0E-5 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T408_fh2.aqt
Title: T408 Falling Head #2
Date: 09/27/16
Time: 14:28:23

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 1 Sept 2016
Test Well: T408

AQUIFER DATA

Saturated Thickness: 22.74 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T408

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.36 ft
Static Water Column Height: 22.74 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.83 ft
Total Well Penetration Depth: 22.31 ft

No. of Observations: 142

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.105	2.278	13.18	1.334
0.118	1.901	13.98	1.334
0.132	1.781	14.88	1.334
0.147	1.557	15.68	1.332
0.163	1.058	16.68	1.336
0.179	1.627	17.68	1.334
0.197	1.213	18.68	1.333
0.216	1.478	19.78	1.332
0.236	1.294	20.98	1.34
0.257	1.342	22.28	1.329
0.279	1.508	23.58	1.327
0.303	1.612	24.98	1.327
0.328	1.498	26.48	1.318
0.354	1.505	28.08	1.32
0.382	1.359	29.68	1.319
0.412	1.354	31.48	1.317
0.443	1.361	33.38	1.318
0.477	1.368	35.38	1.313
0.512	1.363	37.48	1.307

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.549	1.363	39.68	1.311
0.589	1.361	42.08	1.309
0.631	1.354	44.58	1.306
0.675	1.362	47.18	1.303
0.722	1.363	49.98	1.3
0.772	1.364	52.98	1.297
0.825	1.363	56.08	1.294
0.881	1.363	59.48	1.294
0.941	1.361	62.98	1.289
1.001	1.362	70.68	0.908
1.071	1.355	74.88	1.061
1.141	1.363	79.28	1.148
1.211	1.361	83.98	1.267
1.291	1.354	88.98	1.327
1.381	1.37	94.28	1.308
1.461	1.353	99.88	1.3
1.561	1.356	105.9	1.316
1.661	1.355	111.9	1.354
1.761	1.355	118.9	1.351
1.871	1.363	125.9	1.351
1.991	1.355	132.9	1.365
2.121	1.354	140.9	1.367
2.251	1.352	149.9	1.399
2.391	1.35	157.9	1.418
2.541	1.352	167.9	1.428
2.701	1.358	177.9	1.425
2.861	1.358	187.9	1.416
3.041	1.35	198.9	1.39
3.231	1.347	210.9	1.374
3.431	1.348	223.9	1.343
3.641	1.346	236.9	1.314
3.861	1.349	250.9	1.291
4.101	1.347	265.9	1.262
4.351	1.349	281.9	1.24
4.611	1.341	297.9	1.213
4.891	1.344	315.9	1.198
5.191	1.348	334.9	1.183
5.501	1.349	354.9	1.157
5.841	1.344	375.9	1.141
6.191	1.345	397.9	1.131
6.561	1.34	421.9	1.109
6.961	1.343	446.9	1.088
7.381	1.343	472.9	1.065
7.821	1.342	500.9	1.054
8.291	1.346	530.9	1.032
8.791	1.339	561.9	1.005
9.321	1.342	595.9	0.98
9.881	1.343	630.9	0.957
10.48	1.34	667.9	0.935
11.08	1.342	707.9	0.914
11.78	1.341	749.9	0.885
12.48	1.335	793.9	0.867

SOLUTION

Slug Test

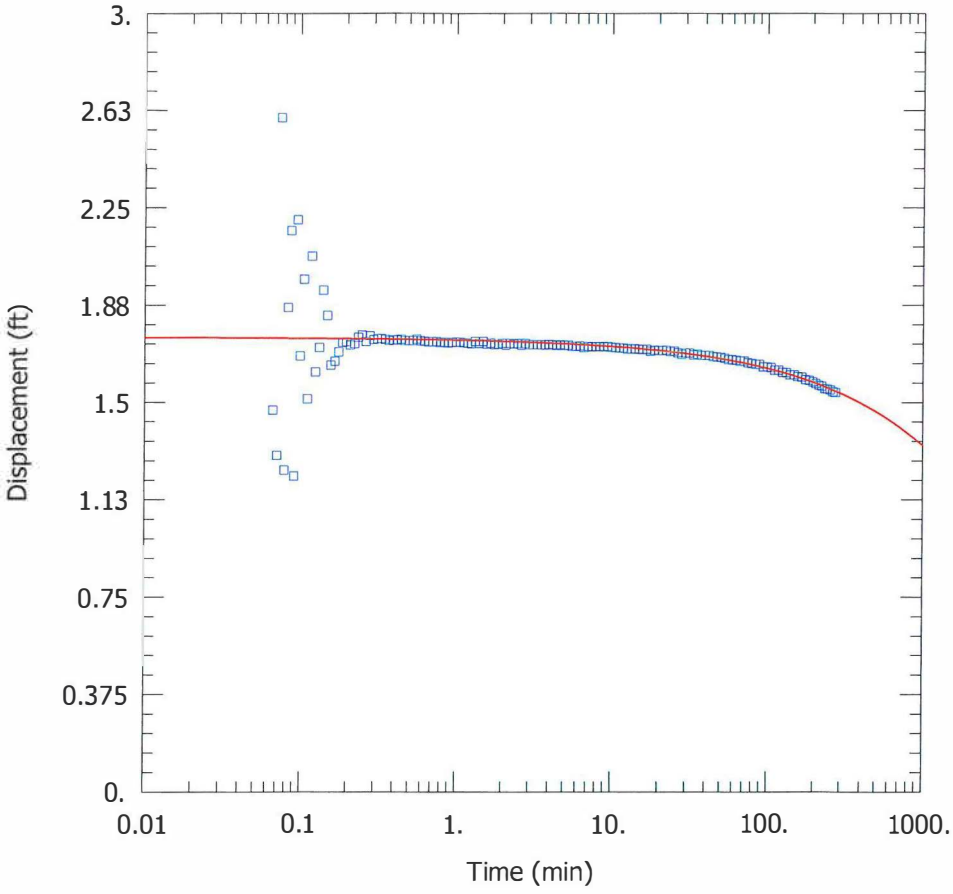
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	9.8E-7	cm/sec
Ss	1.0E-5	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.0006793 cm^2/sec



T408 RISING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T408
Test Date: 1 Sept 2016

AQUIFER DATA

Saturated Thickness: 24.46 ft

WELL DATA (T408)

Initial Displacement: 1.75 ft
Total Well Penetration Depth: 24.03 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 24.46 ft
Screen Length: 4.83 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 7.5E-8 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.015 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T408_rh1.aqt
Title: T408 Rising Head #1
Date: 09/27/16
Time: 14:28:24

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 1 Sept 2016
Test Well: T408

AQUIFER DATA

Saturated Thickness: 24.46 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T408

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.75 ft
Static Water Column Height: 24.46 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.83 ft
Total Well Penetration Depth: 24.03 ft

No. of Observations: 149

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.06667	1.47	4.73	1.722
0.07083	1.296	5.01	1.719
0.075	2.597	5.31	1.72
0.07917	1.239	5.62	1.716
0.08333	1.865	5.96	1.716
0.0875	2.161	6.31	1.717
0.09167	1.215	6.68	1.71
0.09583	2.203	7.08	1.716
0.1	1.678	7.5	1.713
0.106	1.974	7.94	1.714
0.112	1.513	8.41	1.716
0.119	2.062	8.91	1.713
0.126	1.617	9.44	1.715
0.133	1.711	10.	1.712
0.141	1.932	10.6	1.711
0.15	1.834	11.2	1.709
0.158	1.643	11.9	1.709
0.168	1.658	12.6	1.705
0.178	1.693	13.3	1.705

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.188	1.73	14.1	1.707
0.199	1.733	15.	1.704
0.211	1.72	15.8	1.703
0.224	1.725	16.8	1.704
0.237	1.75	17.8	1.697
0.251	1.759	18.8	1.701
0.266	1.734	19.9	1.7
0.282	1.756	21.1	1.7
0.298	1.741	22.4	1.701
0.316	1.745	23.7	1.696
0.335	1.745	25.1	1.697
0.355	1.742	26.6	1.691
0.376	1.738	28.2	1.685
0.398	1.74	29.8	1.689
0.422	1.74	31.6	1.69
0.447	1.742	33.5	1.682
0.473	1.738	35.5	1.686
0.501	1.738	37.6	1.681
0.531	1.738	39.8	1.681
0.562	1.743	42.2	1.681
0.596	1.736	44.7	1.676
0.631	1.735	47.3	1.675
0.668	1.733	50.1	1.674
0.708	1.733	53.1	1.67
0.75	1.734	56.2	1.665
0.794	1.73	59.6	1.663
0.841	1.731	63.1	1.662
0.891	1.728	66.8	1.659
0.944	1.73	70.8	1.659
1.	1.731	75.	1.652
1.06	1.732	79.4	1.65
1.12	1.729	84.1	1.646
1.19	1.728	89.1	1.646
1.26	1.725	94.4	1.636
1.33	1.734	100.	1.636
1.41	1.727	106.	1.634
1.5	1.734	112.	1.624
1.58	1.724	119.	1.624
1.68	1.728	126.	1.616
1.78	1.722	133.	1.614
1.88	1.723	141.	1.605
1.99	1.727	150.	1.605
2.11	1.72	158.	1.6
2.24	1.727	168.	1.597
2.37	1.724	178.	1.587
2.51	1.726	188.	1.584
2.66	1.72	198.	1.578
2.82	1.726	208.	1.572
2.98	1.721	218.	1.566
3.16	1.722	228.	1.562
3.35	1.722	238.	1.552
3.55	1.722	248.	1.551
3.76	1.72	258.	1.547
3.98	1.723	268.	1.541
4.22	1.721	278.	1.538
4.47	1.719		

SOLUTION

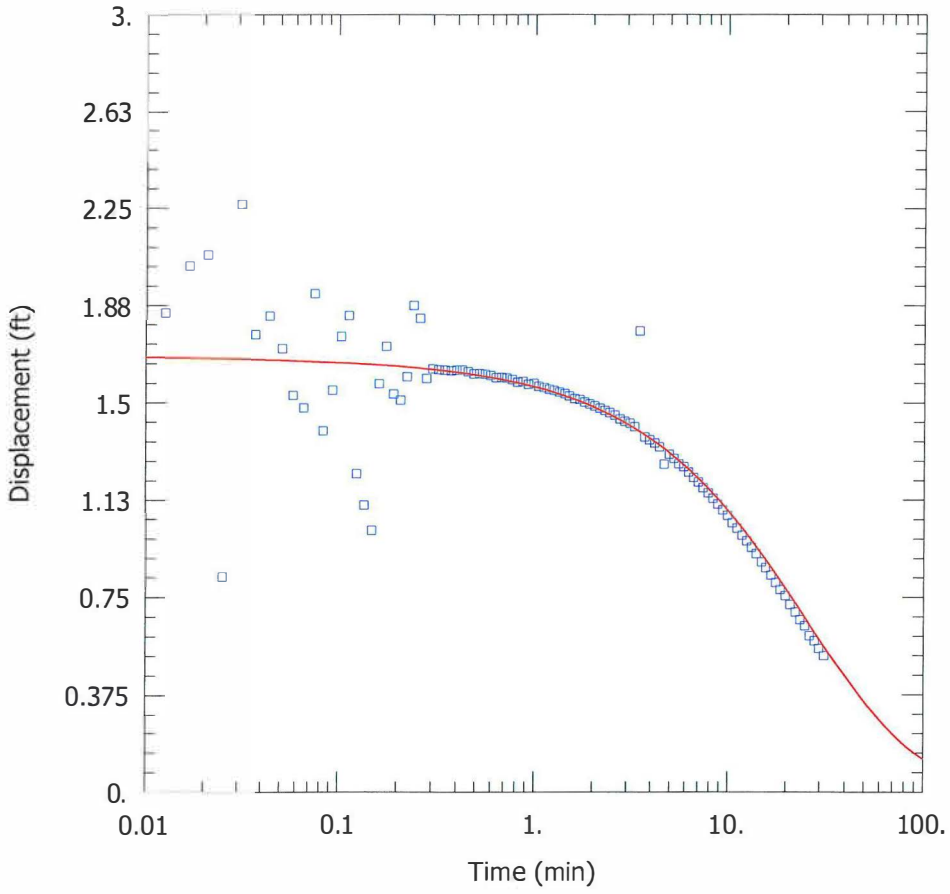
Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	7.5E-8	cm/sec
Ss	0.015	ft^{-1}
Kz/Kr	1.	

T = K*b = 5.592E-5 cm^2/sec



T409 FALLING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T409
Test Date: 31 Aug 2016

AQUIFER DATA

Saturated Thickness: 21.11 ft

WELL DATA (T409)

Initial Displacement: 1.68 ft
Total Well Penetration Depth: 20.71 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 21.11 ft
Screen Length: 4.8 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 4.0E-5 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.00075 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T409_fh1.aqt
Title: T409 Falling Head #1
Date: 09/27/16
Time: 14:28:25

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 31 Aug 2016
Test Well: T409

AQUIFER DATA

Saturated Thickness: 21.11 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T409

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.68 ft
Static Water Column Height: 21.11 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.8 ft
Total Well Penetration Depth: 20.71 ft

No. of Observations: 107

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.	1.591	1.505	1.526
0.004167	1.749	1.605	1.517
0.008333	2.437	1.705	1.513
0.0125	1.849	1.805	1.503
0.01667	2.03	1.915	1.496
0.02083	2.071	2.035	1.488
0.025	0.829	2.165	1.48
0.031	2.267	2.295	1.471
0.037	1.763	2.435	1.462
0.044	1.835	2.585	1.453
0.051	1.709	2.745	1.438
0.058	1.529	2.905	1.429
0.066	1.481	3.085	1.421
0.075	1.922	3.275	1.408
0.083	1.392	3.475	1.777
0.093	1.549	3.685	1.368
0.103	1.756	3.905	1.357
0.113	1.836	4.145	1.345
0.124	1.226	4.395	1.33

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.136	1.106	4.655	1.264
0.149	1.008	4.935	1.302
0.162	1.574	5.235	1.286
0.176	1.718	5.545	1.265
0.191	1.534	5.885	1.254
0.207	1.511	6.235	1.233
0.223	1.601	6.605	1.212
0.241	1.876	7.005	1.195
0.26	1.826	7.425	1.172
0.28	1.595	7.865	1.153
0.301	1.632	8.335	1.132
0.323	1.628	8.835	1.109
0.347	1.627	9.365	1.087
0.372	1.624	9.925	1.066
0.398	1.626	10.53	1.038
0.426	1.626	11.13	1.017
0.456	1.62	11.82	0.989
0.487	1.612	12.53	0.967
0.521	1.613	13.23	0.943
0.556	1.611	14.03	0.918
0.593	1.605	14.93	0.886
0.633	1.597	15.73	0.863
0.675	1.598	16.73	0.835
0.719	1.596	17.73	0.807
0.766	1.589	18.73	0.78
0.816	1.58	19.82	0.756
0.869	1.582	21.02	0.721
0.925	1.571	22.32	0.693
0.985	1.575	23.63	0.664
1.045	1.563	25.02	0.64
1.115	1.559	26.52	0.602
1.185	1.553	28.13	0.582
1.255	1.548	29.73	0.553
1.335	1.541	31.52	0.525
1.425	1.535		

SOLUTION

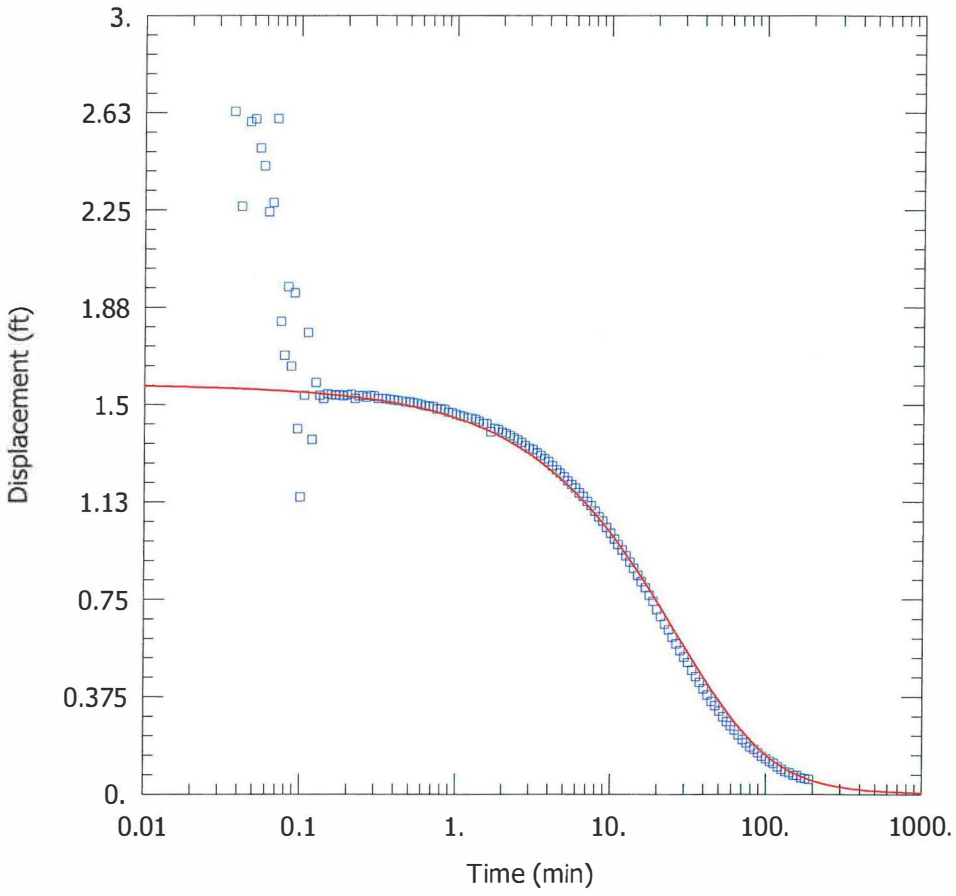
Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	4.0E-5	cm/sec
Ss	0.00075	ft^{-1}
Kz/Kr	1.	

$T = K*b = 0.02574\ cm^2/sec$



T409 FALLING HEAD #2

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T409
Test Date: 31 Aug 2016

AQUIFER DATA

Saturated Thickness: 21.12 ft

WELL DATA (T409)

Initial Displacement: 1.58 ft
Total Well Penetration Depth: 20.72 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 21.12 ft
Screen Length: 4.8 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 3.2E-5 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.0025 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T409_fh2.aqt
Title: T409 Falling Head #2
Date: 09/27/16
Time: 14:28:26

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 31 Aug 2016
Test Well: T409

AQUIFER DATA

Saturated Thickness: 21.12 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T409

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.58 ft
Static Water Column Height: 21.12 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.8 ft
Total Well Penetration Depth: 20.72 ft

No. of Observations: 147

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.0375	2.629	2.98	1.331
0.04167	2.264	3.16	1.327
0.0474	2.589	3.35	1.313
0.05112	2.601	3.55	1.303
0.0548	2.488	3.76	1.291
0.05848	2.419	3.98	1.28
0.0625	2.243	4.22	1.264
0.06667	2.278	4.47	1.248
0.07083	2.602	4.73	1.235
0.075	1.82	5.01	1.222
0.07917	1.69	5.31	1.205
0.08333	1.954	5.62	1.192
0.0875	1.648	5.96	1.178
0.09167	1.93	6.31	1.16
0.09583	1.407	6.68	1.146
0.1	1.144	7.08	1.126
0.106	1.537	7.5	1.111
0.112	1.777	7.94	1.089
0.119	1.365	8.41	1.067

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.126	1.584	8.91	1.051
0.133	1.535	9.44	1.026
0.141	1.523	10.	1.004
0.15	1.541	10.6	0.982
0.158	1.538	11.2	0.961
0.168	1.535	11.9	0.94
0.178	1.538	12.6	0.918
0.188	1.533	13.3	0.893
0.199	1.537	14.1	0.87
0.211	1.539	15.	0.843
0.224	1.523	15.8	0.818
0.237	1.533	16.8	0.795
0.251	1.534	17.8	0.766
0.266	1.528	18.8	0.742
0.282	1.534	19.9	0.711
0.298	1.531	21.1	0.683
0.316	1.523	22.4	0.655
0.335	1.523	23.7	0.633
0.355	1.521	25.1	0.604
0.376	1.518	26.6	0.579
0.398	1.517	28.2	0.552
0.422	1.514	29.8	0.528
0.447	1.513	31.6	0.507
0.473	1.508	33.5	0.477
0.501	1.51	35.5	0.453
0.531	1.505	37.6	0.43
0.562	1.504	39.8	0.406
0.596	1.499	42.2	0.382
0.631	1.494	44.7	0.357
0.668	1.493	47.3	0.341
0.708	1.491	50.1	0.32
0.75	1.482	53.1	0.298
0.794	1.483	56.2	0.28
0.841	1.481	59.6	0.263
0.891	1.47	63.1	0.247
0.944	1.469	66.8	0.229
1.	1.462	70.8	0.211
1.06	1.457	75.	0.198
1.12	1.454	79.4	0.182
1.19	1.447	84.1	0.174
1.26	1.447	89.1	0.16
1.33	1.442	94.4	0.146
1.41	1.435	100.	0.137
1.5	1.427	106.	0.126
1.58	1.426	112.	0.119
1.68	1.394	119.	0.106
1.78	1.408	126.	0.096
1.88	1.403	133.	0.087
1.99	1.393	141.	0.082
2.11	1.387	150.	0.074
2.24	1.38	158.	0.072
2.37	1.371	168.	0.064
2.51	1.364	178.	0.06
2.66	1.354	188.	0.058
2.82	1.341		

SOLUTION

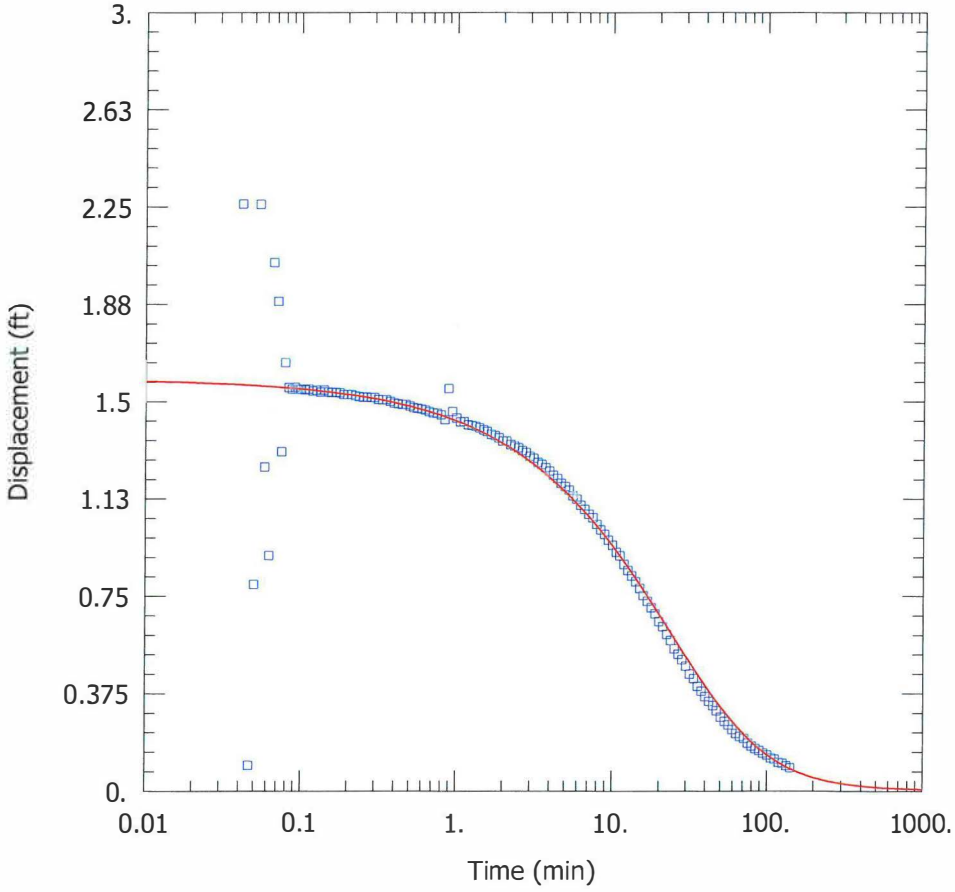
Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	3.2E-5	cm/sec
Ss	0.0025	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.0206 cm^2/sec



T409 RISING HEAD #1

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T409
Test Date: 31 Aug 2016

AQUIFER DATA

Saturated Thickness: 21.19 ft

WELL DATA (T409)

Initial Displacement: 1.59 ft
Total Well Penetration Depth: 20.79 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 21.19 ft
Screen Length: 4.8 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 3.2E-5 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.005 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T409_rh1.aqt
Title: T409 Rising Head #1
Date: 09/27/16
Time: 14:28:27

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 31 Aug 2016
Test Well: T409

AQUIFER DATA

Saturated Thickness: 21.19 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T409

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.59 ft
Static Water Column Height: 21.19 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.8 ft
Total Well Penetration Depth: 20.79 ft

No. of Observations: 141

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.04167	2.261	2.66	1.311
0.04623	0.099	2.82	1.303
0.04998	0.796	2.98	1.288
0.05417	2.26	3.16	1.281
0.05833	1.248	3.35	1.265
0.0625	0.907	3.55	1.257
0.06667	2.035	3.76	1.245
0.07083	1.886	3.98	1.232
0.075	1.307	4.22	1.216
0.07917	1.65	4.47	1.203
0.08333	1.554	4.73	1.184
0.0875	1.548	5.01	1.172
0.09167	1.555	5.31	1.159
0.09583	1.548	5.62	1.137
0.1	1.548	5.96	1.124
0.106	1.545	6.31	1.101
0.112	1.548	6.68	1.085
0.119	1.54	7.08	1.066
0.126	1.544	7.5	1.052

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.133	1.537	7.94	1.027
0.141	1.544	8.41	1.005
0.15	1.537	8.91	0.988
0.158	1.534	9.44	0.966
0.168	1.535	10.	0.946
0.178	1.533	10.6	0.919
0.188	1.527	11.2	0.905
0.199	1.526	11.9	0.872
0.211	1.526	12.6	0.849
0.224	1.521	13.3	0.828
0.237	1.518	14.1	0.805
0.251	1.516	15.	0.78
0.266	1.517	15.8	0.753
0.282	1.514	16.8	0.73
0.298	1.514	17.8	0.705
0.316	1.507	18.8	0.682
0.335	1.506	19.9	0.652
0.355	1.505	21.1	0.633
0.376	1.5	22.4	0.603
0.398	1.493	23.7	0.58
0.422	1.491	25.1	0.548
0.447	1.488	26.6	0.526
0.473	1.488	28.2	0.506
0.501	1.482	29.8	0.481
0.531	1.476	31.6	0.45
0.562	1.473	33.5	0.433
0.596	1.471	35.5	0.403
0.631	1.467	37.6	0.384
0.668	1.461	39.8	0.363
0.708	1.456	42.2	0.345
0.75	1.455	44.7	0.329
0.794	1.449	47.3	0.309
0.841	1.43	50.1	0.285
0.891	1.55	53.1	0.269
0.944	1.461	56.2	0.255
1.	1.437	59.6	0.237
1.06	1.421	63.1	0.222
1.12	1.423	66.8	0.211
1.19	1.41	70.8	0.203
1.26	1.408	75.	0.185
1.33	1.404	79.4	0.173
1.41	1.398	84.1	0.164
1.5	1.391	89.1	0.156
1.58	1.385	94.4	0.146
1.68	1.374	100.	0.139
1.78	1.369	106.	0.128
1.88	1.36	112.	0.123
1.99	1.348	119.	0.11
2.11	1.347	126.	0.107
2.24	1.334	133.	0.097
2.37	1.328	141.	0.09
2.51	1.321		

SOLUTION

Slug Test

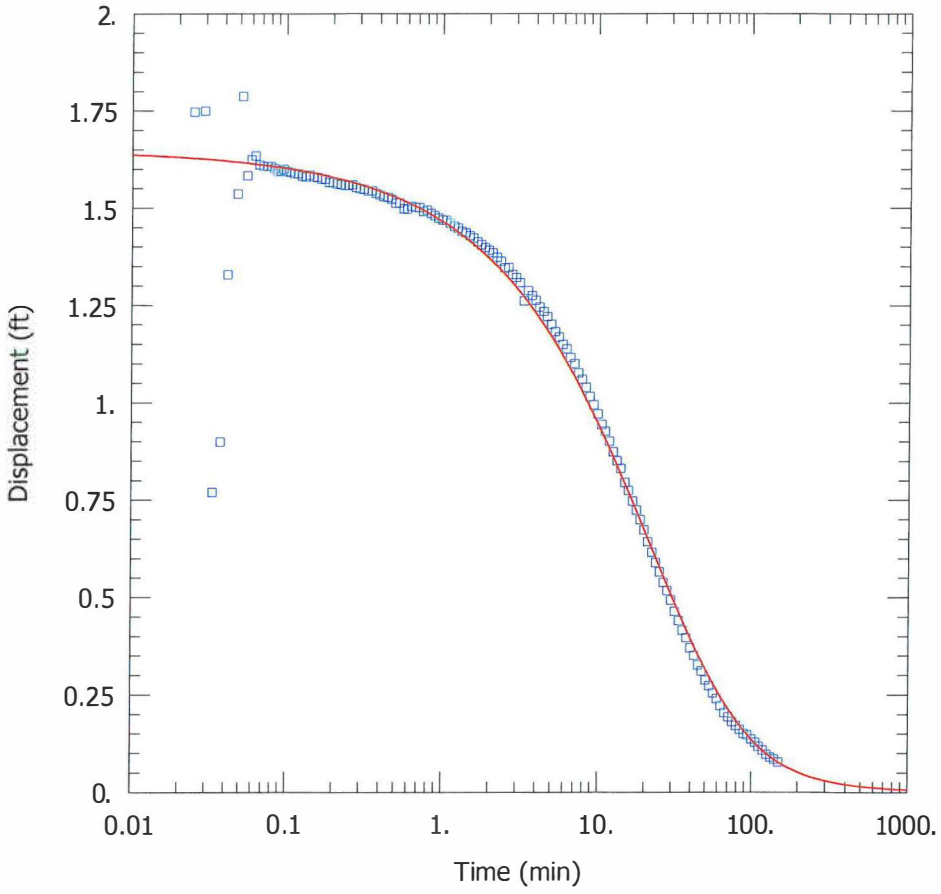
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	3.2E-5	cm/sec
Ss	0.005	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.02067 cm^2/sec



T409 RISING HEAD #2

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Well: T409
Test Date: 31 Aug 2016

AQUIFER DATA

Saturated Thickness: 21.18 ft

WELL DATA (T409)

Initial Displacement: 1.65 ft
Total Well Penetration Depth: 20.78 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 21.18 ft
Screen Length: 4.8 ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined

Kr = 3.3E-5 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.006 ft^{-1}

Data Set: I:\16jobs\16E0080\Admin\15-Field-Laboratory Data\SlugTest2\T409_rh2.aqt
Title: T409 Rising Head #2
Date: 09/27/16
Time: 14:28:28

PROJECT INFORMATION

Company: Hanson Professional Services
Client: Natural Resources Technology,
Project: 16E0080
Location: Coffeen Power Station
Test Date: 31 Aug 2016
Test Well: T409

AQUIFER DATA

Saturated Thickness: 21.18 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: T409

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.65 ft
Static Water Column Height: 21.18 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.25 ft
Screen Length: 4.8 ft
Total Well Penetration Depth: 20.78 ft

No. of Observations: 146

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.02502	1.747	2.37	1.363
0.02918	1.749	2.512	1.346
0.03335	0.77	2.66	1.347
0.03752	0.899	2.82	1.33
0.04168	1.329	2.98	1.321
0.04823	1.536	3.16	1.308
0.05192	1.787	3.35	1.261
0.05568	1.583	3.55	1.288
0.05937	1.624	3.76	1.275
0.06303	1.634	3.98	1.263
0.0667	1.611	4.22	1.246
0.07085	1.608	4.47	1.234
0.07502	1.607	4.73	1.221
0.07918	1.607	5.01	1.201
0.08335	1.601	5.31	1.182
0.08752	1.594	5.62	1.168
0.09168	1.596	5.96	1.149
0.09585	1.6	6.31	1.138
0.1	1.594	6.68	1.116

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.106	1.592	7.08	1.1
0.112	1.589	7.5	1.076
0.119	1.588	7.94	1.06
0.126	1.582	8.41	1.039
0.133	1.58	8.91	1.015
0.141	1.585	9.44	0.995
0.15	1.58	10.	0.971
0.158	1.579	10.6	0.944
0.168	1.575	11.2	0.926
0.178	1.573	11.9	0.901
0.188	1.566	12.6	0.874
0.199	1.565	13.3	0.851
0.211	1.562	14.1	0.831
0.224	1.56	15.	0.795
0.237	1.558	15.8	0.774
0.251	1.558	16.8	0.747
0.266	1.559	17.8	0.724
0.282	1.553	18.8	0.699
0.298	1.549	19.9	0.673
0.316	1.548	21.1	0.642
0.335	1.544	22.4	0.615
0.355	1.544	23.7	0.589
0.376	1.538	25.1	0.565
0.398	1.534	26.6	0.538
0.422	1.529	28.2	0.517
0.447	1.527	29.8	0.493
0.473	1.523	31.6	0.464
0.501	1.512	33.5	0.44
0.531	1.513	35.5	0.415
0.564	1.498	37.6	0.396
0.596	1.497	39.8	0.37
0.631	1.504	42.2	0.351
0.668	1.502	44.7	0.326
0.708	1.501	47.3	0.311
0.75	1.491	50.1	0.288
0.794	1.494	53.1	0.273
0.841	1.486	56.2	0.255
0.891	1.48	59.6	0.24
0.944	1.474	63.1	0.222
1.	1.469	66.8	0.204
1.06	1.468	70.8	0.193
1.12	1.461	75.	0.181
1.19	1.453	79.4	0.171
1.26	1.448	84.1	0.161
1.33	1.44	89.1	0.15
1.41	1.436	94.4	0.147
1.5	1.428	100.	0.136
1.58	1.423	106.	0.128
1.68	1.413	112.	0.117
1.78	1.405	119.	0.107
1.88	1.398	126.	0.097
1.99	1.391	133.	0.089
2.11	1.385	141.	0.084
2.24	1.373	150.	0.077

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: KGS Model

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
Kr	3.3E-5	cm/sec
Ss	0.006	ft^{-1}
Kz/Kr	1.	

T = K*b = 0.0213 cm^2/sec

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
Kr	3.2E-5	3.191E-6	+/- 6.309E-6	10.03	cm/sec
Ss	0.006332	0.002124	+/- 0.0042	2.981	ft^{-1}
Kz/Kr	1.	not estimated			

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

T = K*b = 0.02066 cm^2/sec

Parameter Correlations

	Kr	Ss
Kr	1.00	-0.93
Ss	-0.93	1.00

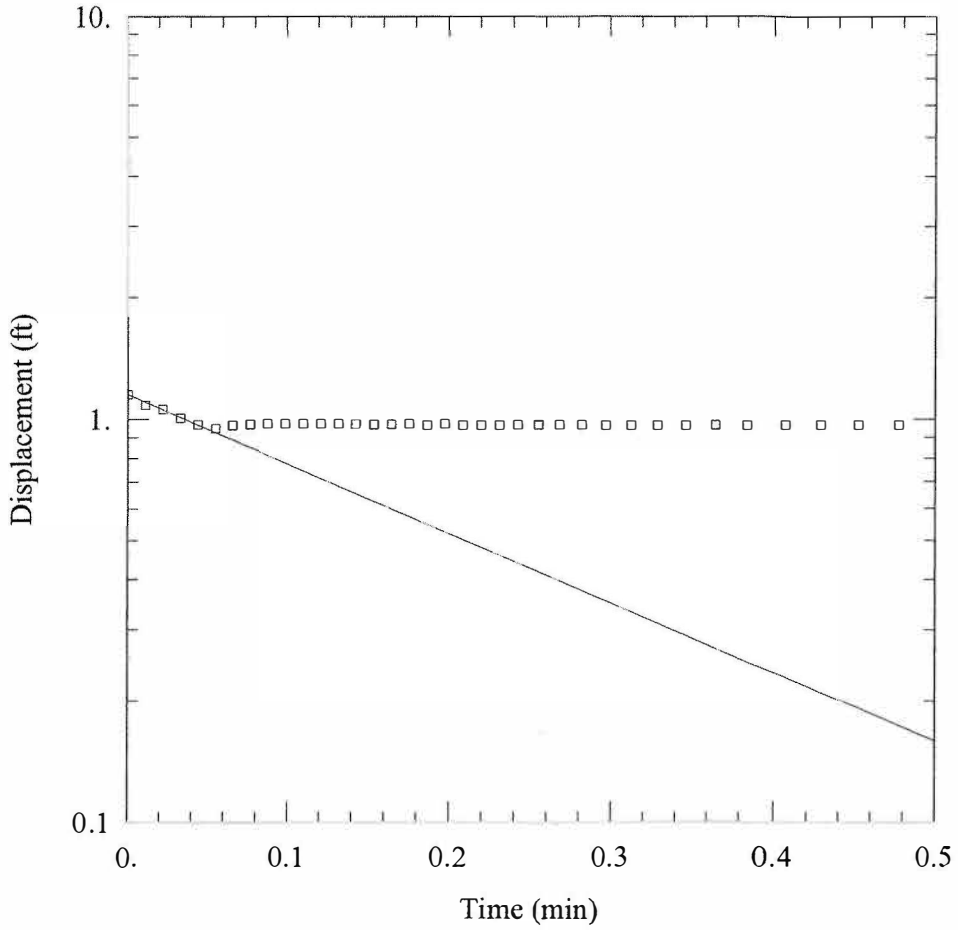
Residual Statistics

for weighted residuals

Sum of Squares . . . . . 1.445 ft^2
Variance . . . . . 0.01003 ft^2
Std. Deviation . . . . . 0.1002 ft
Mean. . . . . -0.01263 ft
No. of Residuals 146
No. of Estimates. 2

APPENDIX B2

HYDRAULIC CONDUCTIVITY ANALYSES (ASH POND PIEZOMETERS)



FALLING HEAD TEST

Data Set: I:\...\CPS_OW1_FH.aqt
Date: 11/11/16 Time: 13:53:32

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW1
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 16.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW1)

Initial Displacement: 1.15 ft
Total Well Penetration Depth: 20. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.8 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.00225 cm/sec y0 = 1.15 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW1_FH.aqt
Title: Falling Head Test
Date: 11/11/16
Time: 13:53:32

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW1

AQUIFER DATA

Saturated Thickness: 16.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW1

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.15 ft
Static Water Column Height: 16.8 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 20. ft

No. of Observations: 87

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	1.082	0.8238	0.972
0.022	1.057	0.8708	0.972
0.033	1.006	0.9207	0.972
0.044	0.969	0.9733	0.972
0.055	0.948	1.029	0.973
0.066	0.948	1.088	0.973
0.077	0.955	1.151	0.972
0.088	0.963	1.217	0.973
0.099	0.967	1.288	0.973
0.11	0.969	1.362	0.973
0.121	0.969	1.441	0.973
0.132	0.969	1.525	0.973
0.143	0.967	1.613	0.975
0.154	0.967	1.707	0.973
0.165	0.969	1.807	0.973
0.176	0.969	1.912	0.973
0.187	0.967	2.023	0.973
0.198	0.969	2.142	0.973

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.969	2.267	0.973
0.22	0.969	2.399	0.973
0.231	0.969	2.54	0.973
0.2427	0.97	2.688	0.973
0.2552	0.969	2.846	0.975
0.2683	0.969	3.013	0.975
0.2823	0.969	3.179	0.975
0.2972	0.969	3.346	0.975
0.3128	0.969	3.513	0.976
0.3295	0.97	3.679	0.975
0.3472	0.97	3.846	0.976
0.3658	0.97	4.013	0.975
0.3857	0.97	4.179	0.975
0.4067	0.97	4.346	0.975
0.4288	0.97	4.513	0.975
0.4523	0.97	4.679	0.975
0.4772	0.97	4.846	0.976
0.5035	0.972	5.013	0.976
0.5315	0.972	5.179	0.975
0.5612	0.972	5.346	0.975
0.5925	0.972	5.513	0.975
0.6257	0.972	5.679	0.976
0.6608	0.972	5.846	0.975
0.6982	0.972	6.013	0.976
0.7377	0.972	6.179	0.975
0.7795	0.972		

SOLUTION

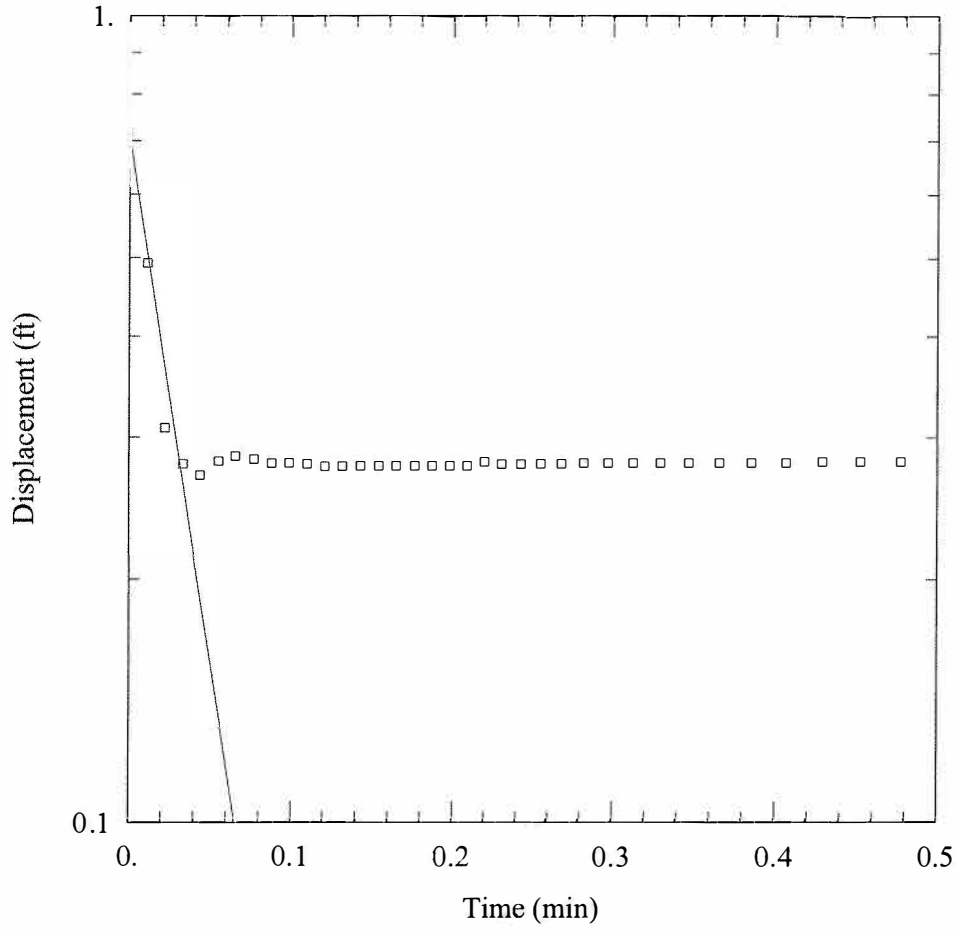
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.192

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00225	cm/sec
y0	1.15	ft

$T = K*b = 1.152$ cm²/sec



RISING HEAD TEST

Data Set: I:\...\CPS_OW1_RH.aqt
Date: 11/11/16 Time: 13:53:33

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW1
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 16.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW1)

Initial Displacement: 1.1 ft
Total Well Penetration Depth: 20. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.8 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.017 cm/sec
y0 = 0.7 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW1_RH.aqt
Title: Rising Head Test
Date: 11/11/16
Time: 13:53:33

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW1

AQUIFER DATA

Saturated Thickness: 16.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW1

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.1 ft
Static Water Column Height: 16.8 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 20. ft

No. of Observations: 88

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	0.493	0.8238	0.278
0.022	0.308	0.8708	0.278
0.033	0.278	0.9207	0.278
0.044	0.272	0.9733	0.278
0.055	0.283	1.029	0.278
0.066	0.287	1.088	0.278
0.077	0.284	1.151	0.28
0.088	0.281	1.217	0.28
0.099	0.281	1.288	0.28
0.11	0.28	1.362	0.28
0.121	0.278	1.441	0.278
0.132	0.278	1.525	0.28
0.143	0.278	1.613	0.28
0.154	0.278	1.707	0.278
0.165	0.278	1.807	0.28
0.176	0.278	1.912	0.281
0.187	0.278	2.023	0.28
0.198	0.278	2.142	0.28

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.278	2.267	0.28
0.22	0.28	2.399	0.28
0.231	0.278	2.54	0.28
0.2427	0.278	2.688	0.281
0.2552	0.278	2.846	0.281
0.2683	0.278	3.013	0.281
0.2823	0.278	3.179	0.281
0.2972	0.278	3.346	0.281
0.3128	0.278	3.513	0.283
0.3295	0.278	3.679	0.281
0.3472	0.278	3.846	0.283
0.3658	0.278	4.013	0.281
0.3857	0.278	4.179	0.281
0.4067	0.278	4.346	0.281
0.4288	0.278	4.513	0.283
0.4523	0.278	4.679	0.281
0.4772	0.278	4.846	0.281
0.5035	0.28	5.013	0.283
0.5315	0.28	5.179	0.281
0.5612	0.28	5.346	0.283
0.5925	0.281	5.513	0.283
0.6257	0.28	5.679	0.281
0.6608	0.28	5.846	0.283
0.6982	0.28	6.013	0.281
0.7377	0.278	6.179	0.283
0.7795	0.277	6.346	0.283

SOLUTION

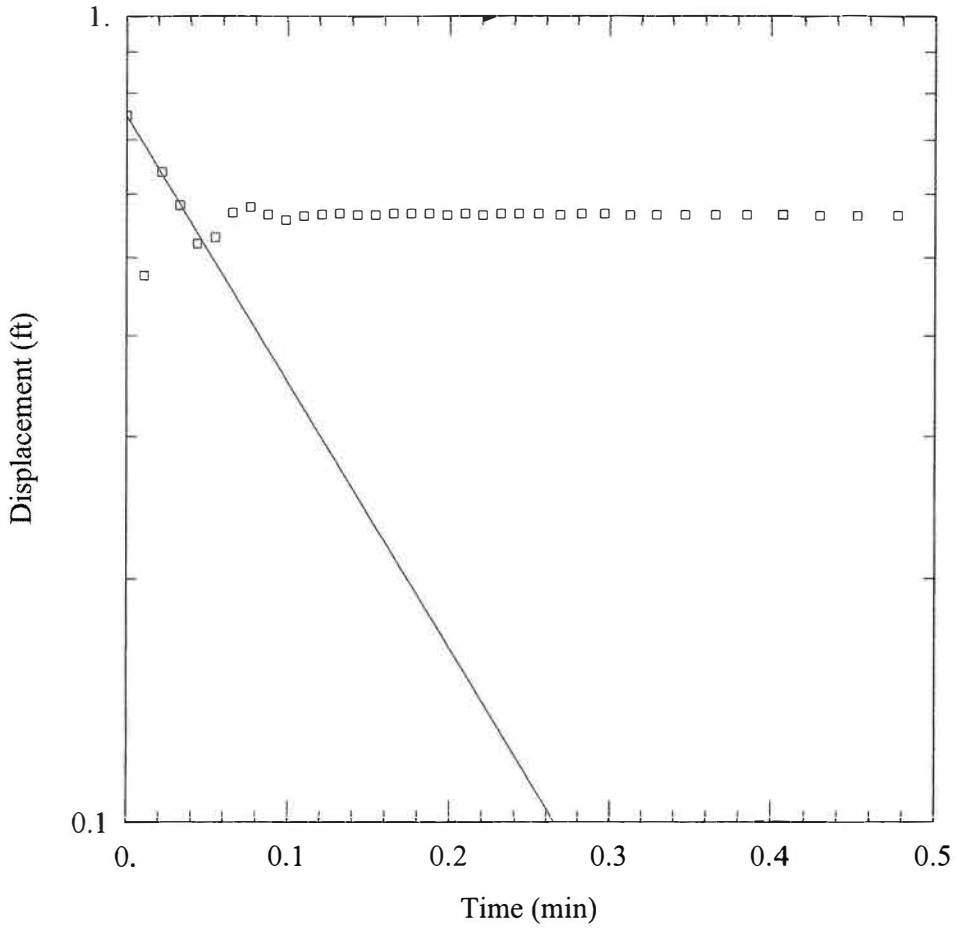
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.192

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.017	cm/sec
y0	0.7	ft

$T = K*b = 8.705$ cm²/sec



FALLING HEAD TEST

Data Set: I:\...\CPS_OW2_FH.aqt
Date: 11/11/16 Time: 13:53:34

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW2
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 22.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW2)

Initial Displacement: 0.75 ft
Total Well Penetration Depth: 26. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 22.7 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.0045 cm/sec y0 = 0.75 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW2_FH.aqt
Title: Falling Head Test
Date: 11/11/16
Time: 13:53:34

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW2

AQUIFER DATA

Saturated Thickness: 22.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW2

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.75 ft
Static Water Column Height: 22.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 26. ft

No. of Observations: 80

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	0.475	0.6608	0.567
0.022	0.639	0.6982	0.567
0.033	0.581	0.7377	0.567
0.044	0.521	0.7795	0.567
0.055	0.53	0.8238	0.567
0.066	0.566	0.8708	0.567
0.077	0.575	0.9207	0.567
0.088	0.563	0.9733	0.567
0.099	0.555	1.029	0.567
0.11	0.56	1.088	0.567
0.121	0.564	1.151	0.567
0.132	0.566	1.217	0.567
0.143	0.564	1.288	0.567
0.154	0.564	1.362	0.567
0.165	0.566	1.441	0.566
0.176	0.566	1.525	0.566
0.187	0.566	1.613	0.567
0.198	0.564	1.707	0.566

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.566	1.807	0.567
0.22	0.564	1.912	0.567
0.231	0.566	2.023	0.567
0.2427	0.566	2.142	0.567
0.2552	0.566	2.267	0.567
0.2683	0.566	2.399	0.567
0.2823	0.567	2.54	0.567
0.2972	0.567	2.688	0.567
0.3128	0.567	2.846	0.567
0.3295	0.567	3.013	0.567
0.3472	0.567	3.179	0.567
0.3658	0.566	3.346	0.567
0.3857	0.567	3.513	0.567
0.4067	0.567	3.679	0.567
0.4288	0.567	3.846	0.567
0.4523	0.566	4.013	0.569
0.4772	0.566	4.179	0.569
0.5035	0.567	4.346	0.567
0.5315	0.567	4.513	0.567
0.5612	0.567	4.679	0.567
0.5925	0.567	4.846	0.569
0.6257	0.567	5.013	0.569

SOLUTION

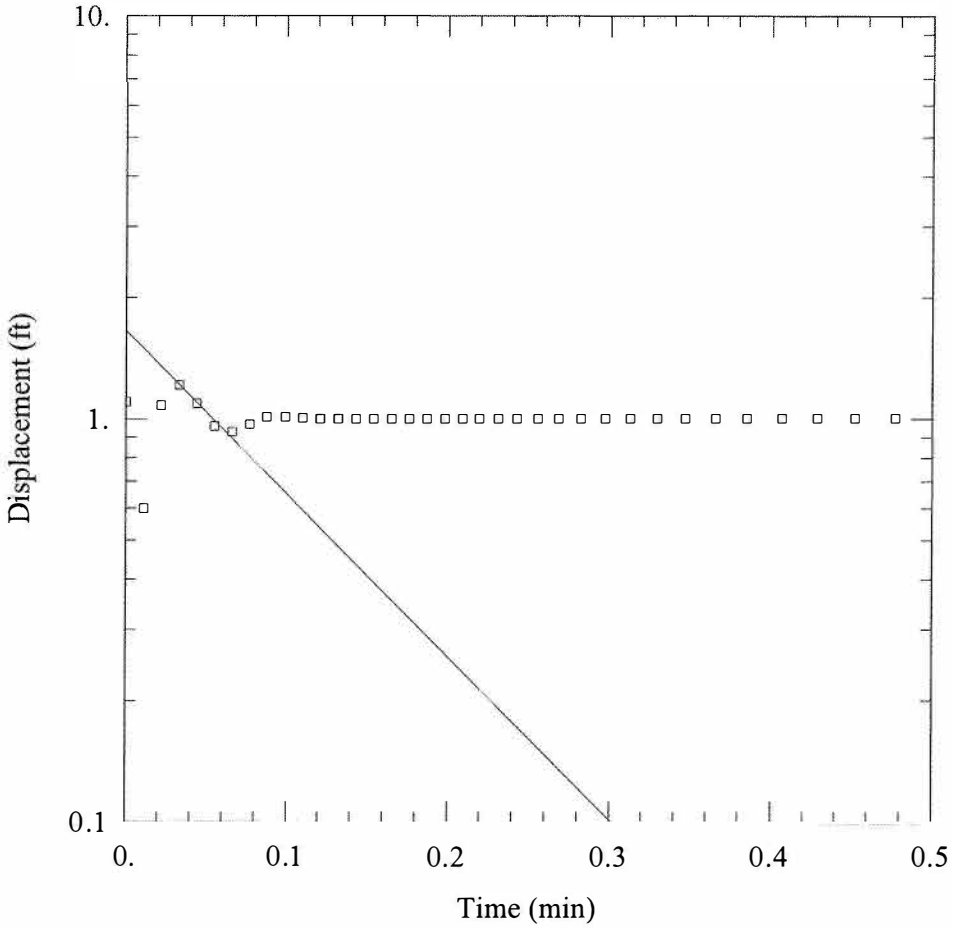
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.359

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0045	cm/sec
y0	0.75	ft

$T = K*b = 3.114$ cm²/sec



RISING HEAD TEST

Data Set: I:\...\CPS_OW2_RH.aqt
Date: 11/11/16 Time: 13:53:34

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW2
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 22.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW2)

Initial Displacement: 1.1 ft
Total Well Penetration Depth: 26. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 22.7 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.0055 cm/sec y0 = 1.65 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW2_RH.aqt
Title: Rising Head Test
Date: 11/11/16
Time: 13:53:35

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW2

AQUIFER DATA

Saturated Thickness: 22.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW2

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.1 ft
Static Water Column Height: 22.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 26. ft

No. of Observations: 86

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	0.601	0.7795	1.005
0.022	1.081	0.8238	1.005
0.033	1.212	0.8708	1.005
0.044	1.093	0.9207	1.005
0.055	0.959	0.9733	1.005
0.066	0.929	1.029	1.005
0.077	0.969	1.088	1.005
0.088	1.011	1.151	1.005
0.099	1.017	1.217	1.005
0.11	1.009	1.288	1.005
0.121	1.	1.362	1.005
0.132	0.997	1.441	1.003
0.143	1.	1.525	1.005
0.154	1.002	1.613	1.005
0.165	1.003	1.707	1.005
0.176	1.003	1.807	1.005
0.187	1.003	1.912	1.005
0.198	1.003	2.023	1.005

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	1.003	2.142	1.003
0.22	1.003	2.267	1.003
0.231	1.003	2.399	1.005
0.2427	1.003	2.54	1.003
0.2552	1.003	2.688	1.005
0.2683	1.003	2.846	1.003
0.2823	1.003	3.013	1.005
0.2972	1.005	3.179	1.003
0.3128	1.005	3.346	1.005
0.3295	1.005	3.513	1.008
0.3472	1.006	3.679	1.008
0.3658	1.005	3.846	1.008
0.3857	1.005	4.013	1.006
0.4067	1.006	4.179	1.005
0.4288	1.005	4.346	1.005
0.4523	1.005	4.513	1.005
0.4772	1.005	4.679	1.005
0.5035	1.005	4.846	1.003
0.5315	1.005	5.013	1.003
0.5612	1.003	5.179	1.003
0.5925	1.005	5.346	1.003
0.6257	1.005	5.513	1.003
0.6608	1.005	5.679	1.003
0.6982	1.005	5.846	1.005
0.7377	1.005	6.013	1.005

SOLUTION

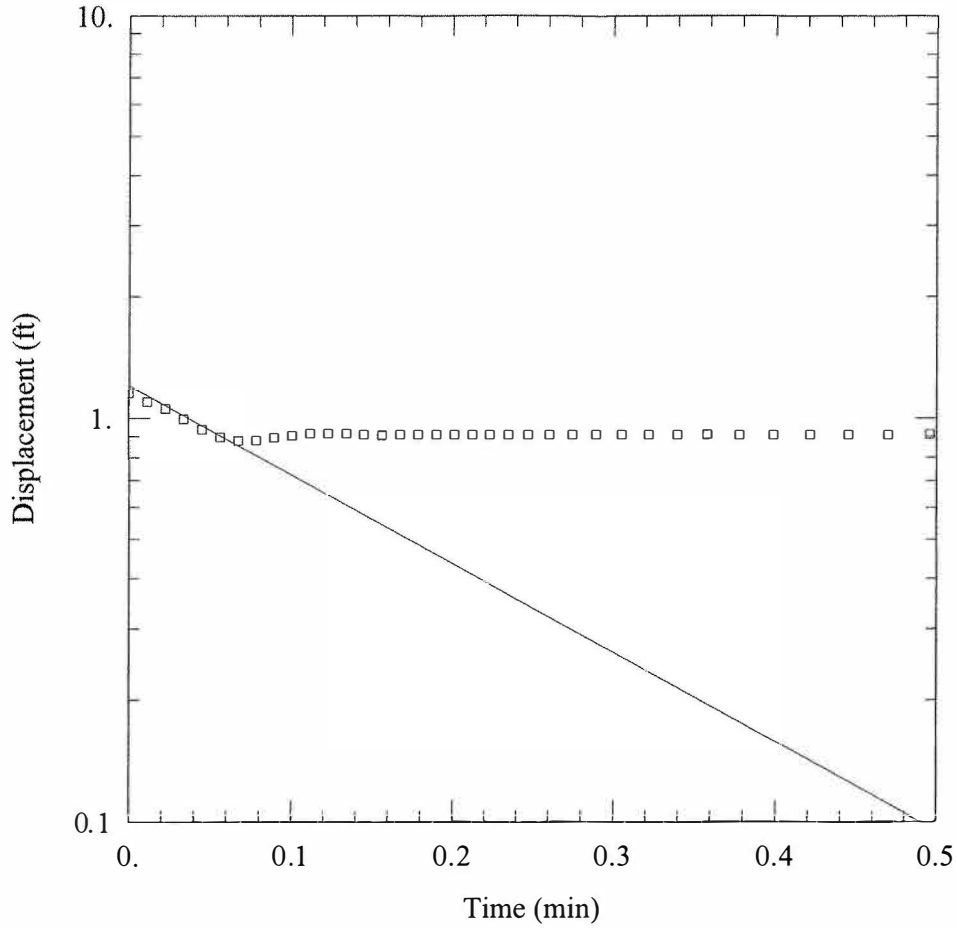
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.359

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0055	cm/sec
y0	1.65	ft

T = K*b = 3.805 cm²/sec



FALLING HEAD TEST

Data Set: I:\...\CPS_OW3_FH.aqt
Date: 11/11/16 Time: 13:53:35

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW3
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 21.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW3)

Initial Displacement: 1.15 ft
Total Well Penetration Depth: 26. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 21.9 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.003 cm/sec y0 = 1.2 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW3_FH.aqt
Title: Falling Head Test
Date: 11/11/16
Time: 13:53:36

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW3

AQUIFER DATA

Saturated Thickness: 21.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW3

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.15 ft
Static Water Column Height: 21.9 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 26. ft

No. of Observations: 75

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.0112	1.095	0.618	0.911
0.0223	1.054	0.6532	0.911
0.0335	0.994	0.6905	0.912
0.0447	0.937	0.73	0.911
0.0558	0.897	0.7718	0.912
0.067	0.879	0.8162	0.912
0.0782	0.882	0.8632	0.911
0.0893	0.894	0.913	0.912
0.1005	0.909	0.9657	0.912
0.1117	0.917	1.022	0.912
0.1228	0.92	1.081	0.912
0.134	0.918	1.143	0.911
0.1452	0.914	1.21	0.912
0.1563	0.911	1.28	0.912
0.1675	0.908	1.355	0.912
0.1787	0.908	1.434	0.912
0.1898	0.909	1.517	0.912
0.201	0.911	1.606	0.912

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.2122	0.912	1.7	0.912
0.2233	0.912	1.799	0.914
0.235	0.912	1.904	0.914
0.2475	0.911	2.016	0.914
0.2607	0.911	2.134	0.914
0.2747	0.911	2.259	0.914
0.2895	0.911	2.392	0.912
0.3052	0.912	2.532	0.914
0.3218	0.911	2.681	0.914
0.3395	0.911	2.838	0.914
0.3582	0.912	3.005	0.914
0.378	0.912	3.172	0.914
0.399	0.911	3.338	0.914
0.4212	0.911	3.505	0.914
0.4447	0.911	3.672	0.915
0.4695	0.911	3.838	0.914
0.4958	0.912	4.005	0.914
0.5238	0.911	4.172	0.914
0.5535	0.912	4.338	0.915
0.5848	0.912		

SOLUTION

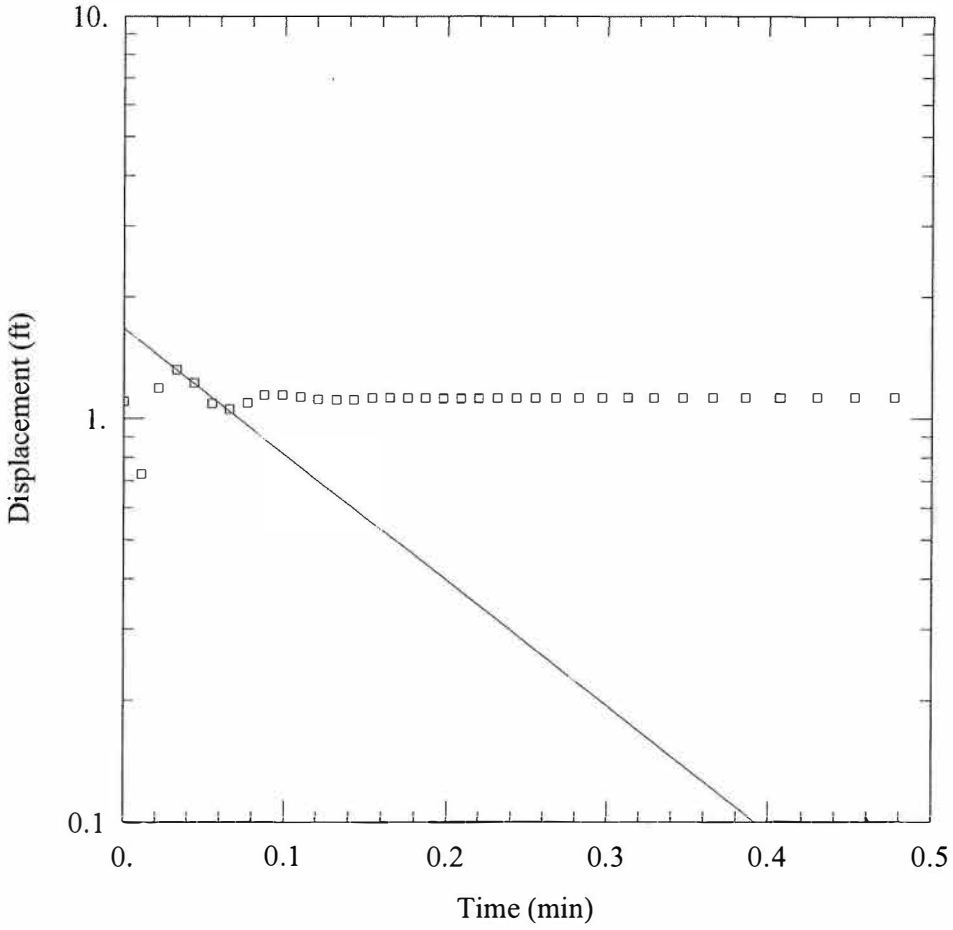
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.359

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.003	cm/sec
y0	1.2	ft

$T = K*b = 2.003$ cm²/sec



RISING HEAD TEST

Data Set: I:\...\CPS_OW3_RH.aqt
Date: 11/11/16 Time: 13:53:36

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW3
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 21.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW3)

Initial Displacement: 1.1 ft
Total Well Penetration Depth: 26. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 21.9 ft
Screen Length: 13. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.00425 cm/sec
y0 = 1.67 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW3_RH.aqt
Title: Rising Head Test
Date: 11/11/16
Time: 13:53:37

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW3

AQUIFER DATA

Saturated Thickness: 21.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW3

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1.1 ft
Static Water Column Height: 21.9 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 13. ft
Total Well Penetration Depth: 26. ft

No. of Observations: 72

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	0.729	0.5315	1.127
0.022	1.192	0.5612	1.127
0.033	1.32	0.5925	1.127
0.044	1.223	0.6257	1.128
0.055	1.088	0.6608	1.128
0.066	1.054	0.6982	1.127
0.077	1.098	0.7377	1.127
0.088	1.144	0.7795	1.127
0.099	1.153	0.8238	1.127
0.11	1.137	0.8708	1.127
0.121	1.121	0.9207	1.127
0.132	1.118	0.9733	1.128
0.143	1.125	1.029	1.127
0.154	1.133	1.088	1.127
0.165	1.133	1.151	1.127
0.176	1.128	1.217	1.128
0.187	1.127	1.288	1.127
0.198	1.127	1.362	1.127

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	1.128	1.441	1.127
0.22	1.128	1.525	1.127
0.231	1.128	1.613	1.127
0.2427	1.128	1.707	1.127
0.2552	1.128	1.807	1.127
0.2683	1.128	1.912	1.127
0.2823	1.128	2.023	1.128
0.2972	1.128	2.142	1.128
0.3128	1.128	2.267	1.127
0.3295	1.128	2.399	1.127
0.3472	1.128	2.54	1.128
0.3658	1.128	2.688	1.128
0.3857	1.128	2.846	1.128
0.4067	1.128	3.013	1.128
0.4288	1.128	3.179	1.137
0.4523	1.128	3.346	1.137
0.4772	1.128	3.513	1.137
0.5035	1.127	3.679	1.137

SOLUTION

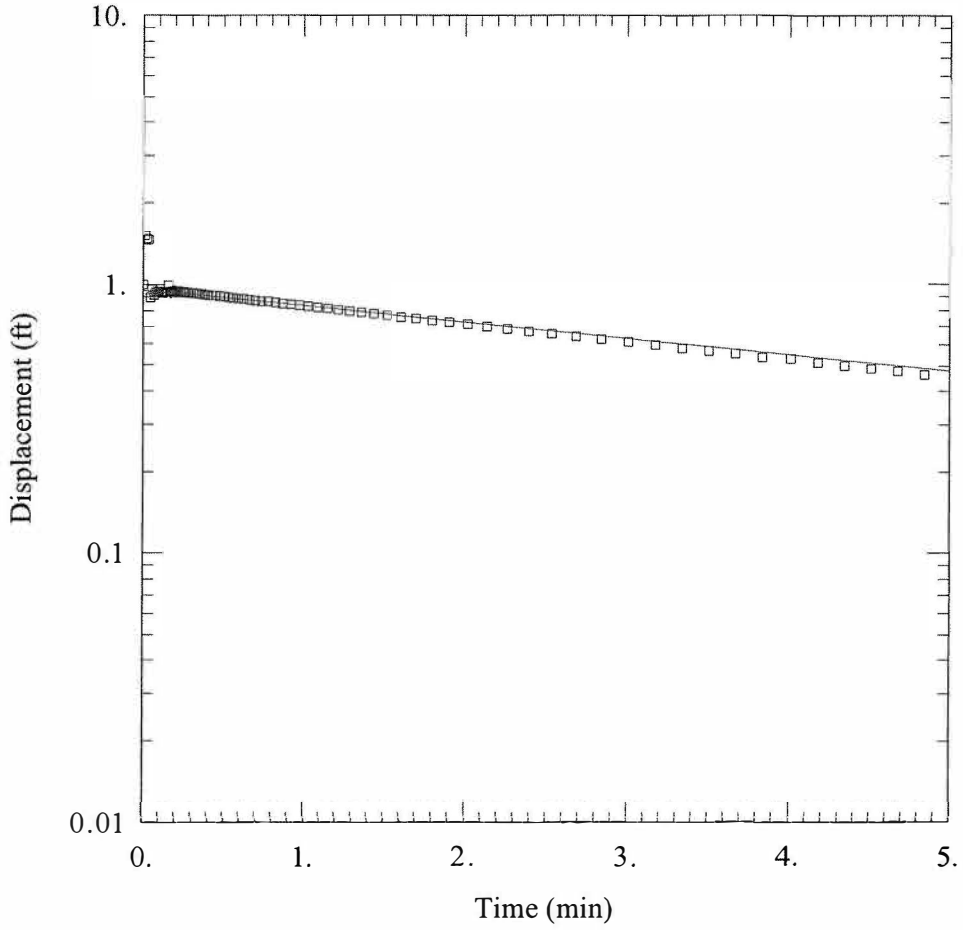
Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.359

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.00425	cm/sec
y0	1.67	ft

$T = K*b = 2.837$ cm²/sec



FALLING HEAD TEST

Data Set: I:\...\CPS_OW5_FH.aqt
Date: 11/11/16 Time: 13:53:37

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW5
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 26.89 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW5)

Initial Displacement: 1. ft
Total Well Penetration Depth: 30. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 26.89 ft
Screen Length: 20. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 5.5E-5 cm/sec y0 = 0.95 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW5_FH.aqt
Title: Falling Head Test
Date: 11/11/16
Time: 13:53:38

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW5

AQUIFER DATA

Saturated Thickness: 26.89 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW5

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 1. ft
Static Water Column Height: 26.89 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 20. ft
Total Well Penetration Depth: 30. ft

No. of Observations: 145

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	1.516	4.013	0.532
0.022	1.474	4.179	0.514
0.033	1.459	4.346	0.502
0.044	0.895	4.513	0.49
0.055	0.962	4.679	0.479
0.066	0.914	4.846	0.465
0.077	0.938	5.013	0.456
0.088	0.944	5.179	0.446
0.099	0.937	5.346	0.435
0.11	0.932	5.513	0.426
0.121	0.931	5.679	0.414
0.132	0.941	5.846	0.405
0.143	0.941	6.013	0.395
0.154	0.992	6.179	0.386
0.165	0.938	6.346	0.376
0.176	0.946	6.513	0.365
0.187	0.928	6.679	0.358
0.198	0.932	6.846	0.35

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.935	7.013	0.341
0.22	0.937	7.179	0.332
0.231	0.925	7.346	0.323
0.2427	0.932	7.513	0.317
0.2552	0.932	7.679	0.307
0.2683	0.928	7.846	0.298
0.2823	0.925	8.013	0.291
0.2972	0.923	8.179	0.283
0.3128	0.922	8.346	0.276
0.3295	0.919	8.513	0.268
0.3472	0.917	8.679	0.262
0.3658	0.914	8.846	0.255
0.3857	0.911	9.013	0.247
0.4067	0.908	9.179	0.241
0.4288	0.905	9.346	0.234
0.4523	0.904	9.513	0.226
0.4772	0.901	9.679	0.219
0.5035	0.898	9.846	0.213
0.5315	0.89	10.01	0.206
0.5612	0.884	10.18	0.2
0.5925	0.88	10.35	0.194
0.6257	0.877	10.51	0.188
0.6608	0.871	10.68	0.182
0.6982	0.866	10.85	0.174
0.7377	0.86	11.01	0.168
0.7795	0.86	11.18	0.165
0.8238	0.852	11.35	0.161
0.8708	0.843	11.51	0.152
0.9207	0.838	11.68	0.147
0.9733	0.831	11.85	0.141
1.029	0.825	12.01	0.135
1.088	0.816	12.18	0.131
1.151	0.808	12.35	0.125
1.217	0.799	12.51	0.121
1.288	0.79	12.68	0.116
1.362	0.783	12.85	0.112
1.441	0.774	13.01	0.106
1.525	0.764	13.18	0.103
1.613	0.753	13.35	0.095
1.707	0.744	13.51	0.091
1.807	0.732	13.68	0.086
1.912	0.723	13.85	0.08
2.023	0.71	14.01	0.077
2.142	0.698	14.18	0.073
2.267	0.684	14.35	0.068
2.399	0.67	14.51	0.064
2.54	0.656	14.68	0.059
2.688	0.643	14.85	0.053
2.846	0.626	15.01	0.05
3.013	0.613	15.18	0.044
3.179	0.598	15.35	0.041
3.346	0.58	15.51	0.037
3.513	0.567	15.68	0.034
3.679	0.555	15.85	0.03
3.846	0.538		

SOLUTION

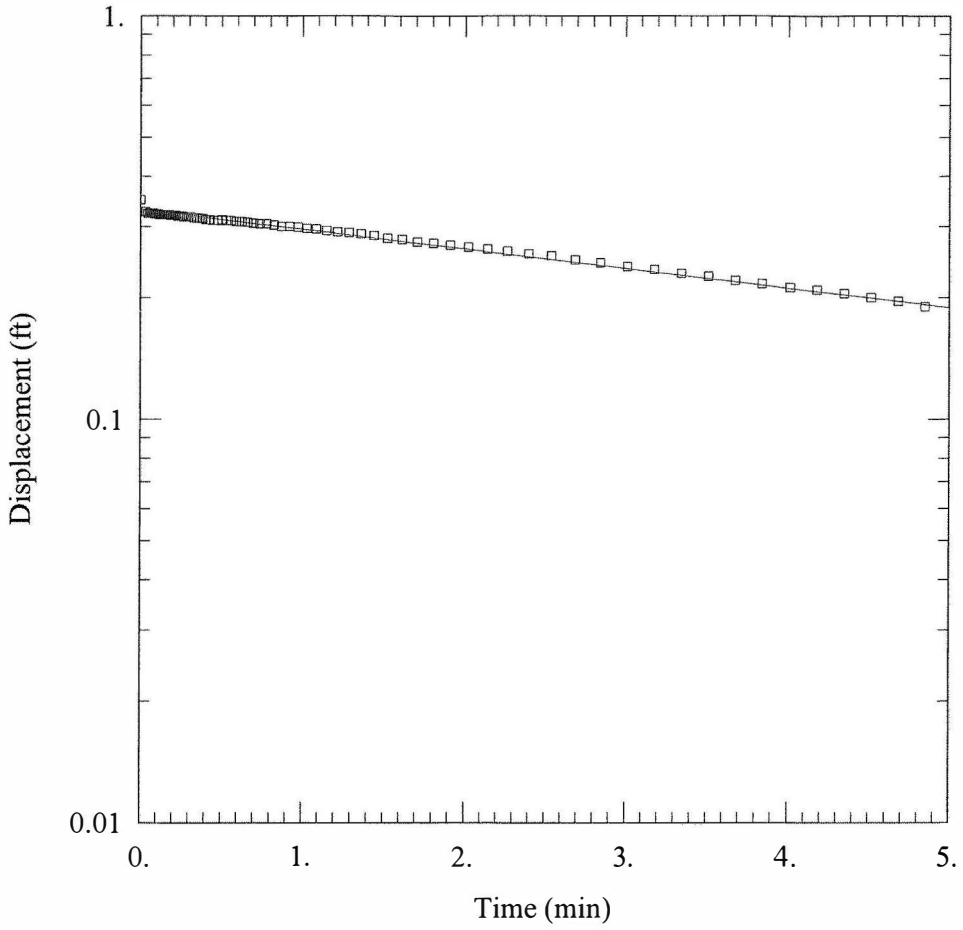
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.57

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	5.5E-5	cm/sec
y0	0.95	ft

$T = K*b = 0.04508$ cm²/sec



RISING HEAD TEST

Data Set: I:\...\CPS_OW5_RH.aqt
Date: 11/11/16 Time: 13:53:38

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Well: OW5
Test Date: 9 Jun 2009

AQUIFER DATA

Saturated Thickness: 26.89 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (OW5)

Initial Displacement: 0.35 ft
Total Well Penetration Depth: 30. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 26.89 ft
Screen Length: 20. ft
Well Radius: 0.08333 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 4.5E-5 cm/sec y0 = 0.33 ft

Data Set: I:\09jobs\09E0045\Admin\15-Field-Laboratory Data\AshPond2_Slug_Tests\CPS_OW5_RH.aqt
Title: Rising Head Test
Date: 11/11/16
Time: 13:53:38

PROJECT INFORMATION

Company: Hanson Professional Services
Client: AEG Coffeen Power Station
Project: 09E0045/3001
Location: Coffeen, IL
Test Date: 9 Jun 2009
Test Well: OW5

AQUIFER DATA

Saturated Thickness: 26.89 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: OW5

X Location: 0. ft
Y Location: 0. ft

Initial Displacement: 0.35 ft
Static Water Column Height: 26.89 ft
Casing Radius: 0.08333 ft
Well Radius: 0.08333 ft
Well Skin Radius: 0.333 ft
Screen Length: 20. ft
Total Well Penetration Depth: 30. ft

No. of Observations: 122

Observation Data

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.011	0.327	2.142	0.264
0.022	0.327	2.267	0.261
0.033	0.327	2.399	0.257
0.044	0.324	2.54	0.254
0.055	0.324	2.688	0.248
0.066	0.324	2.846	0.244
0.077	0.324	3.013	0.239
0.088	0.323	3.179	0.235
0.099	0.323	3.346	0.23
0.11	0.323	3.513	0.226
0.121	0.321	3.679	0.221
0.132	0.321	3.846	0.217
0.143	0.321	4.013	0.212
0.154	0.321	4.179	0.209
0.165	0.321	4.346	0.205
0.176	0.321	4.513	0.2
0.187	0.32	4.679	0.196
0.198	0.32	4.846	0.19

Time (min)	Displacement (ft)	Time (min)	Displacement (ft)
0.209	0.32	5.013	0.185
0.22	0.32	5.179	0.181
0.231	0.318	5.346	0.178
0.2427	0.318	5.513	0.173
0.2552	0.318	5.679	0.169
0.2683	0.317	5.846	0.165
0.2823	0.317	6.013	0.162
0.2972	0.317	6.179	0.157
0.3128	0.317	6.346	0.153
0.3295	0.315	6.513	0.147
0.3472	0.315	6.679	0.142
0.3658	0.315	6.846	0.139
0.3857	0.314	7.013	0.135
0.4067	0.312	7.179	0.132
0.4288	0.312	7.346	0.127
0.4523	0.311	7.513	0.123
0.4772	0.311	7.679	0.118
0.5035	0.312	7.846	0.115
0.5315	0.311	8.013	0.112
0.5612	0.311	8.179	0.108
0.5925	0.309	8.346	0.105
0.6257	0.309	8.513	0.099
0.6608	0.308	8.679	0.096
0.6982	0.306	8.846	0.091
0.7377	0.305	9.013	0.088
0.7795	0.305	9.179	0.084
0.8238	0.303	9.346	0.08
0.8708	0.3	9.513	0.077
0.9207	0.3	9.679	0.074
0.9733	0.299	9.846	0.071
1.029	0.297	10.01	0.066
1.088	0.296	10.18	0.062
1.151	0.293	10.35	0.059
1.217	0.291	10.51	0.054
1.288	0.29	10.68	0.05
1.362	0.288	10.85	0.047
1.441	0.285	11.01	0.044
1.525	0.281	11.18	0.041
1.613	0.279	11.35	0.038
1.707	0.275	11.51	0.033
1.807	0.273	11.68	0.03
1.912	0.27	11.85	0.026
2.023	0.267	12.01	0.023

SOLUTION

Slug Test
Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.57

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	4.5E-5	cm/sec
y0	0.33	ft

$T = K*b = 0.03688\ cm^2/sec$

APPENDIX B3

LABORATORY HYDRAULIC CONDUCTIVITY TESTS

HISTORICAL LABORATORY RESULTS

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-7
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	17B
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay.	DEPTH (FT):	53.0-53.5
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	693.83
SPECIMEN HEIGHT (IN)	3.442
DIAMETER (IN)	2.766
AREA (SQ IN)	6.009
VOLUME (CU IN)	20.683
WET DENSITY (PCF)	127.80
DRY DENSITY (PCF)	103.28
WT. DRY SOIL (G)	560.74
VOLUME DRY SOIL (CU IN)	12.674
SP.GR. ASSUMED	2.70
POROSITY (%)	38.72
HEIGHT OF HEAD (PSI)	3.70
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	32.81
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	74.53	752.87
TARE + DRY SOIL (G)	60.94	613.65
TARE (G)	3.68	50.10
WATER (G)	13.59	139.22
DRY SOIL (G)	57.26	563.55
WATER CONTENT (%)	23.73	24.70

STD. MAX. DEN.(LBS/CU.FT.)	112.00
OPTIMUM MOISTURE (%)	14.70
% COMPACTION	92.22
PRESSURE HEAD (CM H2O)	260.17
PANEL NUMBER	6
PERMEANT USED:	TAP WATER

R001573

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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 05S3004A
CLIENT: AEG Coffeen Power Station
JOB DESCRIPTION: CCB Management Facility
SAMPLE DESCRIPTION: Gray vf. sandy silty clay.

TEST DATE: 7/10/2006
BORING #: SB-7
SAMPLE #: 17B
DEPTH (FT): 53.0-53.5

SPECIMEN HEIGHT (IN) 3.442
DIAMETER (IN) 2.766
AREA (SQ IN) 6.009
1/4 PORE VOLUME 32.81

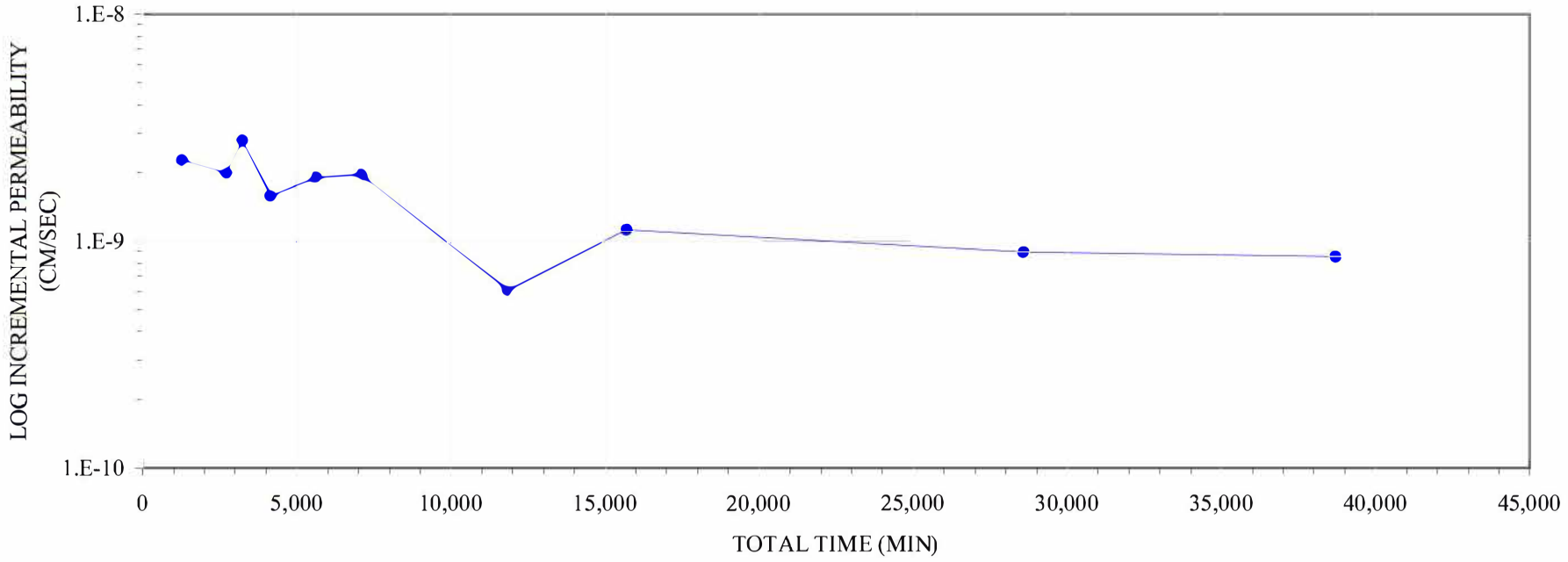
HEIGHT OF HEAD (PSI) 3.70
PRESSURE HEAD (CM H2O) 260.17
PANEL NUMBER 6
FILE NAME: 05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	10:56:30	7/18/2006	8:03:00	0.20	0.2000	1266.50	1266.50	2.28E-09	2.28E-09
7/18/2006	8:03:00	7/19/2006	8:02:00	0.20	0.4000	1439.00	2705.50	2.01E-09	2.14E-09
7/19/2006	8:02:00	7/19/2006	16:41:00	0.10	0.5000	519.00	3224.50	2.78E-09	2.34E-09
7/19/2006	16:41:00	7/20/2006	7:49:00	0.10	0.6000	908.00	4132.50	1.59E-09	2.12E-09
7/20/2006	7:49:00	7/21/2006	9:00:45	0.20	0.8000	1511.75	5644.25	1.91E-09	2.03E-09
7/31/2006	9:20:35	8/1/2006	9:48:00	0.20	1.0000	1467.42	7111.67	1.97E-09	2.02E-09
8/1/2006	9:48:00	8/4/2006	16:36:15	0.20	1.2000	4728.25	11839.92	6.11E-10	1.38E-09
8/4/2006	16:36:15	8/7/2006	8:56:38	0.30	1.5000	3860.38	15700.30	1.12E-09	1.27E-09
8/7/2006	8:56:38	8/16/2006	7:41:00	0.80	2.3000	12884.37	28584.67	8.97E-10	1.05E-09
8/16/2006	7:41:00	8/23/2006	8:12:52	0.60	2.9000	10111.87	38696.53	8.57E-10	8.52E-10

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-7
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	17B
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay.	DEPTH (FT):	53.0-53.5
SPECIMEN HEIGHT (IN)	3.442	HEIGHT OF HEAD (PSI)	3.70
DIAMETER (IN)	2.766	PRESSURE HEAD (CM H2O)	260.17
AREA (SQ IN)	6.009	PANEL NUMBER	6
1/4 PORE VOLUME	32.81	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-9
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	14
SAMPLE DESCRIPTION:	Gray vf. sandy silt / so. clay (tr. c. sand & sm. gravel).	DEPTH (FT):	26.5-27.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	438.57
SPECIMEN HEIGHT (IN)	1.951
DIAMETER (IN)	2.775
AREA (SQ IN)	6.048
VOLUME (CU IN)	11.800
WET DENSITY (PCF)	141.59
DRY DENSITY (PCF)	130.87
WT. DRY SOIL (G)	405.36
VOLUME DRY SOIL (CU IN)	9.162
SP.GR. ASSUMED	2.70
POROSITY (%)	22.36
HEIGHT OF HEAD (PSI)	2.10
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	10.81
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	112.90	56.90
TARE + DRY SOIL (G)	104.63	50.64
TARE (G)	3.69	3.67
WATER (G)	8.27	6.26
DRY SOIL (G)	100.94	46.97
WATER CONTENT (%)	8.19	13.33

STD. MAX. DEN.(LBS/CU.FT.)	N/A
OPTIMUM MOISTURE (%)	N/A
% COMPACTION	N/A
PRESSURE HEAD (CM H2O)	147.67
PANEL NUMBER	5
PERMEANT USED:	TAP WATER

R001576

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	8/30/2007
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-9
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	14
SAMPLE DESCRIPTION:	Gray vf. sandy silt / so. clay (tr. c. sand & sm. gravel).	DEPTH (FT):	26.5-27.0
SPECIMEN HEIGHT (IN)	1.951	HEIGHT OF HEAD (PSI)	2.10
DIAMETER (IN)	2.775	PRESSURE HEAD (CM H2O)	147.67
AREA (SQ IN)	6.048	PANEL NUMBER	5
1/4 PORE VOLUME	10.81	FILE NAME:	05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	10:39:00	7/17/2006	11:36:15	15.70	15.7000	57.25	57.25	3.93E-06	3.93E-06
7/17/2006	11:39:00	7/17/2006	13:13:30	22.50	38.2000	94.50	151.75	3.41E-06	3.66E-06
7/17/2006	13:16:30	7/17/2006	14:55:00	23.20	61.4000	98.50	250.25	3.38E-06	3.56E-06
7/17/2006	14:57:30	7/17/2006	16:10:00	17.50	78.9000	72.50	322.75	3.46E-06	3.54E-06
7/18/2006	8:02:00	7/18/2006	9:57:00	24.00	102.9000	115.00	437.75	2.99E-06	3.30E-06
7/18/2006	9:58:40	7/18/2006	12:38:30	24.30	127.2000	159.83	597.58	2.18E-06	2.95E-06
7/18/2006	12:41:00	7/18/2006	15:23:00	23.40	150.6000	162.00	759.58	2.07E-06	2.61E-06
7/18/2006	15:27:00	7/18/2006	16:36:00	10.80	161.4000	69.00	828.58	2.24E-06	2.35E-06
7/19/2006	8:01:00	7/19/2006	10:52:00	23.60	185.0000	171.00	999.58	1.98E-06	2.12E-06
7/19/2006	10:53:30	7/19/2006	13:55:30	24.50	209.5000	182.00	1181.58	1.93E-06	2.05E-06
7/19/2006	13:59:00	7/19/2006	16:39:00	21.70	231.2000	160.00	1341.58	1.94E-06	2.02E-06
7/20/2006	12:57:00	7/20/2006	16:04:00	24.00	255.2000	187.00	1528.58	1.84E-06	1.92E-06

R001577

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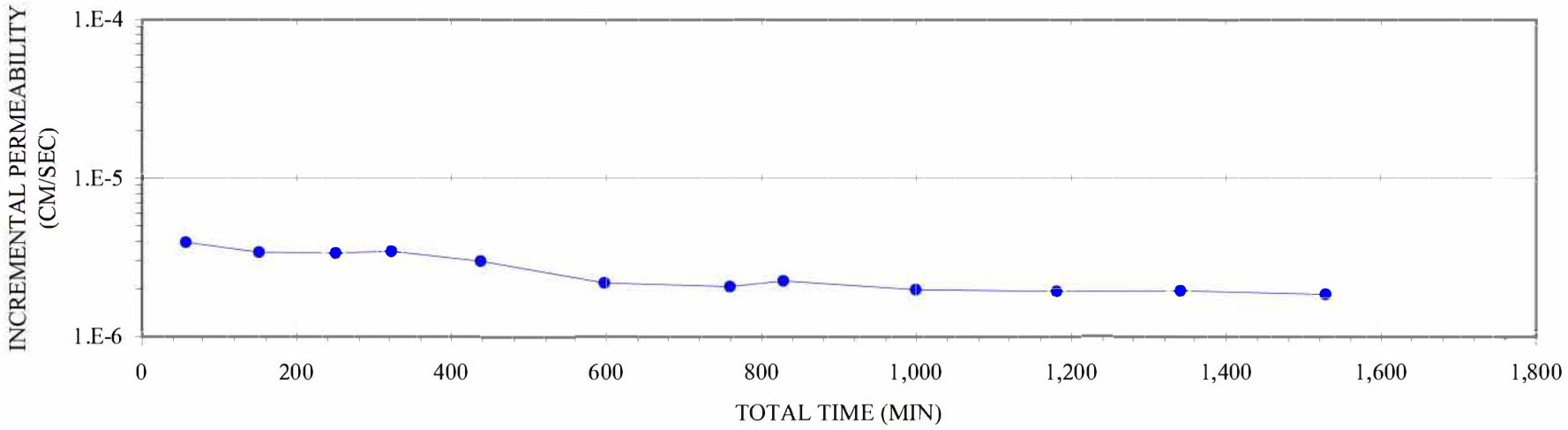
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	8/30/2007
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-9
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	14
SAMPLE DESCRIPTION:	Gray vf. sandy silt / so. clay (tr. c. sand & sm. gravel).	DEPTH (FT):	26.5-27.0
SPECIMEN HEIGHT (IN)	1.951	HEIGHT OF HEAD (PSI)	2.10
DIAMETER (IN)	2.775	PRESSURE HEAD (CM H2O)	147.67
AREA (SQ IN)	6.048	PANEL NUMBER	5
1/4 PORE VOLUME	10.81	FILE NAME:	05S3004A



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CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	4/3/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-11
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	BAG
SAMPLE DESCRIPTION:	Dk. brn. vf. sandy silty clay.	DEPTH (FT):	4.0-8.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	349.45
SPECIMEN HEIGHT (IN)	3.998
DIAMETER (IN)	1.879
AREA (SQ IN)	2.773
VOLUME (CU IN)	11.086
WET DENSITY (PCF)	120.08
DRY DENSITY (PCF)	103.14
WT. DRY SOIL (G)	300.16
VOLUME DRY SOIL (CU IN)	6.784
SP.GR. ASSUMED	2.70
POROSITY (%)	38.81
HEIGHT OF HEAD (PSI)	4.30
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	17.62
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	219.92	369.93
TARE + DRY SOIL (G)	208.47	305.36
TARE (G)	138.74	3.72
WATER (G)	11.45	64.57
DRY SOIL (G)	69.73	301.64
WATER CONTENT (%)	16.42	21.41

STD. MAX. DEN.(LBS/CU.FT.)	108.80
OPTIMUM MOISTURE (%)	16.10
% COMPACTION	94.80
PRESSURE HEAD (CM H2O)	302.36
PANEL NUMBER	7
PERMEANT USED:	Tap Water

HANSON®

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 05S3004A
CLIENT: AEG Coffeen Power Station
JOB DESCRIPTION: CCB Management Facility

TEST DATE: 4/3/2006
BORING #: SB-11
SAMPLE #: BAG
DEPTH (FT): 4.0-8.0

SPECIMEN HEIGHT (IN) 3.998
DIAMETER (IN) 1.879
AREA (SQ IN) 2.773
1/4 PORE VOLUME 17.62

HEIGHT OF HEAD (PSI) 4.30
PRESSURE HEAD (CM H2O) 302.36
PANEL NUMBER 7
FILE NAME: 05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
5/10/2006	13:14:25	5/11/2006	8:22:00	0.80	0.8000	1147.58	1147.58	2.18E-08	2.18E-08
5/11/2006	8:22:00	5/12/2006	8:11:35	1.90	2.7000	1429.58	2577.17	4.16E-08	3.01E-08
5/12/2006	8:11:35	5/15/2006	8:53:00	3.30	6.0000	4361.42	6938.58	2.37E-08	2.78E-08
5/15/2006	8:53:00	5/16/2006	10:31:25	1.00	7.0000	1538.42	8477.00	2.03E-08	2.57E-08
5/16/2006	10:31:25	5/17/2006	7:53:35	0.90	7.9000	1282.17	9759.17	2.20E-08	2.58E-08
5/17/2006	7:53:35	5/18/2006	16:41:40	1.20	9.1000	1968.08	11727.25	1.91E-08	2.12E-08
5/18/2006	16:41:40	5/22/2006	8:25:20	2.80	11.9000	5263.67	16990.92	1.66E-08	1.94E-08
5/22/2006	8:25:20	5/24/2006	9:06:25	1.30	13.2000	2921.08	19912.00	1.39E-08	1.77E-08
5/24/2006	9:06:25	5/25/2006	9:36:40	0.60	13.8000	1470.25	21382.25	1.28E-08	1.54E-08
5/25/2006	9:36:40	5/26/2006	9:44:45	0.70	14.5000	1448.08	22830.33	1.51E-08	1.45E-08
5/26/2006	9:44:45	5/27/2006	9:31:35	0.50	15.0000	1426.83	24257.17	1.10E-08	1.31E-08
5/27/2006	9:31:35	5/28/2006	9:24:15	0.60	15.6000	1432.67	25689.83	1.31E-08	1.29E-08
5/28/2006	9:24:15	5/29/2006	8:21:20	0.40	16.0000	1377.08	27066.92	9.09E-09	1.19E-08
5/29/2006	8:21:20	5/30/2006	12:56:30	0.70	16.7000	1715.17	28782.08	1.28E-08	1.14E-08
5/30/2006	12:56:30	5/31/2006	14:36:35	0.60	17.3000	1540.08	30322.17	1.22E-08	1.17E-08
5/31/2006	14:36:35	6/1/2006	13:16:30	0.40	17.7000	1359.92	31682.08	9.20E-09	1.07E-08
6/1/2006	13:16:30	6/2/2006	10:24:00	0.60	18.3000	1267.50	32949.58	1.48E-08	1.21E-08

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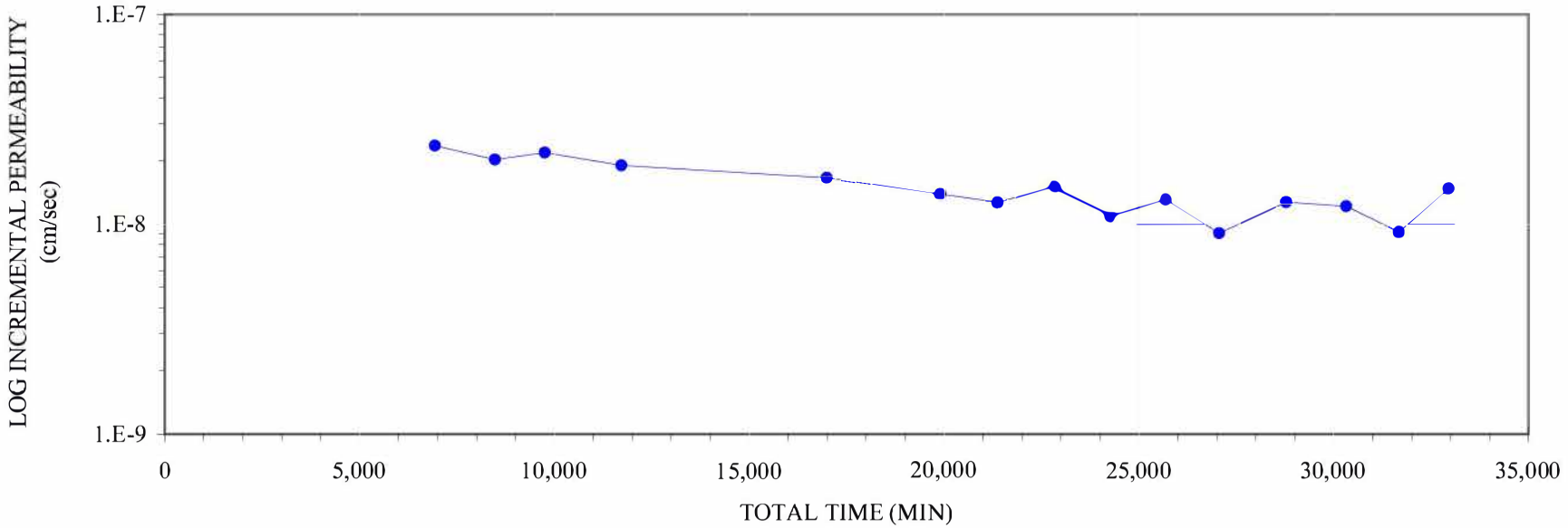
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	4/3/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-11
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	BAG
		DEPTH (FT):	4.0-8.0

SPECIMEN HEIGHT (IN)	3.998	HEIGHT OF HEAD (PSI)	4.30
DIAMETER (IN)	1.879	PRESSURE HEAD (CM H2O)	302.36
AREA (SQ IN)	2.773	PANEL NUMBER	7
1/4 PORE VOLUME	17.62	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-12
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	6B
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand).	DEPTH (FT):	45.0-50.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	459.74
SPECIMEN HEIGHT (IN)	3.419
DIAMETER (IN)	2.347
AREA (SQ IN)	4.326
VOLUME (CU IN)	14.792
WET DENSITY (PCF)	118.40
DRY DENSITY (PCF)	96.94
WT. DRY SOIL (G)	376.40
VOLUME DRY SOIL (CU IN)	8.507
SP.GR. ASSUMED	2.70
POROSITY (%)	42.49
HEIGHT OF HEAD (PSI)	3.60
HYDRAULIC GRADIANT	29.1
1/4 PORE VOLUME	25.75
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	65.87	513.41
TARE + DRY SOIL (G)	54.60	427.45
TARE (G)	3.70	50.03
WATER (G)	11.27	85.96
DRY SOIL (G)	50.90	377.42
WATER CONTENT (%)	22.14	22.78

STD. MAX. DEN.(LBS/CU.FT.)	112.00
OPTIMUM MOISTURE (%)	14.70
% COMPACTION	86.55
PRESSURE HEAD (CM H2O)	253.14
PANEL NUMBER	8
PERMEANT USED:	TAP WATER

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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-12
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	6B
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand).	DEPTH (FT):	45.0-50.0

SPECIMEN HEIGHT (IN)	3.419	HEIGHT OF HEAD (PSI)	3.60
DIAMETER (IN)	2.347	PRESSURE HEAD (CM H2O)	253.14
AREA (SQ IN)	4.326	PANEL NUMBER	8
1/4 PORE VOLUME	25.75	FILE NAME:	05S3004A

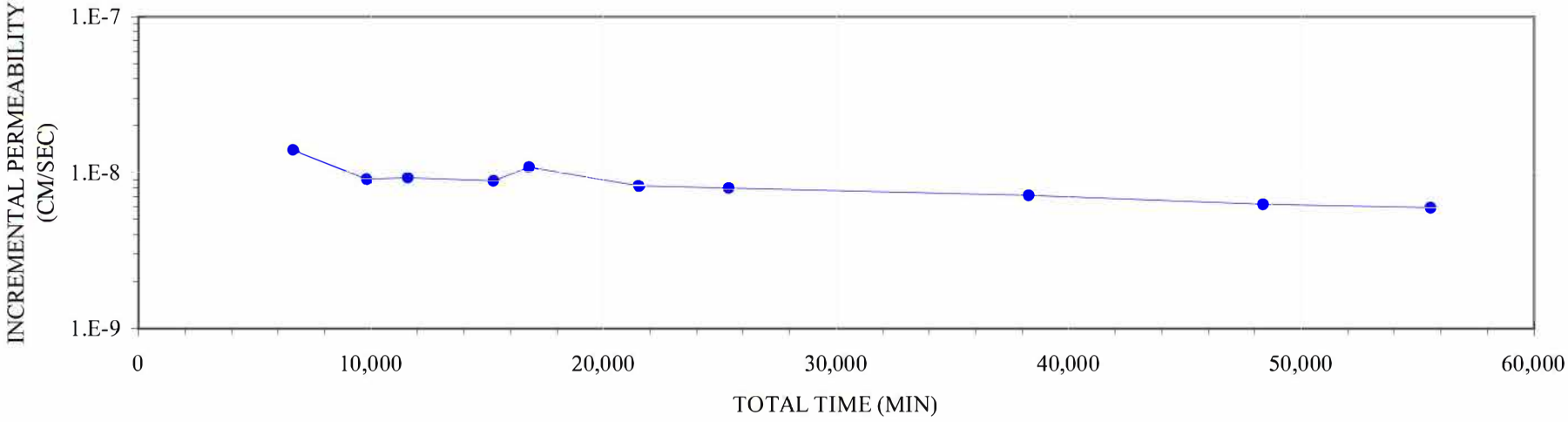
START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	13:26:30	7/18/2006	8:11:00	0.40	0.4000	1124.50	1124.50	7.29E-09	7.29E-09
7/18/2006	8:11:00	7/19/2006	8:09:30	0.30	0.7000	1438.50	2563.00	4.27E-09	5.58E-09
7/19/2006	8:09:30	7/20/2006	7:57:30	0.20	0.9000	1428.00	3991.00	2.87E-09	4.47E-09
7/20/2006	7:57:30	7/21/2006	9:07:45	0.20	1.1000	1510.25	5501.25	2.71E-09	3.95E-09
7/24/2006	13:38:15	7/25/2006	9:05:25	0.80	1.9000	1167.17	6668.42	1.40E-08	4.65E-09
7/25/2006	9:05:25	7/27/2006	13:38:00	1.40	3.3000	3152.58	9821.00	9.10E-09	5.62E-09
7/27/2006	13:38:00	7/28/2006	19:03:30	0.80	4.1000	1765.50	11586.50	9.28E-09	7.53E-09
7/28/2006	19:03:30	7/31/2006	8:43:30	1.60	5.7000	3700.00	15286.50	8.86E-09	1.01E-08
7/31/2006	8:43:30	8/1/2006	9:52:15	0.80	6.5000	1508.75	16795.25	1.09E-08	9.49E-09
8/1/2006	9:52:15	8/4/2006	16:38:10	1.90	8.4000	4725.92	21521.17	8.24E-09	9.26E-09
8/4/2006	16:38:10	8/7/2006	8:58:40	1.50	9.9000	3860.50	25381.67	7.96E-09	8.91E-09
8/7/2006	8:58:40	8/16/2006	7:49:00	4.50	14.4000	12890.33	38272.00	7.15E-09	8.45E-09
8/16/2006	7:49:00	8/23/2006	8:14:00	3.10	17.5000	10105.00	48377.00	6.28E-09	7.37E-09
8/23/2006	8:14:00	8/28/2006	8:02:30	2.10	19.6000	7188.50	55565.50	5.98E-09	6.80E-09

R001583

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-12
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	6B
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand).	DEPTH (FT):	45.0-50.0
SPECIMEN HEIGHT (IN)	3.419	HEIGHT OF HEAD (PSI)	3.60
DIAMETER (IN)	2.347	PRESSURE HEAD (CM H2O)	253.14
AREA (SQ IN)	4.326	PANEL NUMBER	8
1/4 PORE VOLUME	25.75	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-13
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand & sm. gravel).	DEPTH (FT):	25.0-30.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	483.73
SPECIMEN HEIGHT (IN)	3.259
DIAMETER (IN)	2.279
AREA (SQ IN)	4.079
VOLUME (CU IN)	13.294
WET DENSITY (PCF)	138.62
DRY DENSITY (PCF)	123.13
WT. DRY SOIL (G)	429.70
VOLUME DRY SOIL (CU IN)	9.712
SP.GR. ASSUMED	2.70
POROSITY (%)	26.95
HEIGHT OF HEAD (PSI)	3.50
HYDRAULIC GRADIANT	29.7
1/4 PORE VOLUME	14.68
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	125.78	534.14
TARE + DRY SOIL (G)	112.15	475.18
TARE (G)	3.75	50.14
WATER (G)	13.63	58.96
DRY SOIL (G)	108.40	425.04
WATER CONTENT (%)	12.57	13.87

STD. MAX. DEN.(LBS/CU.FT.)	N/A
OPTIMUM MOISTURE (%)	N/A
% COMPACTION	
PRESSURE HEAD (CM H2O)	246.11
PANEL NUMBER	1
PERMEANT USED:	TAP WATER

R001585

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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-13
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand & sm. gravel).	DEPTH (FT):	25.0-30.0
SPECIMEN HEIGHT (IN)	3.259	HEIGHT OF HEAD (PSI)	3.50
DIAMETER (IN)	2.279	PRESSURE HEAD (CM H2O)	246.11
AREA (SQ IN)	4.079	PANEL NUMBER	1
1/4 PORE VOLUME	14.68	FILE NAME:	05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/19/2006	8:38:00	7/20/2006	8:11:10	6.20	6.2000	1413.17	1413.17	9.35E-08	9.35E-08
7/20/2006	8:11:10	7/21/2006	7:58:00	4.20	10.4000	1426.83	2840.00	6.27E-08	7.65E-08
7/21/2006	7:58:00	7/21/2006	16:13:00	1.20	11.6000	495.00	3335.00	5.16E-08	6.71E-08
7/24/2006	13:37:50	7/25/2006	9:06:10	0.90	12.5000	1168.33	4503.33	1.64E-08	4.72E-08
7/25/2006	9:06:10	7/27/2006	13:38:40	1.30	13.8000	3152.50	7655.83	8.78E-09	2.61E-08
7/27/2006	13:38:40	7/28/2006	19:01:35	0.70	14.5000	1762.92	9418.75	8.46E-09	1.58E-08
7/28/2006	19:01:35	7/31/2006	8:44:10	1.40	15.9000	3702.58	13121.33	8.05E-09	9.95E-09
7/31/2006	8:44:10	8/1/2006	9:53:15	0.60	16.5000	1509.08	14630.42	8.47E-09	8.44E-09
8/1/2006	9:53:15	8/4/2006	16:38:45	1.60	18.1000	4725.50	19355.92	7.21E-09	8.03E-09
8/4/2006	16:38:45	8/7/2006	8:59:19	1.20	19.3000	3860.57	23216.48	6.62E-09	7.55E-09
8/7/2006	8:59:19	8/16/2006	7:49:30	3.80	23.1000	12890.18	36106.67	6.28E-09	7.10E-09

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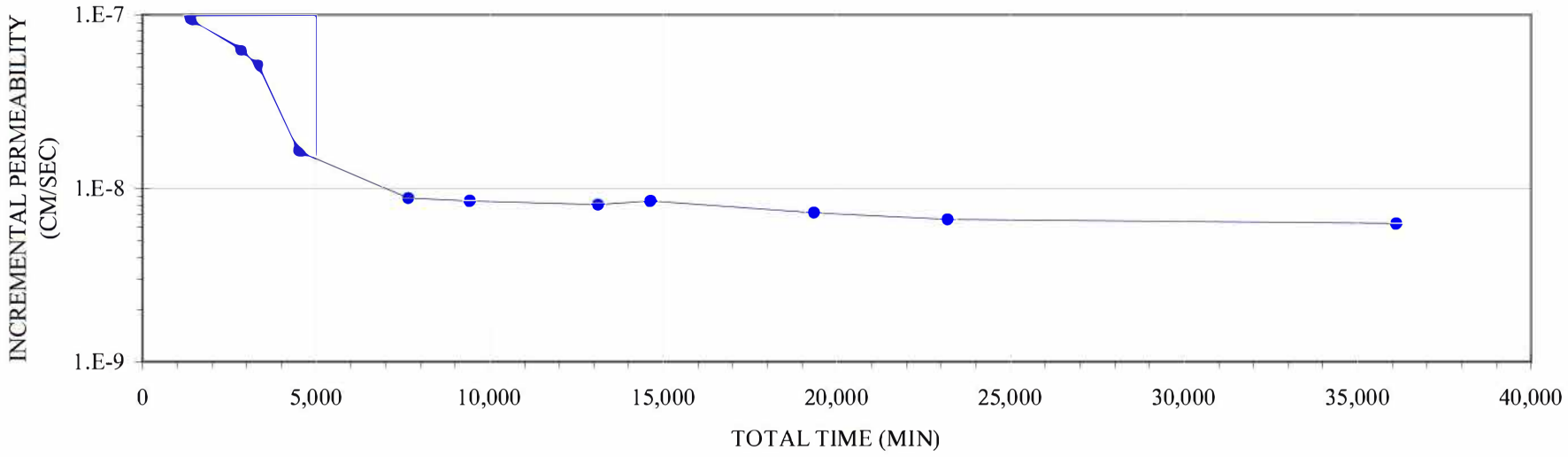
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-13
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray vf. sandy silty clay (tr. c. sand & sm. gravel).	DEPTH (FT):	25.0-30.0
SPECIMEN HEIGHT (IN)	3.259	HEIGHT OF HEAD (PSI)	3.50
DIAMETER (IN)	2.279	PRESSURE HEAD (CM H2O)	246.11
AREA (SQ IN)	4.079	PANEL NUMBER	1
1/4 PORE VOLUME	14.68	FILE NAME:	05S3004A



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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	5/5/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-14
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	BAG
SAMPLE DESCRIPTION:	Brn. vf. sandy silty clay (tr. sm. gravel).	DEPTH (FT):	5.0-10.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	356.11
SPECIMEN HEIGHT (IN)	3.998
DIAMETER (IN)	1.879
AREA (SQ IN)	2.773
VOLUME (CU IN)	11.086
WET DENSITY (PCF)	122.37
DRY DENSITY (PCF)	106.70
WT. DRY SOIL (G)	310.52
VOLUME DRY SOIL (CU IN)	7.018
SP.GR. ASSUMED	2.70
POROSITY (%)	36.69
HEIGHT OF HEAD (PSI)	4.30
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	16.67
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	214.34	378.18
TARE + DRY SOIL (G)	204.66	316.21
TARE (G)	138.73	3.78
WATER (G)	9.68	61.97
DRY SOIL (G)	65.93	312.43
WATER CONTENT (%)	14.68	19.83

STD. MAX. DEN.(LBS/CU.FT.)	111.80
OPTIMUM MOISTURE (%)	14.90
% COMPACTION	95.44
PRESSURE HEAD (CM H2O)	302.36
PANEL NUMBER	3
PERMEANT USED:	TAP WATER

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 05S3004A
CLIENT: AEG Coffeen Power Station
JOB DESCRIPTION: CCB Management Facility

TEST DATE: 5/5/2006
BORING #: SB-14
SAMPLE #: BAG
DEPTH (FT): 5.0-10.0

SPECIMEN HEIGHT (IN) 3.998
DIAMETER (IN) 1.879
AREA (SQ IN) 2.773
1/4 PORE VOLUME 16.67

HEIGHT OF HEAD (PSI) 4.30
PRESSURE HEAD (CM H2O) 302.36
PANEL NUMBER 3
FILE NAME: 05S3004A

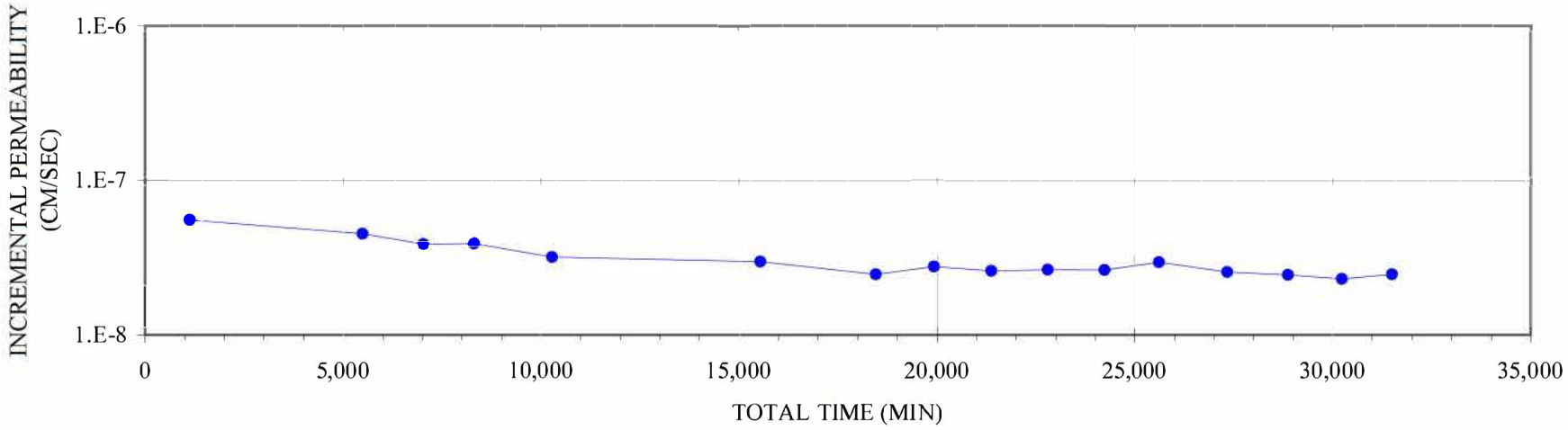
START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
5/11/2006	13:24:00	5/12/2006	8:13:00	2.00	2.0000	1129.00	1129.00	5.54E-08	5.54E-08
5/12/2006	8:13:00	5/15/2006	8:54:20	6.30	8.3000	4361.33	5490.33	4.52E-08	5.01E-08
5/15/2006	8:54:20	5/16/2006	10:33:00	1.90	10.2000	1538.67	7029.00	3.86E-08	4.59E-08
5/16/2006	10:33:00	5/17/2006	7:54:30	1.60	11.8000	1281.50	8310.50	3.91E-08	4.41E-08
5/17/2006	7:54:30	5/18/2006	16:42:10	2.00	13.8000	1967.67	10278.17	3.18E-08	3.84E-08
5/18/2006	16:42:10	5/22/2006	8:26:15	5.00	18.8000	5264.08	15542.25	2.97E-08	3.46E-08
5/22/2006	8:27:45	5/24/2006	9:07:00	2.30	21.1000	2919.25	18461.50	2.47E-08	3.09E-08
5/24/2006	9:07:00	5/25/2006	9:37:25	1.30	22.4000	1470.42	19931.92	2.77E-08	2.83E-08
5/25/2006	9:37:25	5/26/2006	9:45:15	1.20	23.6000	1447.83	21379.75	2.59E-08	2.69E-08
5/26/2006	9:45:15	5/27/2006	9:30:50	1.20	24.8000	1425.58	22805.33	2.63E-08	2.61E-08
5/27/2006	9:30:50	5/28/2006	9:22:30	1.20	26.0000	1431.67	24237.00	2.62E-08	2.65E-08
5/28/2006	9:22:30	5/29/2006	8:22:00	1.30	27.3000	1379.50	25616.50	2.95E-08	2.70E-08
5/29/2006	8:22:00	5/30/2006	13:01:00	1.40	28.7000	1719.00	27335.50	2.55E-08	2.68E-08
5/30/2006	13:01:00	5/31/2006	14:38:00	1.20	29.9000	1537.00	28872.50	2.44E-08	2.63E-08
5/31/2006	14:38:00	6/1/2006	13:19:00	1.00	30.9000	1361.00	30233.50	2.30E-08	2.55E-08
6/1/2006	13:19:00	6/2/2006	10:27:00	1.00	31.9000	1268.00	31501.50	2.47E-08	2.44E-08

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	5/5/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-14
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	BAG
		DEPTH (FT):	5.0-10.0

SPECIMEN HEIGHT (IN)	3.998	HEIGHT OF HEAD (PSI)	4.30
DIAMETER (IN)	1.879	PRESSURE HEAD (CM H2O)	302.36
AREA (SQ IN)	2.773	PANEL NUMBER	3
1/4 PORE VOLUME	16.67	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-16
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18A
SAMPLE DESCRIPTION:	Brn. & gray f. sandy silt (tr. clay) / so.	DEPTH (FT):	37.0-37.5
	c. sand & sm. gravel.	FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	855.13
SPECIMEN HEIGHT (IN)	3.811
DIAMETER (IN)	2.735
AREA (SQ IN)	5.875
VOLUME (CU IN)	22.389
WET DENSITY (PCF)	145.50
DRY DENSITY (PCF)	132.33
WT. DRY SOIL (G)	777.72
VOLUME DRY SOIL (CU IN)	17.578
SP.GR. ASSUMED	2.70
POROSITY (%)	21.49
HEIGHT OF HEAD (PSI)	4.10
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	19.71
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	128.66	124.70
TARE + DRY SOIL (G)	117.35	113.65
TARE (G)	3.72	3.71
WATER (G)	11.31	11.05
DRY SOIL (G)	113.63	109.94
WATER CONTENT (%)	9.95	10.05

STD. MAX. DEN.(LBS/CU.FT.)	112.00
OPTIMUM MOISTURE (%)	14.70
% COMPACTION	118.15
PRESSURE HEAD (CM H2O)	288.30
PANEL NUMBER	3
PERMEANT USED:	TAP WATER

R001591

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-16
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18A
SAMPLE DESCRIPTION:	Brn. & gray f. sandy silt (tr. clay) / so. c. sand & sm. gravel.	DEPTH (FT):	37.0-37.5
SPECIMEN HEIGHT (IN)	3.811	HEIGHT OF HEAD (PSI)	4.10
DIAMETER (IN)	2.735	PRESSURE HEAD (CM H2O)	288.30
AREA (SQ IN)	5.875	PANEL NUMBER	3
1/4 PORE VOLUME	19.71	FILE NAME:	05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	11:36:30	7/17/2006	13:01:30	24.30	24.3000	85.00	85.00	4.22E-06	4.22E-06
7/17/2006	13:04:30	7/17/2006	14:52:00	22.60	46.9000	107.50	192.50	3.10E-06	3.62E-06
7/17/2006	14:54:00	7/17/2006	16:12:15	15.60	62.5000	78.25	270.75	2.94E-06	3.38E-06
7/18/2006	8:08:00	7/18/2006	10:14:00	23.80	86.3000	126.00	396.75	2.79E-06	3.22E-06
7/18/2006	10:21:30	7/18/2006	13:47:00	23.10	109.4000	205.50	602.25	1.66E-06	2.55E-06
7/18/2006	13:48:30	7/18/2006	16:34:00	18.50	127.9000	165.50	767.75	1.65E-06	2.18E-06
7/19/2006	8:08:00	7/19/2006	11:38:00	22.60	150.5000	210.00	977.75	1.59E-06	1.87E-06
7/19/2006	11:40:00	7/19/2006	15:28:30	23.80	174.3000	228.50	1206.25	1.54E-06	1.61E-06
7/19/2006	15:30:30	7/19/2006	16:43:30	8.10	182.4000	73.00	1279.25	1.64E-06	1.60E-06
7/20/2006	7:55:00	7/20/2006	11:32:30	23.10	205.5000	217.50	1496.75	1.57E-06	1.58E-06
7/20/2006	11:35:30	7/20/2006	15:23:50	22.90	228.4000	228.33	1725.08	1.48E-06	1.56E-06
7/20/2006	15:27:00	7/20/2006	16:26:00	6.30	234.7000	59.00	1784.08	1.58E-06	1.56E-06

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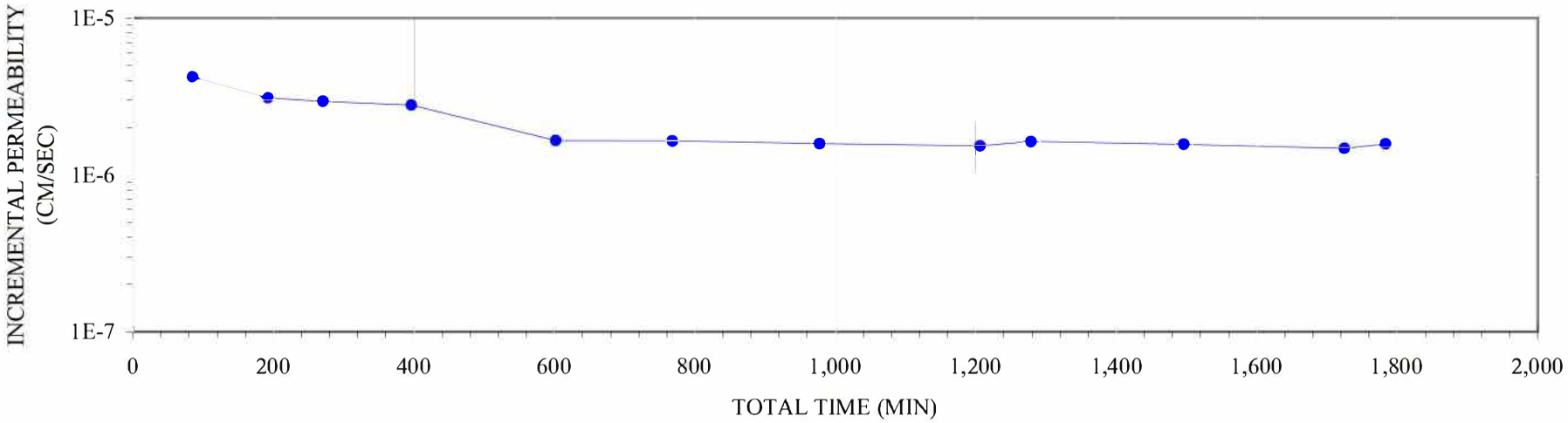
CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-16
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18A
SAMPLE DESCRIPTION:	Brn. & gray f. sandy silt (tr. clay) / so. c. sand & sm. gravel.	DEPTH (FT):	37.0-37.5
SPECIMEN HEIGHT (IN)	3.811	HEIGHT OF HEAD (PSI)	4.10
DIAMETER (IN)	2.735	PRESSURE HEAD (CM H2O)	288.30
AREA (SQ IN)	5.875	PANEL NUMBER	3
1/4 PORE VOLUME	19.71	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-16
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	32A
SAMPLE DESCRIPTION:	Yel. brn. vf.-f. sandy silty clay / so. c.	DEPTH (FT):	78.0-78.5
	sand & sm. gravel & cobbles.	FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	203.47
SPECIMEN HEIGHT (IN)	1.873
DIAMETER (IN)	1.949
AREA (SQ IN)	2.983
VOLUME (CU IN)	5.588
WET DENSITY (PCF)	138.71
DRY DENSITY (PCF)	121.11
WT. DRY SOIL (G)	177.64
VOLUME DRY SOIL (CU IN)	4.015
SP.GR. ASSUMED	2.70
POROSITY (%)	28.15
HEIGHT OF HEAD (PSI)	2.00
HYDRAULIC GRADIANT	29.6
1/4 PORE VOLUME	6.44
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	159.86	258.48
TARE + DRY SOIL (G)	140.04	227.76
TARE (G)	3.71	50.15
WATER (G)	19.82	30.72
DRY SOIL (G)	136.33	177.61
WATER CONTENT (%)	14.54	17.30

STD. MAX. DEN.(LBS/CU.FT.)	112.00
OPTIMUM MOISTURE (%)	14.70
% COMPACTION	108.13
PRESSURE HEAD (CM H2O)	140.63
PANEL NUMBER	4
PERMEANT USED:	TAP WATER

R001594

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 05S3004A
CLIENT: AEG Coffeen Power Station
JOB DESCRIPTION: CCB Management Facility
SAMPLE DESCRIPTION: Yel. brn. vf.-f. sandy silty clay / so. c. sand & sm. gravel & cobbles.

SPECIMEN HEIGHT (IN): 1.873
DIAMETER (IN): 1.949
AREA (SQ IN): 2.983
1/4 PORE VOLUME: 6.444

TEST DATE: 7/10/2006
BORING #: SB-16
SAMPLE #: 32A
DEPTH (FT): 78.0-78.5

HEIGHT OF HEAD (PSI): 2.00
PRESSURE HEAD (CM H2O): 140.63
PANEL NUMBER: 4
FILE NAME: 05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	11:33:00	7/18/2006	8:09:00	0.80	0.8000	1236.00	1236.00	1.90E-08	1.90E-08
7/18/2006	8:09:00	7/19/2006	8:09:00	0.70	1.5000	1440.00	2676.00	1.42E-08	1.64E-08
7/19/2006	8:09:00	7/20/2006	7:56:00	0.80	2.3000	1427.00	4103.00	1.64E-08	1.64E-08
7/20/2006	7:56:00	7/21/2006	9:06:10	0.60	2.9000	1510.17	5613.17	1.16E-08	1.51E-08
7/24/2006	13:37:15	7/25/2006	9:04:50	0.70	3.6000	1167.58	6780.75	1.76E-08	1.48E-08
7/25/2006	9:04:50	7/27/2006	13:37:20	1.80	5.4000	3152.50	9933.25	1.67E-08	1.54E-08
7/27/2006	13:37:20	7/28/2006	19:03:10	1.00	6.4000	1765.83	11699.08	1.66E-08	1.54E-08
7/28/2006	19:03:10	7/31/2006	8:43:10	2.00	8.4000	3700.00	15399.08	1.58E-08	1.67E-08
7/31/2006	8:43:10	8/1/2006	9:51:30	0.80	9.2000	1508.33	16907.42	1.55E-08	1.62E-08
8/1/2006	9:51:30	8/4/2006	16:37:45	2.20	11.4000	4726.25	21633.67	1.36E-08	1.54E-08
8/4/2006	16:37:45	8/7/2006	8:58:05	1.80	13.2000	3860.33	25494.00	1.37E-08	1.46E-08
8/7/2006	8:58:05	8/16/2006	7:45:30	5.10	18.3000	12887.42	38381.42	1.16E-08	1.35E-08
8/16/2006	7:45:30	8/23/2006	8:13:36	4.60	22.9000	10108.10	48489.52	1.33E-08	1.30E-08

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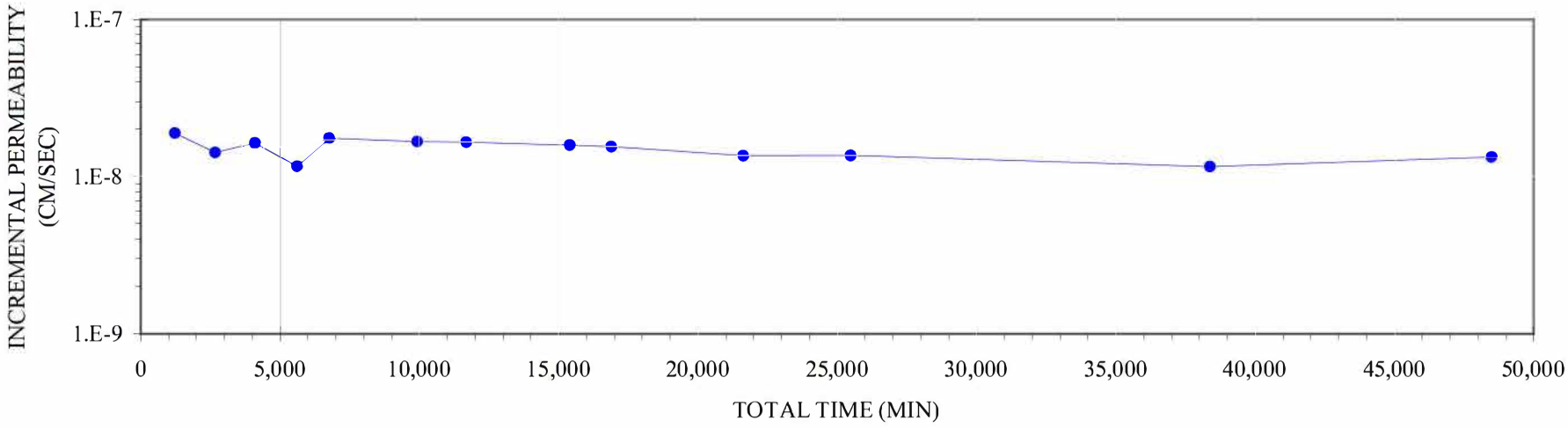
CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-16
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	32A
SAMPLE DESCRIPTION:	Yel. brn. vf.-f. sandy silty clay / so. c. sand & sm. gravel & cobbles.	DEPTH (FT):	78.0-78.5
SPECIMEN HEIGHT (IN)	1.873	HEIGHT OF HEAD (PSI)	2.00
DIAMETER (IN)	1.949	PRESSURE HEAD (CM H2O)	140.63
AREA (SQ IN)	2.983	PANEL NUMBER	4
1/4 PORE VOLUME	6.444	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-18
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray f. sandy silt / so. c. sand & sm. gravel.	DEPTH (FT):	22.5-23.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	733.77
SPECIMEN HEIGHT (IN)	3.163
DIAMETER (IN)	2.746
AREA (SQ IN)	5.922
VOLUME (CU IN)	18.732
WET DENSITY (PCF)	149.22
DRY DENSITY (PCF)	142.56
WT. DRY SOIL (G)	700.99
VOLUME DRY SOIL (CU IN)	15.843
SP.GR. ASSUMED	2.70
POROSITY (%)	15.42
HEIGHT OF HEAD (PSI)	3.40
HYDRAULIC GRADIANT	29.8
1/4 PORE VOLUME	11.83
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	87.91	784.05
TARE + DRY SOIL (G)	82.64	736.02
TARE (G)	3.73	49.33
WATER (G)	3.69	48.03
DRY SOIL (G)	78.91	686.69
WATER CONTENT (%)	4.68	6.99

STD. MAX. DEN.(LBS/CU.FT.)	112.00
OPTIMUM MOISTURE (%)	14.70
% COMPACTION	127.28
PRESSURE HEAD (CM H2O)	239.08
PANEL NUMBER	7
PERMEANT USED:	TAP WATER

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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-18
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray f. sandy silt / so. c. sand & sm. gravel.	DEPTH (FT):	22.5-23.0
SPECIMEN HEIGHT (IN)	3.163	HEIGHT OF HEAD (PSI)	3.40
DIAMETER (IN)	2.746	PRESSURE HEAD (CM H2O)	239.08
AREA (SQ IN)	5.922	PANEL NUMBER	7
1/4 PORE VOLUME	11.83	FILE NAME:	05S3004A

START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	11:18:00	7/18/2006	8:05:00	8.50	8.5000	1247.00	1247.00	9.99E-08	9.99E-08
7/18/2006	8:05:00	7/19/2006	8:03:00	7.20	15.7000	1438.00	2685.00	7.34E-08	8.56E-08
7/19/2006	8:03:00	7/20/2006	7:50:00	6.20	21.9000	1427.00	4112.00	6.37E-08	7.76E-08
7/20/2006	7:50:00	7/20/2006	11:29:30	0.90	22.8000	219.50	4331.50	6.01E-08	7.28E-08
7/20/2006	11:31:30	7/20/2006	16:07:00	1.40	24.2000	275.50	4607.00	7.45E-08	6.76E-08
7/20/2006	16:07:00	7/21/2006	9:03:20	4.60	28.8000	1016.33	5623.33	6.63E-08	6.59E-08
7/24/2006	13:35:30	7/25/2006	9:04:20	1.30	30.1000	1168.83	6792.17	1.63E-08	4.69E-08
7/25/2006	9:04:20	7/27/2006	13:36:50	1.40	31.5000	3152.50	9944.67	6.51E-09	2.69E-08
7/27/2006	13:36:50	7/28/2006	19:02:50	1.20	32.7000	1766.00	11710.67	9.96E-09	1.63E-08
7/28/2006	19:02:50	7/31/2006	8:42:30	2.50	35.2000	3699.67	15410.33	9.91E-09	1.01E-08
7/31/2006	8:42:30	8/1/2006	9:50:45	1.00	36.2000	1508.25	16918.58	9.72E-09	8.89E-09
8/1/2006	9:50:45	8/4/2006	16:37:20	2.90	39.1000	4726.58	21645.17	8.99E-09	9.64E-09
8/4/2006	16:37:20	8/7/2006	8:57:34	2.30	41.4000	3860.23	25505.40	8.73E-09	9.33E-09
8/7/2006	8:57:34	8/16/2006	7:43:30	6.80	48.2000	12885.93	38391.33	7.74E-09	8.77E-09

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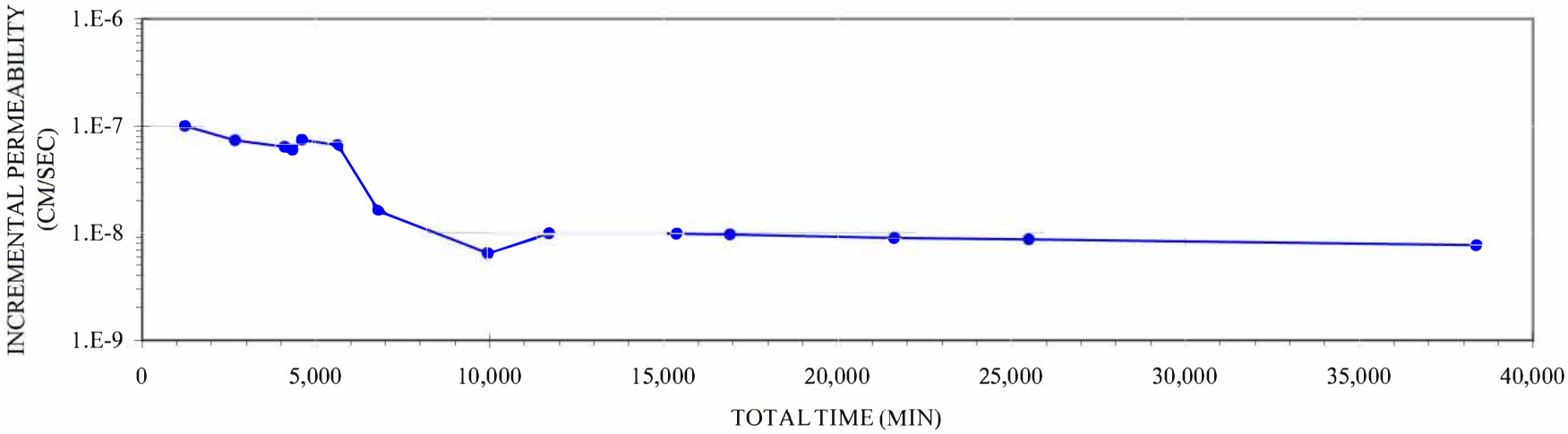
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/7/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-18
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	12
SAMPLE DESCRIPTION:	Gray f. sandy silt / so. c. sand & sm. gravel.	DEPTH (FT):	22.5-23.0
SPECIMEN HEIGHT (IN)	3.163	HEIGHT OF HEAD (PSI)	3.40
DIAMETER (IN)	2.746	PRESSURE HEAD (CM H2O)	239.08
AREA (SQ IN)	5.922	PANEL NUMBER	7
1/4 PORE VOLUME	11.83	FILE NAME:	05S3004A



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-19
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18
SAMPLE DESCRIPTION:	Brn. & gray vf. sandy silty clay.	DEPTH (FT):	55.0-60.0
		FILE NAME:	05S3004A

SPECIMEN WEIGHT (G)	438.75
SPECIMEN HEIGHT (IN)	3.586
DIAMETER (IN)	2.165
AREA (SQ IN)	3.681
VOLUME (CU IN)	13.201
WET DENSITY (PCF)	126.61
DRY DENSITY (PCF)	102.66
WT. DRY SOIL (G)	355.75
VOLUME DRY SOIL (CU IN)	8.041
SP.GR. ASSUMED	2.70
POROSITY (%)	39.09
HEIGHT OF HEAD (PSI)	3.90
HYDRAULIC GRADIANT	30.1
1/4 PORE VOLUME	21.14
TEST METHOD USED:	IEPA ASTM D5084

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	103.57	491.35
TARE + DRY SOIL (G)	84.68	406.17
TARE (G)	3.71	49.88
WATER (G)	18.89	85.18
DRY SOIL (G)	80.97	356.29
WATER CONTENT (%)	23.33	23.91

STD. MAX. DEN.(LBS/CU.FT.)	N/A
OPTIMUM MOISTURE (%)	N/A
% COMPACTION	
PRESSURE HEAD (CM H2O)	274.24
PANEL NUMBER	2
PERMEANT USED:	TAP WATER

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CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-19
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18
SAMPLE DESCRIPTION:	Brn. & gray vf. sandy silty clay.	DEPTH (FT):	55.0-60.0
SPECIMEN HEIGHT (IN)	3.586	HEIGHT OF HEAD (PSI)	3.90
DIAMETER (IN)	2.165	PRESSURE HEAD (CM H2O)	274.24
AREA (SQ IN)	3.681	PANEL NUMBER	2
1/4 PORE VOLUME	21.142	FILE NAME:	05S3004A

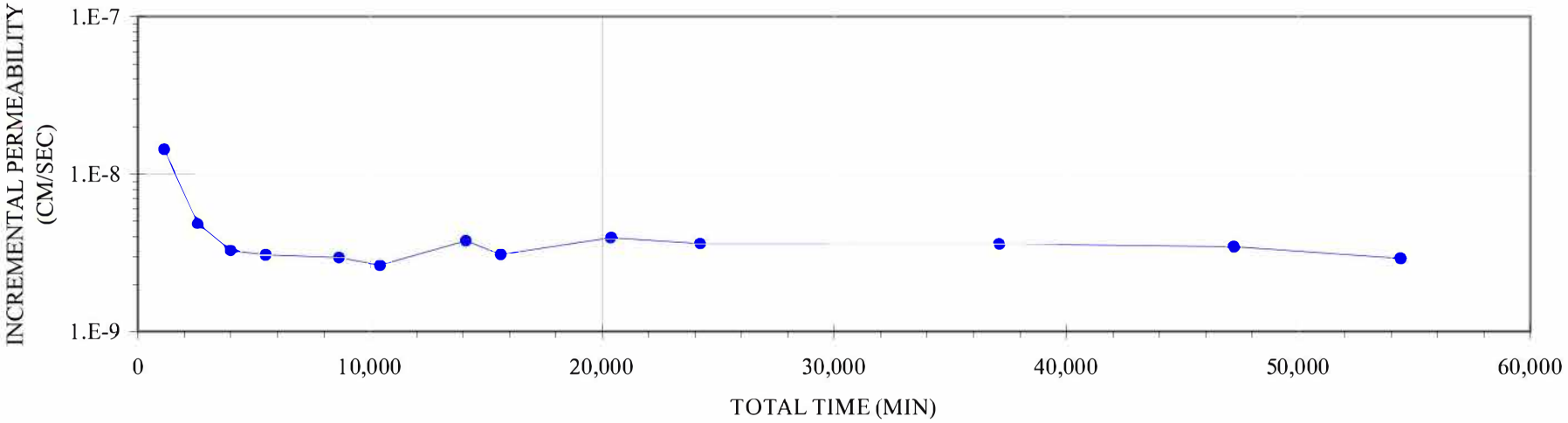
START DATE	START TIME	STOP DATE	STOP TIME	INCREMENT. FLOW (CC)	TOTAL FLOW (CC)	INCREMENT. TIME (MIN)	TOTAL TIME (MIN)	PERMEABILITY (cm/sec) INCREMENTAL	PERMEABILITY (cm/sec) MOVING AVG. GEOMEAN
7/17/2006	13:19:45	7/18/2006	8:13:00	0.70	0.7000	1133.25	1133.25	1.44E-08	1.44E-08
7/18/2006	8:13:00	7/19/2006	8:12:30	0.30	1.0000	1439.50	2572.75	4.86E-09	8.36E-09
7/19/2006	8:12:30	7/20/2006	7:59:00	0.20	1.2000	1426.50	3999.25	3.27E-09	6.11E-09
7/20/2006	7:59:00	7/21/2006	9:12:50	0.20	1.4000	1513.83	5513.08	3.08E-09	5.15E-09
7/25/2006	9:06:45	7/27/2006	13:39:04	0.40	1.8000	3152.32	8665.40	2.96E-09	3.47E-09
7/27/2006	13:39:04	7/28/2006	19:02:15	0.20	2.0000	1763.18	10428.58	2.64E-09	2.98E-09
7/28/2006	19:02:15	7/31/2006	8:44:30	0.60	2.6000	3702.25	14130.83	3.78E-09	3.09E-09
7/31/2006	8:44:30	8/1/2006	9:54:00	0.20	2.8000	1509.50	15640.33	3.09E-09	3.09E-09
8/1/2006	9:54:00	8/4/2006	16:39:20	0.80	3.6000	4725.33	20365.67	3.95E-09	3.32E-09
8/4/2006	16:39:20	8/7/2006	8:59:50	0.60	4.2000	3860.50	24226.17	3.62E-09	3.59E-09
8/7/2006	8:59:50	8/16/2006	7:51:30	2.00	6.2000	12891.67	37117.83	3.62E-09	3.55E-09
8/16/2006	7:51:30	8/23/2006	8:15:00	1.50	7.7000	10103.50	47221.33	3.46E-09	3.66E-09
8/23/2006	8:15:00	8/28/2006	8:03:30	0.90	8.6000	7188.50	54409.83	2.92E-09	3.39E-09

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER:	05S3004A	TEST DATE:	7/10/2006
CLIENT:	AEG Coffeen Power Station	BORING #:	SB-19
JOB DESCRIPTION:	CCB Management Facility	SAMPLE #:	18
SAMPLE DESCRIPTION:	Brn. & gray vf. sandy silty clay.	DEPTH (FT):	55.0-60.0

SPECIMEN HEIGHT (IN)	3.586	HEIGHT OF HEAD (PSI)	3.90
DIAMETER (IN)	2.165	PRESSURE HEAD (CM H2O)	274.24
AREA (SQ IN)	3.681	PANEL NUMBER	2
1/4 PORE VOLUME	21.142	FILE NAME:	05S3004A



AECOM 2015 LABORATORY RESULTS

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	7/30/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B001 S7 21.0 - 23.0 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	FAT CLAY WITH SAND, GRAY WITH YELLOWISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	145.02	WET WT, g	475.6		
D & T, g	123.94	DIA, in	2.872	7.29	cm
T, g	33.98	HT, in	2.225	5.65	cm
		AREA		41.80	cm^2
MOIST-		DENSITY:	125.7	PCF WET	
URE, %	**23.4**	DENSITY:	**101.8**	PCF DRY	

ADDITIONAL DATA

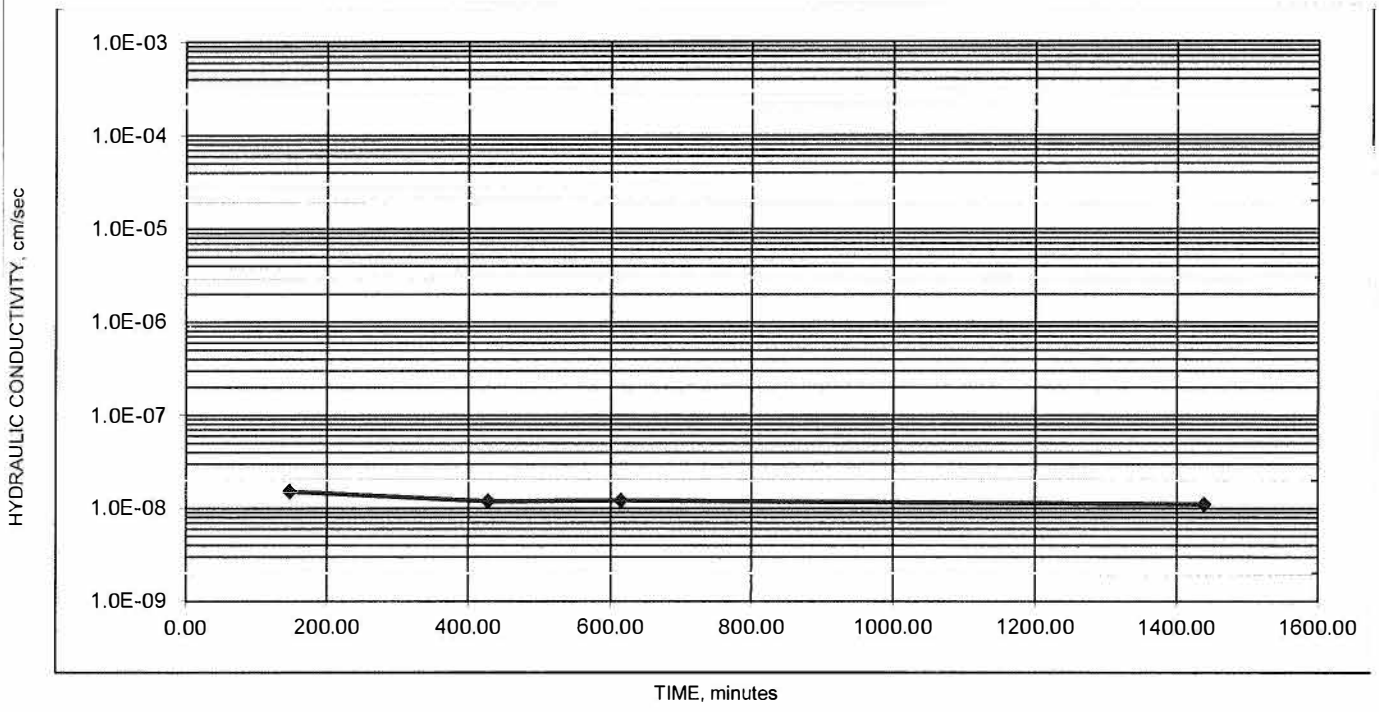
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	39.6	OPTIMUM, %:	NA
SATURATION, %:	96.6	COMPACTION, %:	NA
VOID RATIO:	0.66	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
8.8	67.6	0.00	58.8									
9.0	67.4	147.00	58.4	0.006826	1.52E-08	0.06	0.06	1.00	10.3	21	23.0	0.931
9.3	67.1	428.00	57.8	0.010327	1.20E-08	0.09	0.09	1.00	10.2	5	23.3	0.925
9.5	66.9	614.00	57.4	0.006944	1.22E-08	0.06	0.06	1.00	10.2	3	23.2	0.927
10.3	66.1	1439.00	55.8	0.028270	1.11E-08	0.25	0.25	1.00	9.9	12	23.6	0.918

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 1.3E-08 cm/sec

MAXIMUM	1.0E-03 TO	1.0E-04	2	0.75<	30 % < 25 AT
HYDRAULIC	1.0E-04 TO	1.0E-05	5	RATIO	MAX > 1.0E-8
GRADIENT	1.0E-05 TO	1.0E-06	10	<1.25	HYDRAULIC OR
	1.0E-06 TO	1.0E-07	20		GRADIENT % < 50 AT
	less than	1.0E-07	30		ALLOWED < 1.0E-8



MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	7/30/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B002 S4 8.5 - 10.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	LEAN CLAY WITH SAND, GRAY WITH YELLOWISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	143.03	WET WT, g	495.1		
D & T, g	126.58	DIA, in	2.861	7.27	cm
T, g	33.92	HT, in	2.182	5.54	cm
		AREA		41.48	cm^2
MOIST-		DENSITY:	134.5	PCF WET	
URE, %	**17.8**	DENSITY:	**114.2**	PCF DRY	

ADDITIONAL DATA

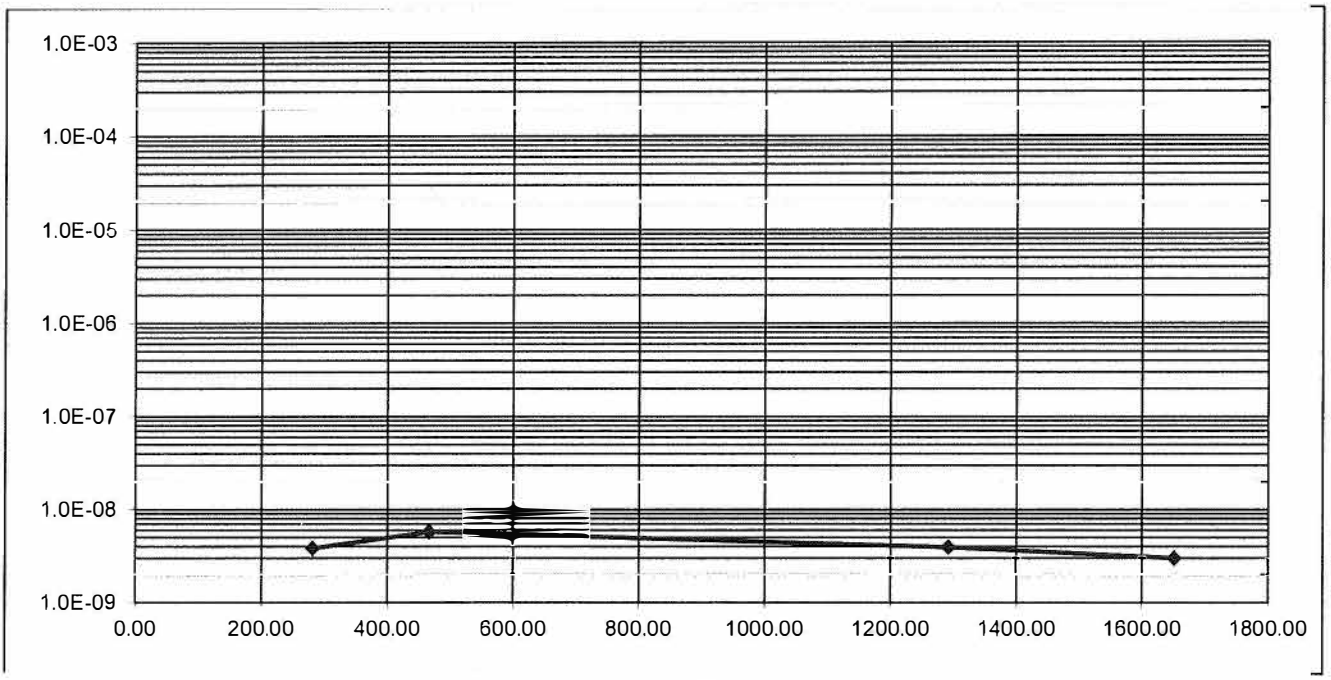
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	32.3	OPTIMUM, %:	NA
SATURATION, %:	100.7	COMPACTION, %:	NA
VOID RATIO:	0.48	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
7.4	67.7	0.00	60.3									
7.5	67.6	281.00	60.1	0.003322	3.83E-09	0.03	0.03	1.00	10.8	7	23.0	0.931
7.6	67.5	467.00	59.9	0.003333	5.76E-09	0.03	0.03	1.00	10.8	39	23.3	0.925
7.9	67.2	1292.00	59.3	0.010067	3.93E-09	0.09	0.09	1.00	10.7	5	23.2	0.927
8.0	67.1	1651.00	59.1	0.003378	3.01E-09	0.03	0.03	1.00	10.7	27	23.6	0.918

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 4.1E-09 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	30	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/9/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B003 S9 30.0 - 30.0 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SILTY SAND, DARK YELLOWISH BROWN WITH GRAYISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	170.46	WET WT, g	482.1		
D & T, g	155.96	DIA, in	2.858	7.26	cm
T, g	32.90	HT, in	2.022	5.14	cm
		AREA		41.39	cm^2
MOIST-		DENSITY:	141.6	PCF WET	
URE, %	**11.8**	DENSITY:	**126.7**	PCF DRY	

ADDITIONAL DATA

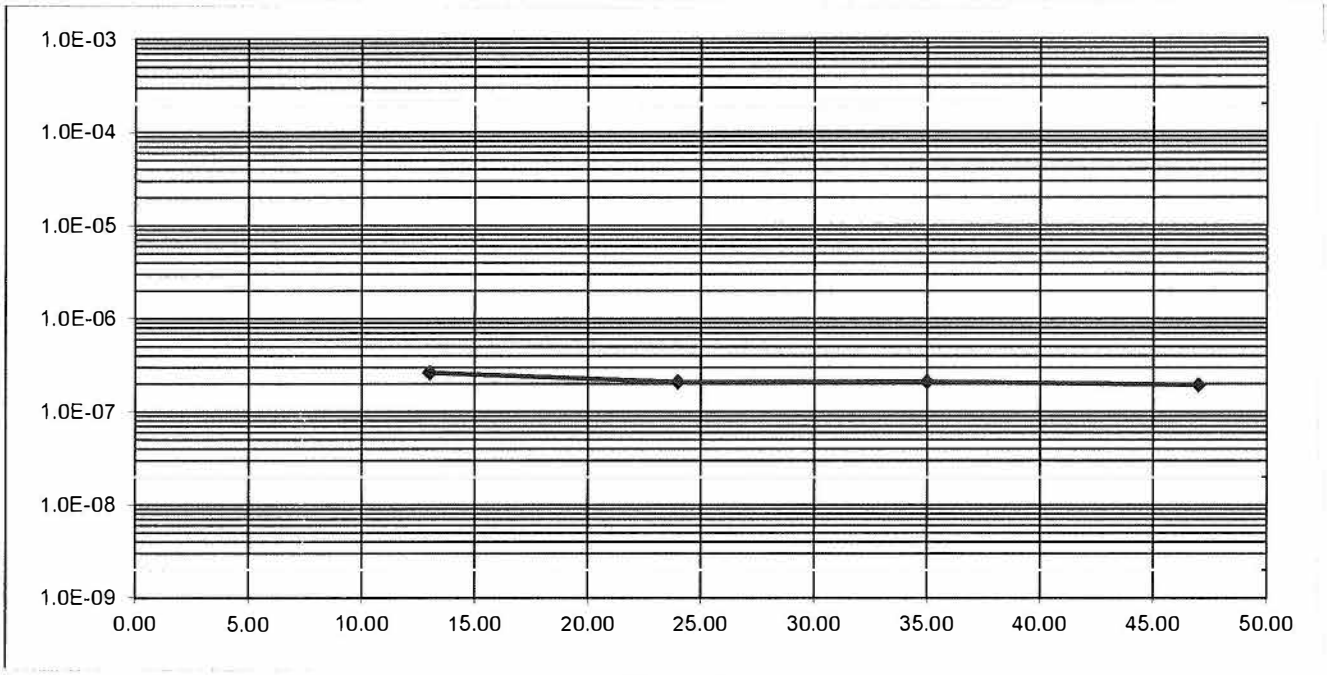
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	24.9	OPTIMUM, %:	NA
SATURATION, %:	96.2	COMPACTION, %:	NA
VOID RATIO:	0.33	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
11.8	64.6	0.00	52.8									
12.1	64.3	13.00	52.2	0.011429	2.63E-07	0.09	0.09	1.00	10.2	20	23.3	0.925
12.3	64.1	24.00	51.8	0.007692	2.09E-07	0.06	0.06	1.00	10.1	5	23.3	0.925
12.5	63.9	35.00	51.4	0.007752	2.10E-07	0.06	0.06	1.00	10.0	4	23.3	0.925
12.7	63.7	47.00	51.0	0.007813	1.94E-07	0.06	0.06	1.00	9.9	11	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 2.2E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	20	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/4/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B004 S7 23.5.0 - 25.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY FAT CLAY, REDDISH BROWN WITH DARK GRAY	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	140.98	WET WT, g	438.0		
D & T, g	122.69	DIA, in	2.857	7.26	cm
T, g	33.88	HT, in	2.010	5.11	cm
		AREA		41.36	cm^2
MOIST-		DENSITY:	129.5	PCF WET	
URE, %	**20.6**	DENSITY:	**107.4**	PCF DRY	

ADDITIONAL DATA

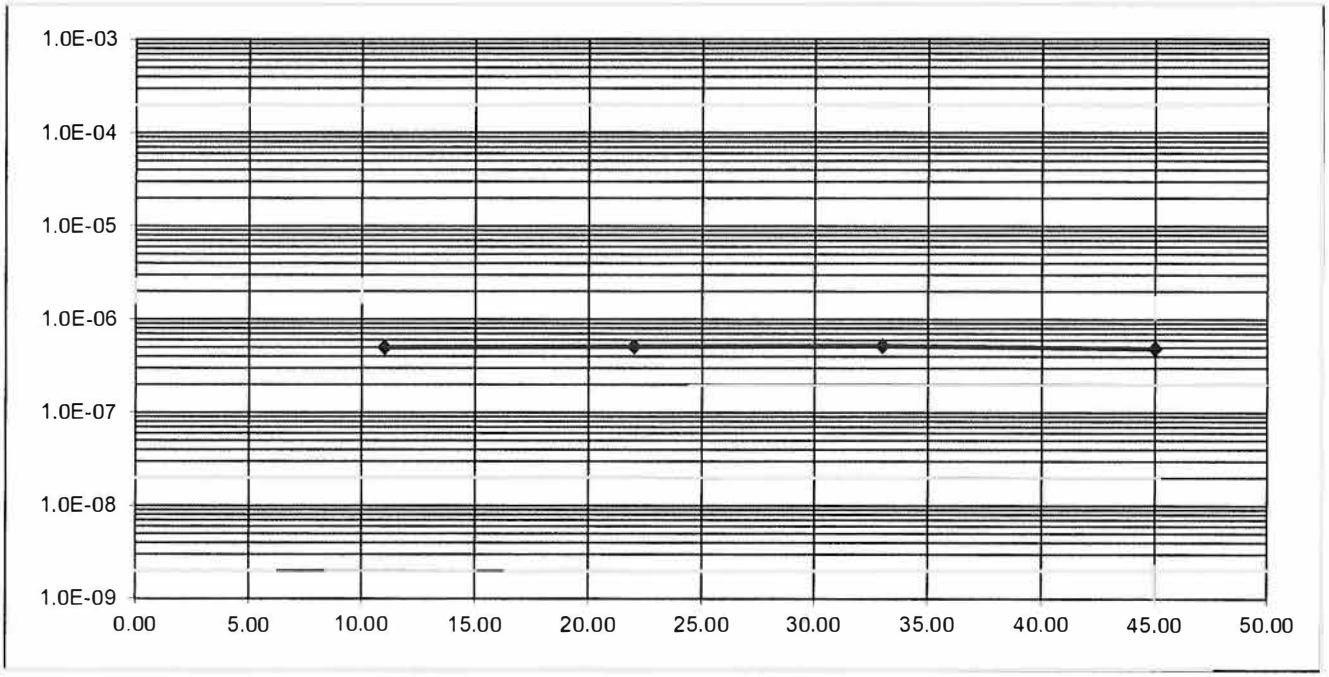
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	36.3	OPTIMUM, %:	NA
SATURATION, %:	97.6	COMPACTION, %:	NA
VOID RATIO:	0.57	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
15.6	59.2	0.00	43.6									
16.0	58.8	11.00	42.8	0.018519	5.00E-07	0.12	0.12	1.00	8.4	1	23.3	0.925
16.4	58.4	22.00	42.0	0.018868	5.10E-07	0.12	0.12	1.00	8.2	1	23.3	0.925
16.8	58.0	33.00	41.2	0.019231	5.19E-07	0.12	0.12	1.00	8.1	3	23.3	0.925
17.2	57.6	45.00	40.4	0.019608	4.85E-07	0.12	0.12	1.00	7.9	4	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 5.0E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	20	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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Terracon

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/4/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B005 S2 3.5 - 5.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY LEAN CLAY, BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	177.91	WET WT, g	409.4		
D & T, g	167.15	DIA, in	2.882	7.32	cm
T, g	33.00	HT, in	1.750	4.45	cm
		AREA		42.09	cm^2
MOIST-		DENSITY:	136.6	PCF WET	
URE, %	8.0	DENSITY:	126.5	PCF DRY	

ADDITIONAL DATA

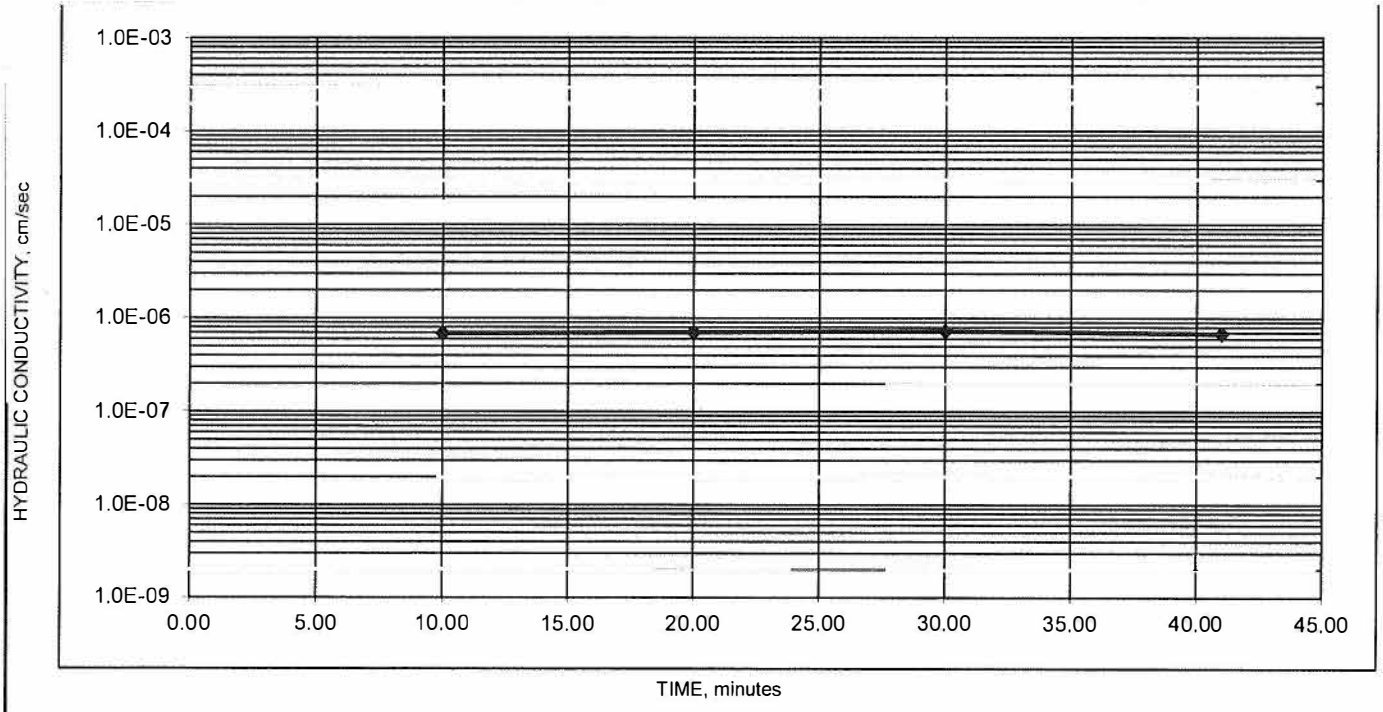
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	25.0	OPTIMUM, %:	NA
SATURATION, %:	65.1	COMPACTION, %:	NA
VOID RATIO:	0.33	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
18.5	55.8	0.00	37.3									
19.0	55.3	10.00	36.3	0.027176	6.88E-07	0.16	0.16	1.00	8.2	2	23.5	0.920
19.5	54.8	20.00	35.3	0.027935	7.07E-07	0.16	0.16	1.00	7.9	1	23.5	0.920
20.0	54.3	30.00	34.3	0.028738	7.29E-07	0.16	0.16	1.00	7.7	4	23.4	0.923
20.5	53.8	41.00	33.3	0.029588	6.82E-07	0.16	0.16	1.00	7.5	3	23.4	0.923

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 7.0E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	20	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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Terracon

MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	7/30/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B007 S8 22.0 - 24.0 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY LEAN CLAY, YELLOWISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	142.44	WET WT, g	432.7		
D & T, g	125.52	DIA, in	2.863	7.27	cm
T, g	33.26	HT, in	1.992	5.06	cm
		AREA		41.53	cm^2
MOIST-		DENSITY:	128.5	PCF WET	
URE, %	18.3	DENSITY:	108.6	PCF DRY	

ADDITIONAL DATA

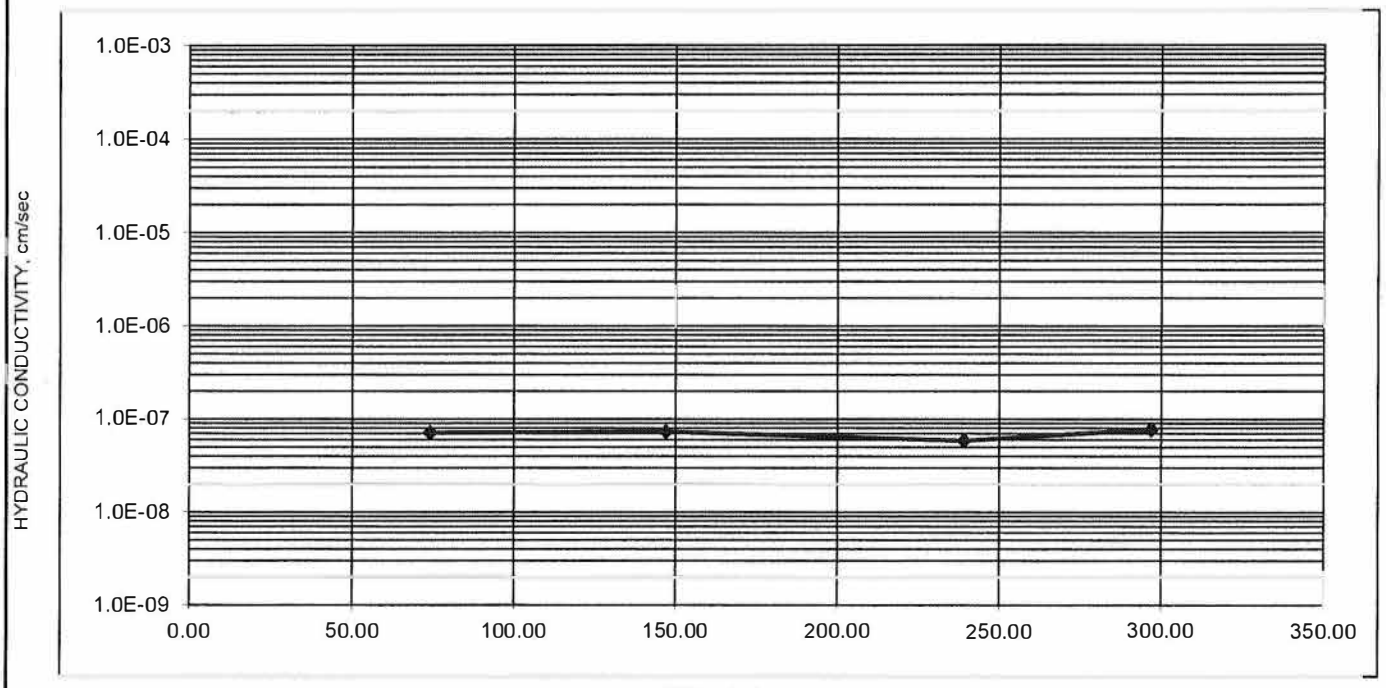
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	35.6	OPTIMUM, %:	NA
SATURATION, %:	89.7	COMPACTION, %:	NA
VOID RATIO:	0.55	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
9.2	64.7	0.00	55.5									
9.7	64.2	74.00	54.5	0.018182	7.14E-08	0.16	0.16	1.00	10.8	2	23.7	0.916
10.2	63.7	147.00	53.5	0.018519	7.32E-08	0.16	0.16	1.00	10.6	4	24.0	0.910
10.7	63.2	239.00	52.5	0.018868	5.88E-08	0.16	0.16	1.00	10.4	16	24.3	0.904
11.1	62.8	297.00	51.7	0.015355	7.76E-08	0.12	0.12	1.00	10.2	11	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = **AVERAGE 7.0E-08 cm/sec**

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	30	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/4/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B004 S7 23.5.0 - 25.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY FAT CLAY, REDDISH BROWN WITH DARK GRAY	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	140.98	WET WT, g	438.0		
D & T, g	122.69	DIA, in	2.857	7.26	cm
T, g	33.88	HT, in	2.010	5.11	cm
		AREA		41.36	cm^2
MOIST-		DENSITY:	129.5	PCF WET	
URE, %	**20.6**	DENSITY:	**107.4**	PCF DRY	

ADDITIONAL DATA

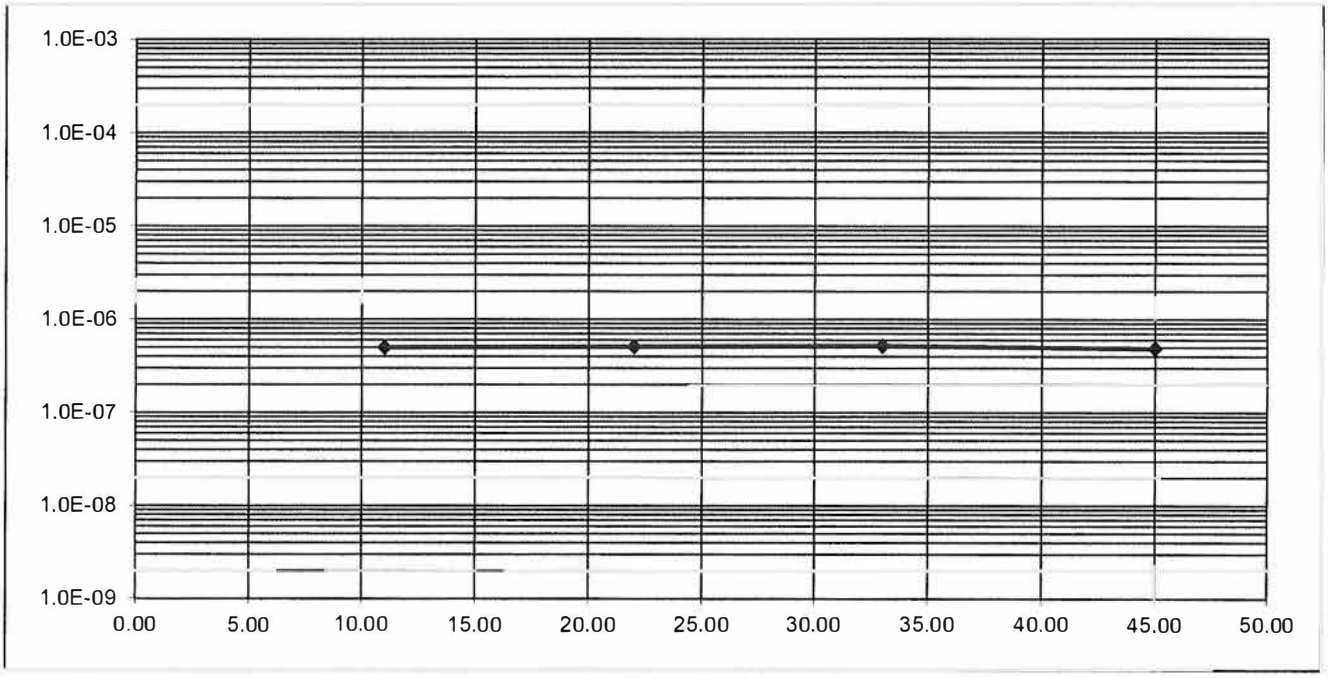
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	36.3	OPTIMUM, %:	NA
SATURATION, %:	97.6	COMPACTION, %:	NA
VOID RATIO:	0.57	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
15.6	59.2	0.00	43.6									
16.0	58.8	11.00	42.8	0.018519	5.00E-07	0.12	0.12	1.00	8.4	1	23.3	0.925
16.4	58.4	22.00	42.0	0.018868	5.10E-07	0.12	0.12	1.00	8.2	1	23.3	0.925
16.8	58.0	33.00	41.2	0.019231	5.19E-07	0.12	0.12	1.00	8.1	3	23.3	0.925
17.2	57.6	45.00	40.4	0.019608	4.85E-07	0.12	0.12	1.00	7.9	4	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 5.0E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	20	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/4/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B005 S2 3.5 - 5.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY LEAN CLAY, BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	177.91	WET WT, g	409.4		
D & T, g	167.15	DIA, in	2.882	7.32	cm
T, g	33.00	HT, in	1.750	4.45	cm
		AREA		42.09	cm^2
MOIST-		DENSITY:	136.6	PCF WET	
URE, %	**8.0**	DENSITY:	**126.5**	PCF DRY	

ADDITIONAL DATA

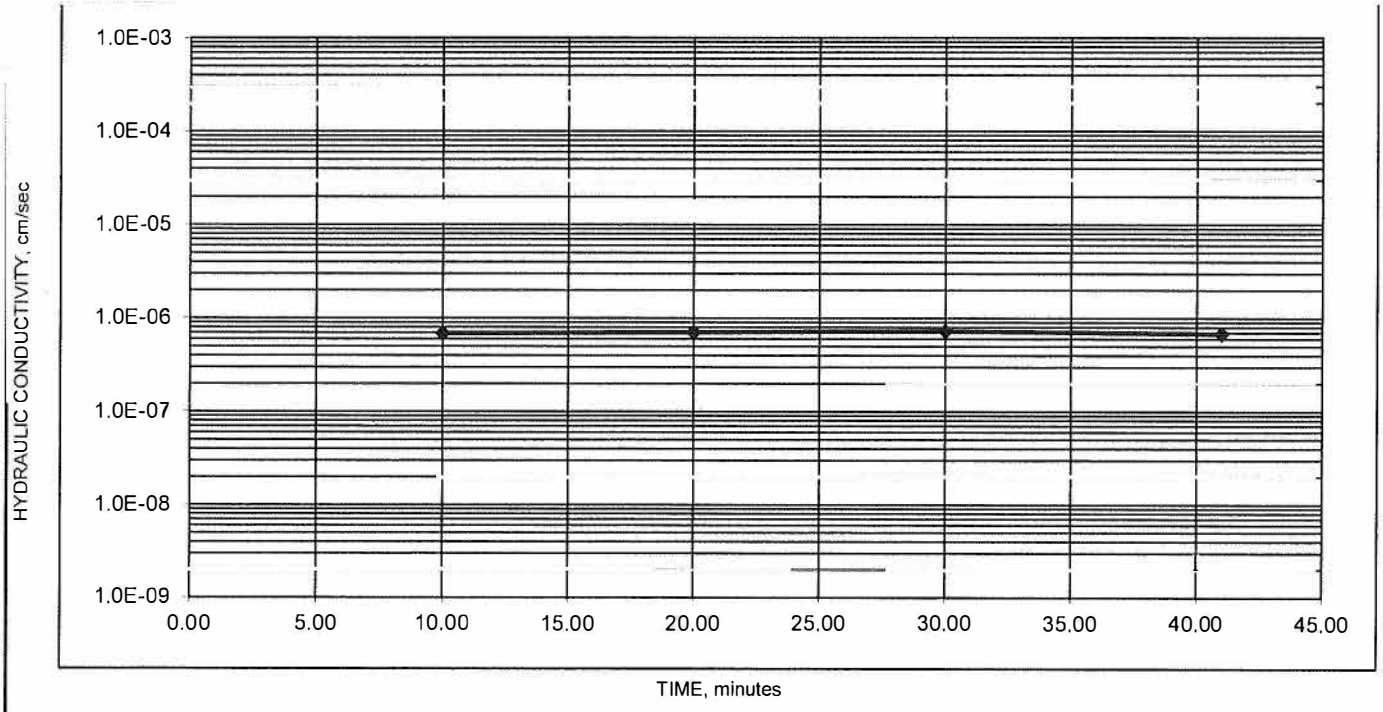
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	25.0	OPTIMUM, %:	NA
SATURATION, %:	65.1	COMPACTION, %:	NA
VOID RATIO:	0.33	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
18.5	55.8	0.00	37.3									
19.0	55.3	10.00	36.3	0.027176	6.88E-07	0.16	0.16	1.00	8.2	2	23.5	0.920
19.5	54.8	20.00	35.3	0.027935	7.07E-07	0.16	0.16	1.00	7.9	1	23.5	0.920
20.0	54.3	30.00	34.3	0.028738	7.29E-07	0.16	0.16	1.00	7.7	4	23.4	0.923
20.5	53.8	41.00	33.3	0.029588	6.82E-07	0.16	0.16	1.00	7.5	3	23.4	0.923

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 7.0E-07 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	20	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	7/30/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B007 S8 22.0 - 24.0 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY LEAN CLAY, YELLOWISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	142.44	WET WT, g	432.7		
D & T, g	125.52	DIA, in	2.863	7.27	cm
T, g	33.26	HT, in	1.992	5.06	cm
		AREA		41.53	cm^2
MOIST-		DENSITY:	128.5	PCF WET	
URE, %	18.3	DENSITY:	108.6	PCF DRY	

ADDITIONAL DATA

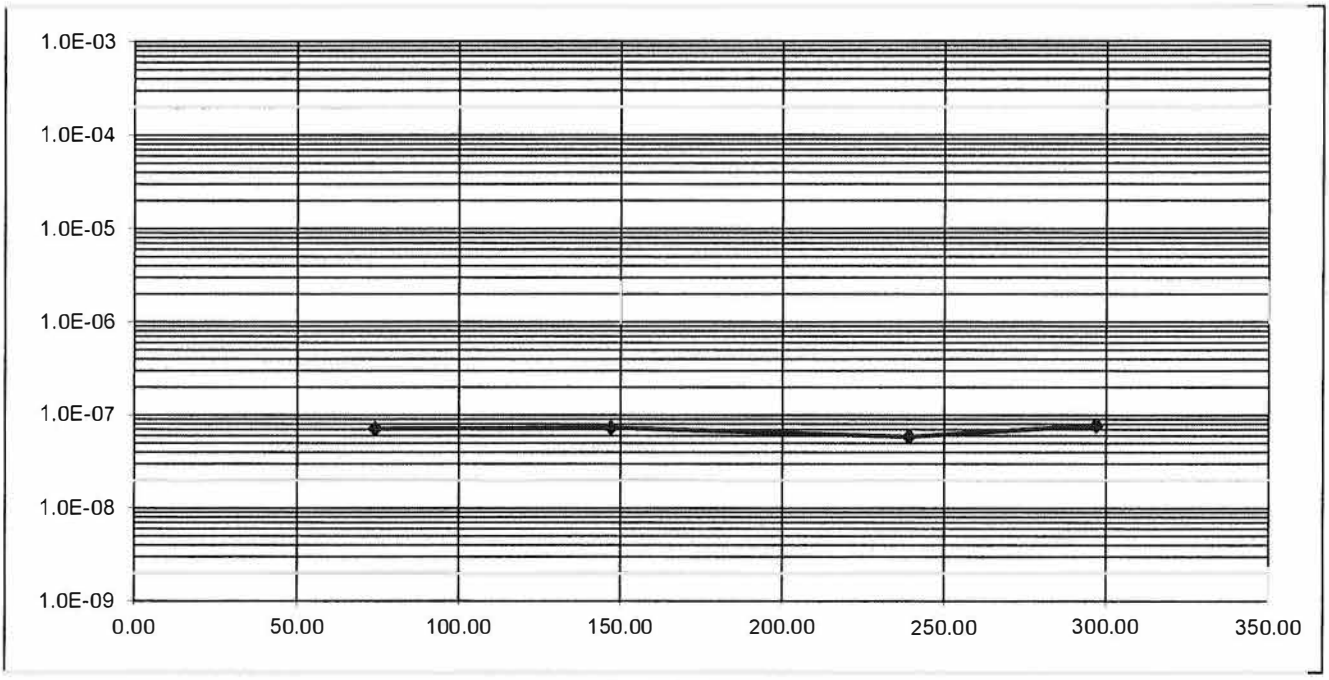
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	35.6	OPTIMUM, %:	NA
SATURATION, %:	89.7	COMPACTION, %:	NA
VOID RATIO:	0.55	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
9.2	64.7	0.00	55.5									
9.7	64.2	74.00	54.5	0.018182	7.14E-08	0.16	0.16	1.00	10.8	2	23.7	0.916
10.2	63.7	147.00	53.5	0.018519	7.32E-08	0.16	0.16	1.00	10.6	4	24.0	0.910
10.7	63.2	239.00	52.5	0.018868	5.88E-08	0.16	0.16	1.00	10.4	16	24.3	0.904
11.1	62.8	297.00	51.7	0.015355	7.76E-08	0.12	0.12	1.00	10.2	11	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = **AVERAGE 7.0E-08 cm/sec**

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	30	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/10/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B008 S5 11.0 - 13.0 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	LEAN CLAY WITH SAND, DARK GRAY WITH GRAY TRACE GRAYISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	125.65	WET WT, g	468.5		
D & T, g	112.54	DIA, in	2.865	7.28	cm
T, g	33.72	HT, in	2.105	5.35	cm
		AREA		41.59	cm^2
MOIST-		DENSITY:	131.5	PCF WET	
URE, %	**16.6**	DENSITY:	**112.8**	PCF DRY	

ADDITIONAL DATA

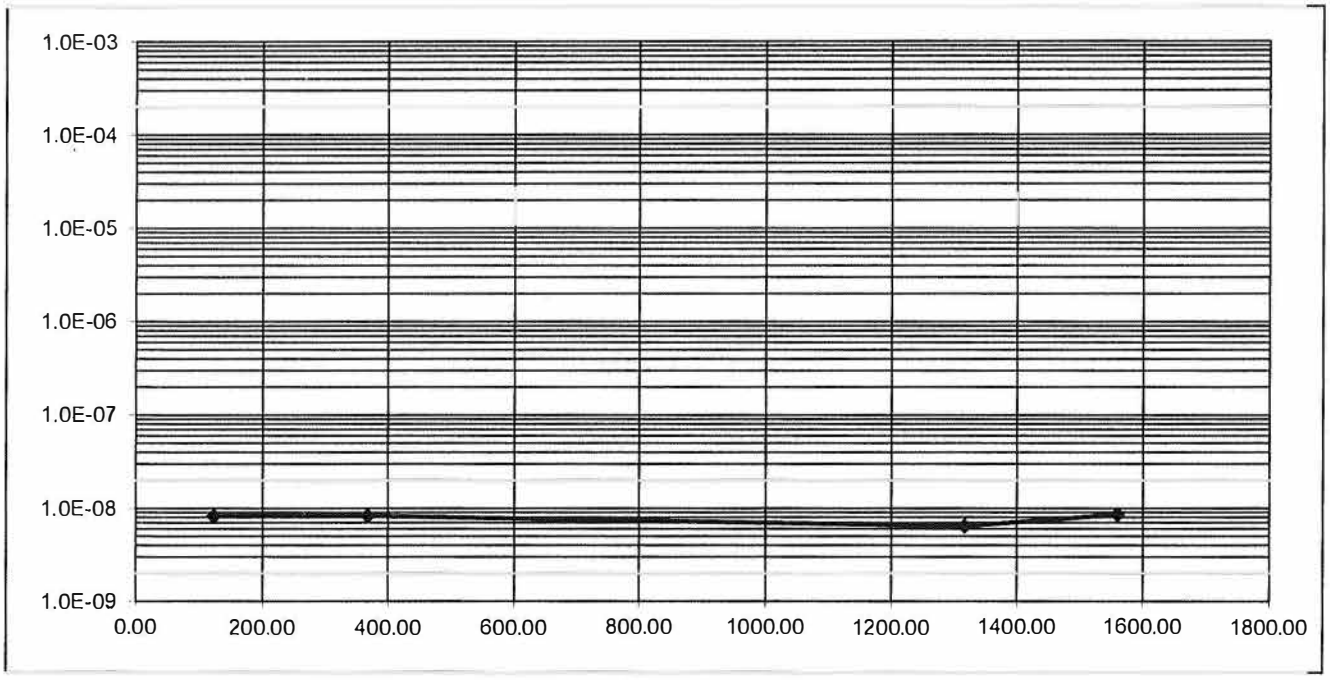
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	33.1	OPTIMUM, %:	NA
SATURATION, %:	90.8	COMPACTION, %:	NA
VOID RATIO:	0.49	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1: 100.0	psi
				BIAS PRESSURE (=H1-H2)	0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k, cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP., C	TEMP. CORR.:
7.4	69.0	0.00	61.6									
7.5	68.9	123.00	61.4	0.003252	8.22E-09	0.03	0.03	1.00	11.5	4	23.1	0.929
7.7	68.7	368.00	61.0	0.006536	8.29E-09	0.06	0.06	1.00	11.4	5	23.1	0.929
8.3	68.1	1317.00	59.8	0.019868	6.43E-09	0.19	0.19	1.00	11.2	18	23.6	0.918
8.5	67.9	1560.00	59.4	0.006711	8.55E-09	0.06	0.06	1.00	11.1	9	23.3	0.925

HYDRAULIC CONDUCTIVITY (k_{20}) = AVERAGE 7.9E-09 cm/sec

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	30	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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MEASUREMENT OF HYDRAULIC CONDUCTIVITY OF SATURATED POROUS MATERIALS
USING A FLEXIBLE WALL PERMEAMETER
ASTM D 5084 - 03 METHOD C TEST WITH INCREASING TAILWATER LEVEL
FLUID: DEAIRED TAP WATER WITH 0.005 N CaSO4

PROJECT NAME:	DYNEGY	PROJECT NUMBER:	15151122
LOCATION:	COFFEEN, ILLINOIS	DATE:	9/4/2015
		PANEL IDENTIFICATION:	Lenexa Perm Board
SAMPLE ID:	COF-B011 S6 13.5 - 15.5 feet	BURETTE AREA:	0.312 cm^2
SAMPLE DESCR.:	SANDY LEAN CLAY, YELLOWISH BROWN WITH GRAYISH BROWN	BURETTE INCREMENT LENGTH:	1.000 cm
		VOLUME PER INCREMENT:	0.312 cm^3

INITIAL

MOISTURE%		DENSITY			
W & T, g	151.23	WET WT, g	464.3		
D & T, g	139.17	DIA, in	2.861	7.27	cm
T, g	33.87	HT, in	1.975	5.02	cm
		AREA		41.48	cm^2
MOIST-		DENSITY:	139.3	PCF WET	
URE, %	**11.5**	DENSITY:	**125.0**	PCF DRY	

ADDITIONAL DATA

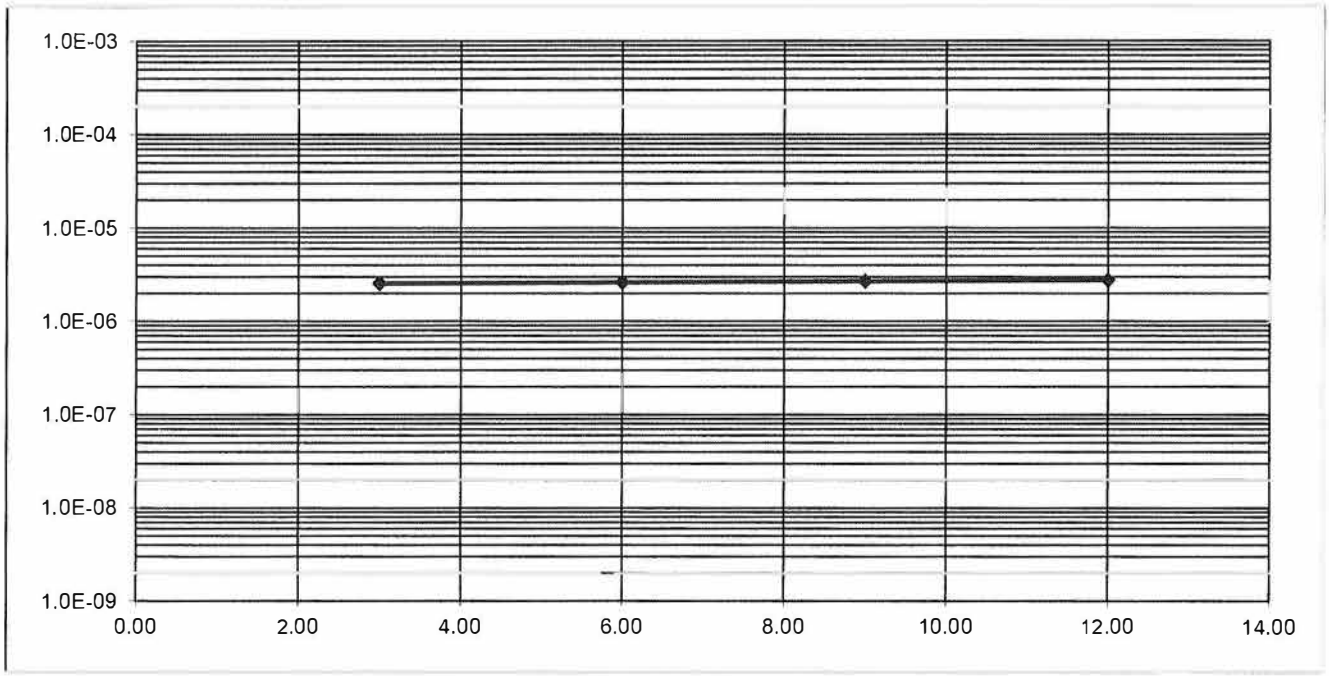
SPECIFIC GRAVITY:	2.70	RECOMPACTED?:	NO
SPECIFIC GRAVITY:	ASSUMED	PROCTOR, pcf:	NA
POROSITY, %:	25.8	OPTIMUM, %:	NA
SATURATION, %:	88.7	COMPACTION, %:	NA
VOID RATIO:	0.35	OVER OPTIMUM, %:	NA

SATURATION:	LATERAL PRESS.:	104.0	psi	BACK PRESSURE (=UPPER=LOWER):	100.0	psi	
DURING TEST:	LATERAL PRESS.:	104.0	psi	H2: 100.0 psi	H1:	100.0	psi
				BIAS PRESSURE (=H1-H2)		0.0	psi

H1 VALUE	H2 VALUE	ELAPSED TIME, min	DELTA H cm	Ln H1/H2	HYD CON k_t cm/sec	OUT FLOW cm^3	IN FLOW cm^3	OUT/IN RATIO	HYD GRAD	% FROM MEAN k	TEMP.: C	TEMP. CORR.:
8.5	23.9	0.00	15.4									
8.7	23.7	3.00	15.0	0.026317	2.55E-06	0.06	0.06	1.00	3.0	4	23.4	0.923
8.9	23.5	6.00	14.6	0.027029	2.62E-06	0.06	0.06	1.00	2.9	1	23.4	0.923
9.1	23.3	9.00	14.2	0.027780	2.69E-06	0.06	0.06	1.00	2.8	1	23.4	0.923
9.3	23.1	12.00	13.8	0.028573	2.77E-06	0.06	0.06	1.00	2.8	4	23.4	0.923

HYDRAULIC CONDUCTIVITY (k_{20}) = **AVERAGE 2.7E-06 cm/sec**

MAXIMUM	1.0E-03 TO 1.0E-04	2	0.75<	10	% < 25 AT
HYDRAULIC	1.0E-04 TO 1.0E-05	5	RATIO	MAX	> 1.0E-8
GRADIENT	1.0E-05 TO 1.0E-06	10	<1.25	HYDRAULIC	OR
	1.0E-06 TO 1.0E-07	20		GRADIENT	% < 50 AT
	less than 1.0E-07	30		ALLOWED	< 1.0E-8



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HANSON 2016 LABORATORY RESULTS

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	16E0080	TEST DATE:	08/23/2016
CLIENT:	Natural Resource Technology, Inc.	BORING #:	G405D
JOB DESCRIPTION:	Coffeen Ash Pond 2	SAMPLE #:	11-2
SAMPLE DESCRIPTION:	Gray silty CLAY, trace coarse sand and small gravel.	DEPTH (FT):	34.5-35.0

FOR ESTIMATING PORE VOLUME ONLY

				WATER CONTENT OF TRIMMINGS	
				BEFORE TEST	AFTER TEST
SPECIMEN WEIGHT (G)	868.38				
SPECIMEN HEIGHT (IN)	3.748		TARE + WET SOIL (G)	280.51	924.55
DIAMETER (IN)	2.861		TARE + DRY SOIL (G)	245.00	806.34
AREA (SQ IN)	6.429		TARE (G)	3.75	50.12
VOLUME (CU IN)	24.095		WET SOIL(G)	n/a	874.43
WET DENSITY (PCF)	137.30		WATER (G)	35.51	118.21
DRY DENSITY (PCF)	119.68	*	DRY SOIL (G)	241.25	756.22
WT. DRY SOIL (G)	756.96	*	WATER CONTENT (%)	14.72	15.63
WT. DRY SOIL (G)	756.22		INITIAL DEGREE OF SATURATION	102.03	
VOLUME DRY SOIL (CU IN)	17.431	*	FINAL DEGREE OF SATURATION	107.98	
SP.GR. ASSUMED	2.65				
POROSITY (%)	27.66	*	STD. MAX. DEN.(LBS/CU.FT.)	N/A	
HEIGHT OF HEAD (PSI)	4.00		OPTIMUM MOISTURE (%)	N/A	
HYDRAULIC GRADIANT	29.5	*	% COMPACTION	N/A	
PRESSURE HEAD (CM H2O)	281.27		SAMPLE PREPARATION	Tube	
			PANEL NUMBER	5	

TEST METHOD USED: ASTM D5084 PERMEANT USED: Tap Water

* **Estimates Only**

Remarks:

R001616

HANSON.
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Dynegy
JOB DESCRIPTION: Coffeen Ash Pond 2

TEST DATE: 8/25/2016
BORING #: G405D
SAMPLE #: 11-2
DEPTH (FT): 34.5-35.0

SPECIMEN HEIGHT (IN) 3.748
DIAMETER (IN) 2.861
AREA (SQ IN) 6.429
INITIAL DEGREE OF SATURATION 102.03

HEIGHT OF HEAD (PSI) 4.00
PRESSURE HEAD (CM H2O) 281.27
PANEL NUMBER 5

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for $k < 1 \times 10^{-8}$ cm/sec.

START DATE	START TIME	STOP DATE	STOP TIME	INC. INFLOW (CC)	INC. OUTFLOW (CC)	TEMP. (°C)	AVG, INC. FLOW (CC)	OUTFLOW INFLOW (RATIO) *	INC. TIME (MIN)	TOTAL TIME (MIN)	INC. PERM. (CM/SEC)	AVG. PERM. (CM/SEC)	INC. MEAN RATIO **
08/25/2016	9:21:00	08/25/2016	15:24:00	9.50	10.6	23.4	10.0500	1.116	363.	363.	3.47E-07	3.47E-07	1.000
08/25/2016	15:30:00	08/26/2016	8:19:00	9.10	9.0	24.4	9.0500	0.989	1009.	1372.	1.10E-07	2.29E-07	0.481
08/26/2016	8:19:00	08/26/2016	13:58:00	3.00	3.0	23.4	3.0000	1.000	339.	1711.	1.11E-07	1.89E-07	0.586
08/29/2016	8:01:00	08/29/2016	16:19:00	10.90	10.5	23.4	10.7000	0.963	498.	2209.	2.70E-07	2.09E-07	1.287
8/29/2016	16:22:00	08/30/2016	7:51:00	18.80	18.7	24.2	18.7500	0.995	929.	3138.	2.49E-07	1.85E-07	1.345
08/30/2016	7:53:00	08/31/2016	8:19:00	21.70	21.8	24.2	21.7500	1.005	1466.	4604.	1.83E-07	2.03E-07	0.900
08/31/2016	8:22:00	09/01/2016	8:05:00	15.20	15.2	23.8	15.2000	1.000	1423.	6027.	1.33E-07	2.08E-07	0.637
09/01/2016	8:07:00	09/02/2016	8:02:00	13.60	13.7	23.8	13.6500	1.007	1435.	7462.	1.18E-07	1.71E-07	0.693
09/02/2016	8:02:00	09/02/2016	14:59:00	3.10	3.0	23.4	3.0500	0.968	417.	7879.	9.18E-08	1.31E-07	0.698
09/06/2016	8:14:00	09/07/2016	8:19:00	13.20	13.3	24.4	13.2500	1.008	1445.	9324.	1.12E-07	1.14E-07	0.988
09/07/2016	8:24:00	09/08/2016	7:56:00	10.20	10.2	24.4	10.2000	1.000	1412.	10736.	8.86E-08	1.03E-07	0.862
09/08/2016	7:56:00	09/09/2016	8:18:00	6.30	6.4	24.2	6.3500	1.016	1462.	12198.	5.35E-08	8.66E-08	0.618
09/09/2016	8:18:00	09/09/2016	14:26:00	1.40	1.2	23.6	1.3000	0.857	368.	12566.	4.41E-08	7.47E-08	0.591
09/12/2016	8:37:00	09/13/2016	8:10:00	7.40	7.4	23.6	7.4000	1.000	1413.	13979.	6.54E-08	6.29E-08	1.040
09/14/2016	8:52:00	09/15/2016	8:10:00	1.50	2.7	24.2	2.1000	1.800	1398.	15377.	1.85E-08	4.54E-08	0.408
09/15/2016	16:00:00	09/16/2016	8:12:00	0.50	0.8	24.2	0.6500	1.600	972.	16349.	8.24E-09	3.41E-08	0.242

R001617

HANSON.
Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Dynegy
JOB DESCRIPTION: Coffeen Ash Pond 2

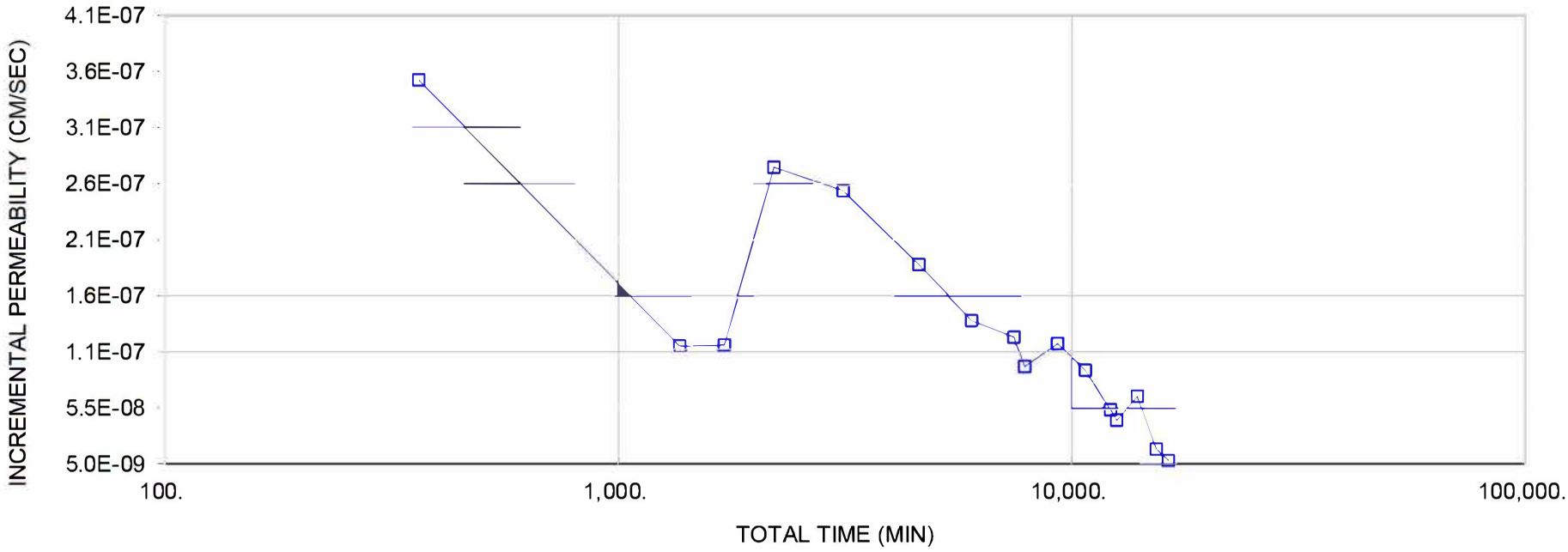
TEST DATE: 8/25/2016
BORING #: G405D
SAMPLE #: 11-2
DEPTH (FT): 34.5-35.0

SPECIMEN HEIGHT (IN) 3.748
DIAMETER (IN) 2.861
AREA (SQ IN) 6.429
INITIAL DEGREE OF SATURATION 102.03

HEIGHT OF HEAD (PSI) 4.00
PRESSURE HEAD (CM H2O) 281.27
PANEL NUMBER 5

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for k < 1 x 10^{-8} cm/sec.



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	16E0080	TEST DATE:	08/23/2016
CLIENT:	Natural Resource Technology, Inc.	BORING #:	G406D
JOB DESCRIPTION:	Coffeen Ash Pond 2	SAMPLE #:	23-3
SAMPLE DESCRIPTION:	Gray silty CLAY, trace coarse sand and small gravel	DEPTH (FT):	43.0-43.5

FOR ESTIMATING PORE VOLUME ONLY

SPECIMEN WEIGHT (G)	827.45		
SPECIMEN HEIGHT (IN)	3.592		
DIAMETER (IN)	2.861		
AREA (SQ IN)	6.429		
VOLUME (CU IN)	23.092		
WET DENSITY (PCF)	136.51		
DRY DENSITY (PCF)	117.59 *		
WT. DRY SOIL (G)	712.77 *		
WT. DRY SOIL (G)	713.55		
VOLUME DRY SOIL (CU IN)	16.414 *		
SP.GR. ASSUMED	2.65		
POROSITY (%)	28.92 *		
HEIGHT OF HEAD (PSI)	3.80		
HYDRAULIC GRADIANT	29.3 *		
PRESSURE HEAD (CM H2O)	267.21		

WATER CONTENT OF TRIMMINGS

	BEFORE TEST	AFTER TEST
TARE + WET SOIL (G)	333.17	880.57
TARE + DRY SOIL (G)	287.51	763.54
TARE (G)	3.71	49.99
WET SOIL(G)	329.46	830.58
WATER (G)	45.66	117.03
DRY SOIL (G)	283.80	713.55
WATER CONTENT (%)	16.09	16.40

INITIAL DEGREE OF SATURATION	104.79
FINAL DEGREE OF SATURATION	107.22
STD. MAX. DEN.(LBS/CU.FT.)	N/A
OPTIMUM MOISTURE (%)	N/A
% COMPACTION	N/A
SAMPLE PREPARATION	Tube
PANEL NUMBER	6

TEST METHOD USED: ASTM D5084

PERMEANT USED: Tap Water

* **Estimates Only**

Remarks:

R001619

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Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

TEST DATE: 8/23/2016
BORING #: G406D
SAMPLE #: 23-3
DEPTH (FT): 43.0-43.5

SPECIMEN HEIGHT (IN) 3.592
DIAMETER (IN) 2.861
AREA (SQ IN) 6.429
INITIAL DEGREE OF SATURATION 104.79

HEIGHT OF HEAD (PSI) 3.80
PRESSURE HEAD (CM H2O) 267.21
PANEL NUMBER 6

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for $k < 1 \times 10^{-8}$ cm/sec.

START DATE	START TIME	STOP DATE	STOP TIME	INC. INFLOW (CC)	INC. OUTFLOW (CC)	TEMP. (°C)	AVG, INC. FLOW (CC)	OUTFLOW INFLOW (RATIO) *	INC. TIME (MIN)	TOTAL TIME (MIN)	INC. PERM. (CM/SEC)	AVG. PERM. (CM/SEC)	INC. MEAN RATIO **
08/25/2016	9:27:00	08/25/2016	15:25:00	3.20	5.4	23.4	4.3000	1.688	358.	358.	1.52E-07	1.52E-07	1.000
08/25/2016	16:18:00	08/26/2016	8:20:00	3.90	2.1	24.2	3.0000	0.538	962.	1320.	3.88E-08	9.54E-08	0.406
08/26/2016	8:20:00	08/26/2016	14:00:00	1.10	1.0	23.4	1.0500	0.909	340.	1660.	3.91E-08	7.66E-08	0.510
08/29/2016	8:03:00	08/29/2016	16:22:00	1.30	1.0	23.4	1.1500	0.769	499.	2159.	2.92E-08	6.48E-08	0.450
08/29/2016	16:22:00	08/30/2016	7:54:00	1.90	1.9	24.2	1.9000	1.000	932.	3091.	2.53E-08	3.31E-08	0.766
08/30/2016	7:54:00	08/31/2016	8:22:00	2.60	2.7	24.2	2.6500	1.038	1468.	4559.	2.24E-08	2.90E-08	0.773
08/31/2016	8:22:00	09/01/2016	8:08:00	2.40	2.3	23.8	2.3500	0.958	1426.	5985.	2.07E-08	2.44E-08	0.847
09/01/2016	8:08:00	09/02/2016	8:04:00	2.10	2.1	23.8	2.1000	1.000	1436.	7421.	1.83E-08	2.17E-08	0.845
09/02/2016	8:04:00	09/02/2016	15:00:00	0.60	0.5	23.4	0.5500	0.833	416.	7837.	1.67E-08	1.95E-08	0.856
09/06/2016	8:16:00	09/07/2016	8:25:00	2.00	2.0	24.6	2.0000	1.000	1449.	9286.	1.70E-08	1.82E-08	0.935

R001620

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

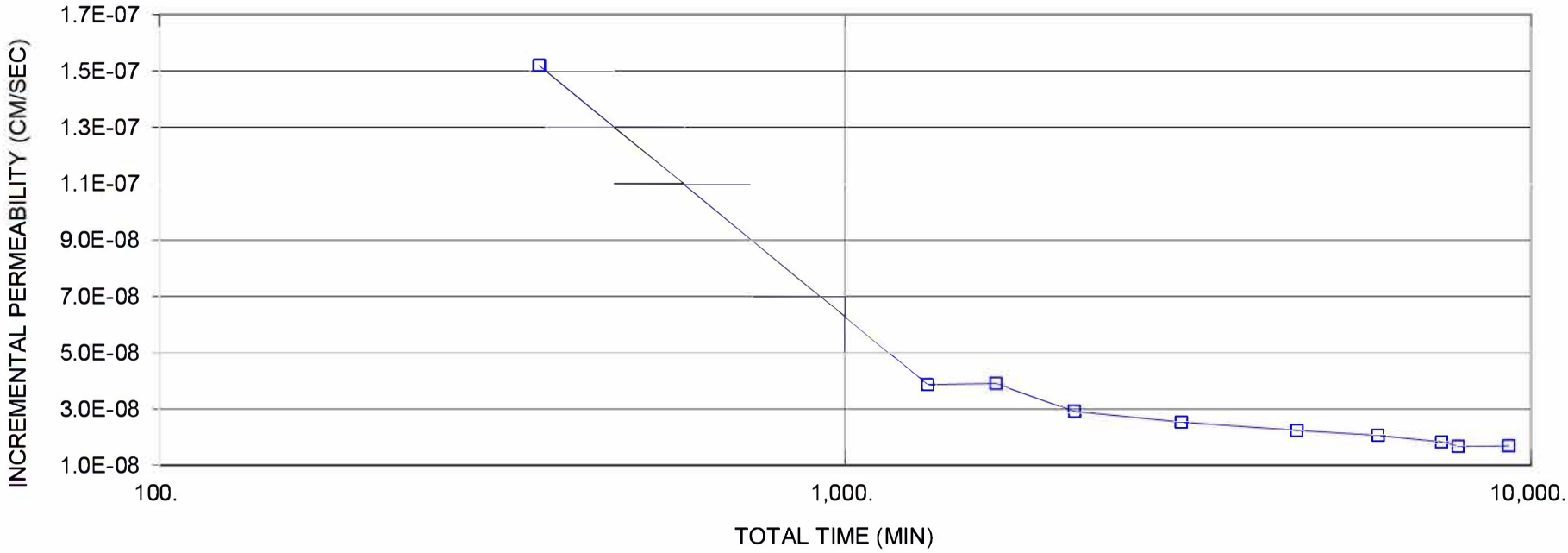
TEST DATE: 8/23/2016
BORING #: G406D
SAMPLE #: 23-3
DEPTH (FT): 43.0-43.5

SPECIMEN HEIGHT (IN) 3.592
DIAMETER (IN) 2.861
AREA (SQ IN) 6.429
INITIAL DEGREE OF SATURATION 104.79

HEIGHT OF HEAD (PSI) 3.80
PRESSURE HEAD (CM H2O) 267.21
PANEL NUMBER 6

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for k < 1 x 10^{-8} cm/sec.



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	16E0080	TEST DATE:	08/30/2016
CLIENT:	Natural Resource Technology, Inc.	BORING #:	G406D
JOB DESCRIPTION:	Coffeen Ash Pond 2	SAMPLE #:	13-2
SAMPLE DESCRIPTION:	Brn & gray fine sandy SILT, some clay, coarse sand and small gravel.	DEPTH (FT):	22.75-23.25

FOR ESTIMATING PORE VOLUME ONLY

			WATER CONTENT OF TRIMMINGS	
			BEFORE TEST	AFTER TEST
SPECIMEN WEIGHT (G)	560.94			
SPECIMEN HEIGHT (IN)	3.605	TARE + WET SOIL (G)	95.16	615.02
DIAMETER (IN)	2.301	TARE + DRY SOIL (G)	88.98	568.27
AREA (SQ IN)	4.158	TARE (G)	14.31	49.99
VOLUME (CU IN)	14.991	WET SOIL(G)	80.85	565.03
WET DENSITY (PCF)	142.55	WATER (G)	6.18	46.75
DRY DENSITY (PCF)	131.65 *	DRY SOIL (G)	74.67	518.28
WT. DRY SOIL (G)	518.06 *	WATER CONTENT (%)	8.28	9.02
WT. DRY SOIL (G)	518.28	INITIAL DEGREE OF SATURATION		79.72
VOLUME DRY SOIL (CU IN)	11.709 *	FINAL DEGREE OF SATURATION		87.06
SP.GR. ASSUMED	2.70			
POROSITY (%)	21.89 *	STD. MAX. DEN.(LBS/CU.FT.)	N/A	
HEIGHT OF HEAD (PSI)	3.90	OPTIMUM MOISTURE (%)	N/A	
HYDRAULIC GRADIANT	29.9 *	% COMPACTION	N/A	
PRESSURE HEAD (CM H2O)	274.24	SAMPLE PREPARATION	Tube	
		PANEL NUMBER	8	

TEST METHOD USED: ASTM D5084 PERMEANT USED: Tap Water

* **Estimates Only**

Remarks:

R001622

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

TEST DATE: 08/30/16
BORING #: G406D
SAMPLE #: 13-2
DEPTH (FT): 22.75-23.25

SPECIMEN HEIGHT (IN) 3.605
DIAMETER (IN) 2.301
AREA (SQ IN) 4.158
INITIAL DEGREE OF SATURATION 79.72

HEIGHT OF HEAD (PSI) 3.90
PRESSURE HEAD (CM H2O) 274.24
PANEL NUMBER 8

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for $k < 1 \times 10^{-8}$ cm/sec.

START DATE	START TIME	STOP DATE	STOP TIME	INC. INFLOW (CC)	INC. OUTFLOW (CC)	TEMP. (°C)	AVG, INC. FLOW (CC)	OUTFLOW INFLOW (RATIO) *	INC. TIME (MIN)	TOTAL TIME (MIN)	INC. PERM. (CM/SEC)	AVG. PERM. (CM/SEC)	INC. MEAN RATIO **
09/01/2016	9:10:00	09/01/2016	9:33:00	24.00	24.7	24.2	24.3500	1.029	23.	23.	1.99E-05	1.99E-05	1.000
09/01/2016	13:39:00	09/01/2016	16:17:00	66.78	65.2	24.0	65.9900	0.976	158.	181.	7.88E-06	1.39E-05	0.568
09/02/2016	8:21:00	09/02/2016	15:18:00	121.80	116.8	23.8	119.3000	0.959	417.	598.	5.42E-06	1.11E-05	0.490
09/06/2016	8:27:00	09/06/2016	13:56:00	91.14	90.0	25.6	90.5700	0.987	329.	927.	5.01E-06	9.55E-06	0.524
09/06/2016	14:04:00	09/06/2016	16:25:00	32.34	31.6	24.2	31.9700	0.977	141.	1068.	4.26E-06	5.64E-06	0.755
09/07/2016	8:54:00	09/07/2016	16:06:00	81.48	79.6	25.0	80.5400	0.977	432.	1500.	3.44E-06	4.53E-06	0.759
09/08/2016	8:02:00	09/08/2016	16:19:00	61.32	60.0	25.2	60.6600	0.978	497.	1997.	2.24E-06	3.74E-06	0.600
09/09/2016	8:23:00	09/09/2016	14:35:00	41.16	41.4	23.8	41.2800	1.006	372.	2369.	2.10E-06	3.01E-06	0.699
09/14/2016	9:45:00	09/15/2016	8:30:00	17.22	17.2	24.2	17.2100	0.999	1365.	3734.	2.37E-07	2.01E-06	0.118
09/15/2016	8:30:00	09/15/2016	16:10:00	4.62	4.8	25.2	4.7100	1.039	460.	4194.	1.88E-07	1.19E-06	0.158
09/15/2016	16:10:00	09/16/2016	8:29:00	9.66	9.2	24.2	9.4300	0.952	979.	5173.	1.81E-07	6.77E-07	0.267

R001623

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

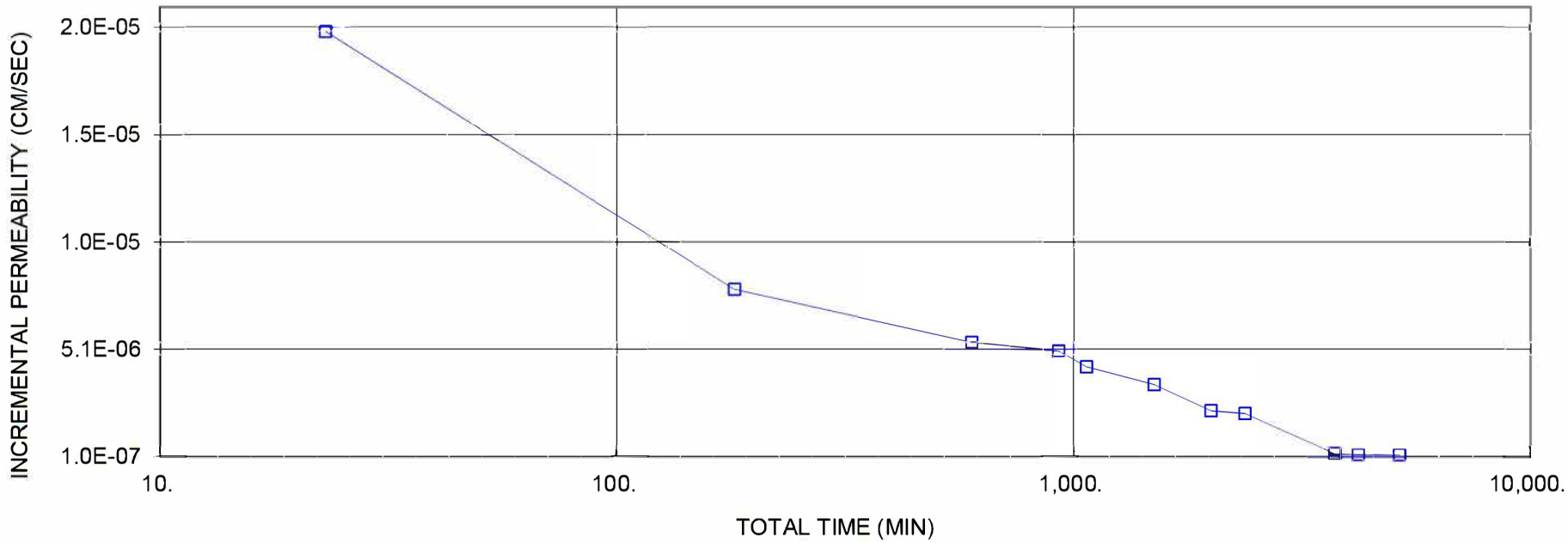
TEST DATE: 08/30/16
BORING #: G406D
SAMPLE #: 13-2
DEPTH (FT): 22.75-23.25

SPECIMEN HEIGHT (IN) 3.605
DIAMETER (IN) 2.301
AREA (SQ IN) 4.158
INITIAL DEGREE OF SATURATION 79.72

HEIGHT OF HEAD (PSI) 3.90
PRESSURE HEAD (CM H2O) 274.24
PANEL NUMBER 8

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for k < 1 x 10^{-8} cm/sec.



Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

ASTM D5084

JOB NUMBER:	16E0080	TEST DATE:	09/02/2016
CLIENT:	Natural Resource Technology, Inc.	BORING #:	T408
JOB DESCRIPTION:	Coffeen Ash Pond 2	SAMPLE #:	7-2A
SAMPLE DESCRIPTION:	Brn & gray fine sandy SILT, some clay, coarse sand and small gravel.	DEPTH (FT):	23.5-24.0

FOR ESTIMATING PORE VOLUME ONLY

				WATER CONTENT OF TRIMMINGS	
				BEFORE TEST	AFTER TEST
SPECIMEN WEIGHT (G)	474.47				
SPECIMEN HEIGHT (IN)	3.491		TARE + WET SOIL (G)	99.67	523.99
DIAMETER (IN)	2.165		TARE + DRY SOIL (G)	92.29	487.75
AREA (SQ IN)	3.681		TARE (G)	3.77	50.16
VOLUME (CU IN)	12.852		WET SOIL(G)	95.90	473.83
WET DENSITY (PCF)	140.64		WATER (G)	7.38	36.24
DRY DENSITY (PCF)	129.82	*	DRY SOIL (G)	88.52	437.59
WT. DRY SOIL (G)	437.96	*	WATER CONTENT (%)	8.34	8.28
WT. DRY SOIL (G)	437.59		INITIAL DEGREE OF SATURATION	75.45	
VOLUME DRY SOIL (CU IN)	9.898	*	FINAL DEGREE OF SATURATION	74.68	
SP.GR. ASSUMED	2.70				
POROSITY (%)	22.98	*	STD. MAX. DEN.(LBS/CU.FT.)	N/A	
HEIGHT OF HEAD (PSI)	3.70		OPTIMUM MOISTURE (%)	N/A	
HYDRAULIC GRADIANT	29.3	*	% COMPACTION	N/A	
PRESSURE HEAD (CM H2O)	260.17		SAMPLE PREPARATION	Tube	
			PANEL NUMBER	7	

TEST METHOD USED: ASTM D5084 PERMEANT USED: Tap Water

* **Estimates Only**

Remarks:

R001625

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

TEST DATE: 9/2/2016
BORING #: T408
SAMPLE #: 7-2A
DEPTH (FT): 23.5-24.0

SPECIMEN HEIGHT (IN) 3.491
DIAMETER (IN) 2.165
AREA (SQ IN) 3.681
INITIAL DEGREE OF SATURATION 79.72

HEIGHT OF HEAD (PSI) 3.70
PRESSURE HEAD (CM H2O) 260.17
PANEL NUMBER 7

* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for $k < 1 \times 10^{-8}$ cm/sec.

START DATE	START TIME	STOP DATE	STOP TIME	INC. INFLOW (CC)	INC. OUTFLOW (CC)	TEMP. (°C)	AVG, INC. FLOW (CC)	OUTFLOW INFLOW (RATIO) *	INC. TIME (MIN)	TOTAL TIME (MIN)	INC. PERM. (CM/SEC)	AVG. PERM. (CM/SEC)	INC. MEAN RATIO **
09/06/2016	8:53:00	09/06/2016	16:18:00	19.70	20.2	24.2	19.9500	1.025	445.	445.	9.71E-07	9.71E-07	1.000
09/06/2016	16:30:00	09/07/2016	8:33:00	32.76	29.52	26.2	31.1400	0.901	963.	1408.	6.69E-07	8.20E-07	0.816
09/07/2016	16:29:00	09/08/2016	7:58:00	4.29	4.32	25.6	4.3050	1.007	929.	2337.	9.72E-08	5.79E-07	0.168
09/08/2016	8:24:00	09/09/2016	8:20:00	7.80	8.0	25.2	7.9000	1.026	1436.	3773.	1.16E-07	4.64E-07	0.251
09/09/2016	8:20:00	09/09/2016	14:31:00	9.80	10.0	24.2	9.9000	1.020	371.	4144.	5.78E-07	3.65E-07	1.582
09/12/2016	8:38:00	09/13/2016	8:12:00	7.20	7.5	23.8	7.3500	1.042	1414.	5558.	1.14E-07	2.26E-07	0.502
09/14/2016	8:58:00	09/15/2016	8:21:00	10.60	10.8	24.4	10.7000	1.019	1403.	6961.	1.64E-07	2.43E-07	0.676
09/15/2016	8:21:00	09/15/2016	16:05:00	3.60	3.7	25.2	3.6500	1.028	464.	7425.	1.67E-07	2.56E-07	0.651
09/15/2016	16:05:00	09/16/2016	8:16:00	7.40	7.3	24.2	7.3500	0.986	971.	8396.	1.64E-07	1.52E-07	1.078

R001626

HANSON

Hanson Professional Services Inc.

CONSTANT HEAD PERMEABILITY TEST

JOB NUMBER: 16E0080
CLIENT: Natural Resource Technology, Inc.
JOB DESCRIPTION: Coffeen Ash Pond 2

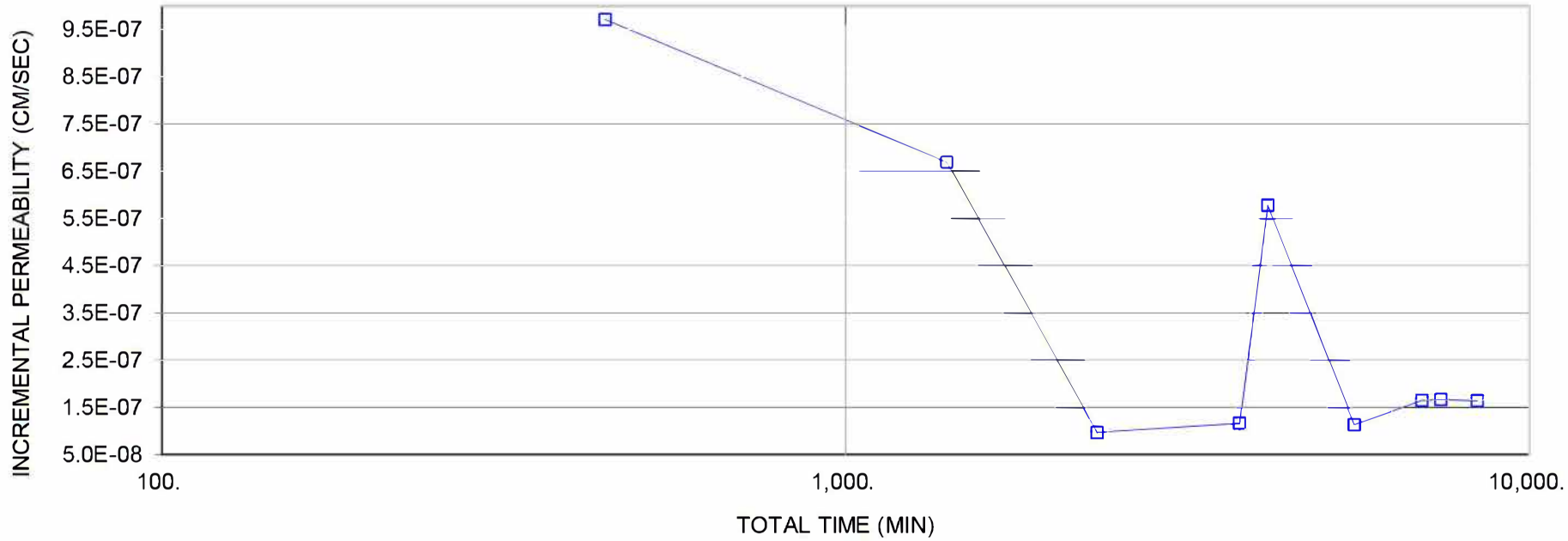
TEST DATE: 9/2/2016
BORING #: T408
SAMPLE #: 7-2A
DEPTH (FT): 23.5-24.0

SPECIMEN HEIGHT (IN) 3.491
DIAMETER (IN) 2.165
AREA (SQ IN) 3.681
INITIAL DEGREE OF SATURATION 79.72

HEIGHT OF HEAD (PSI) 3.70
PRESSURE HEAD (CM H2O) 260.17
PANEL NUMBER 7

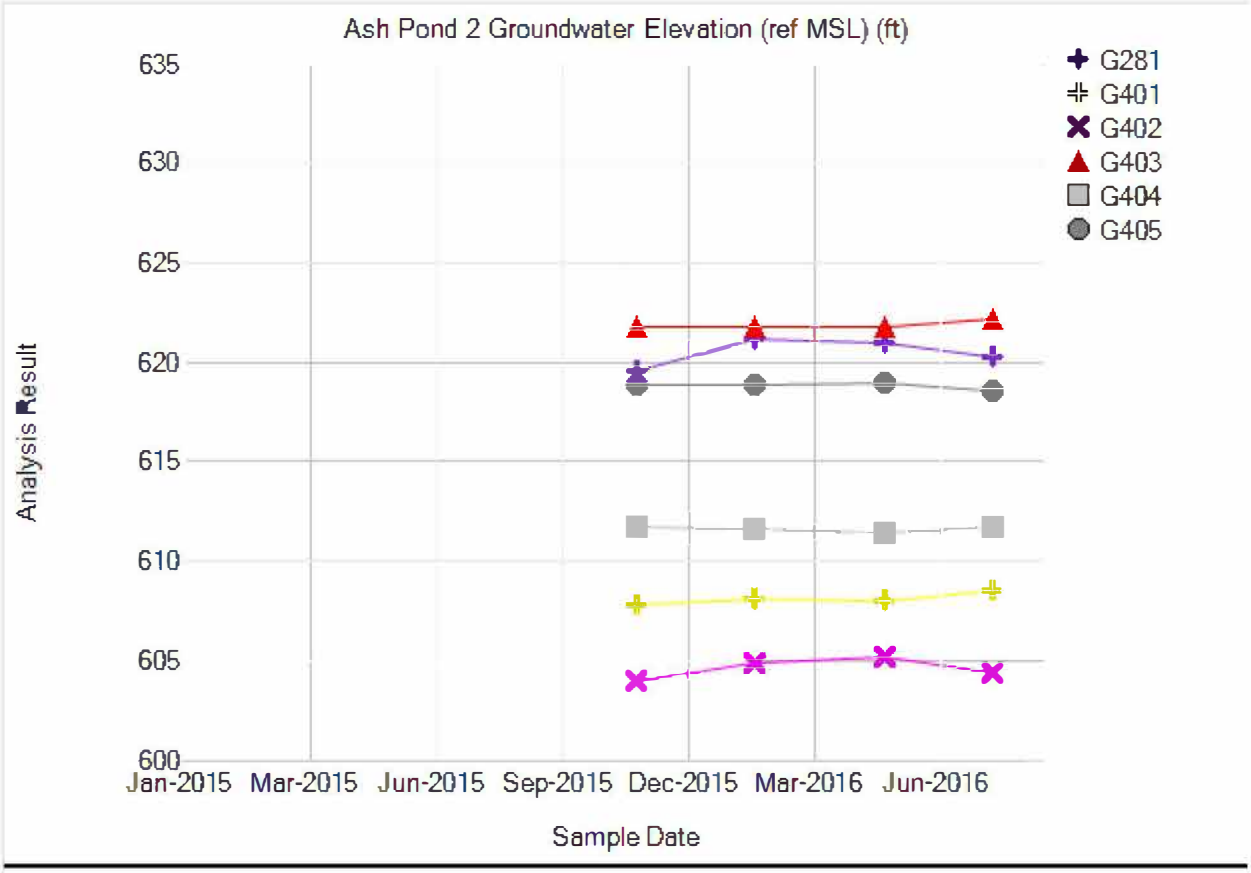
* 4 Readings - Ratio of Outflow to Inflow is between .75 to 1.25 or Steady.

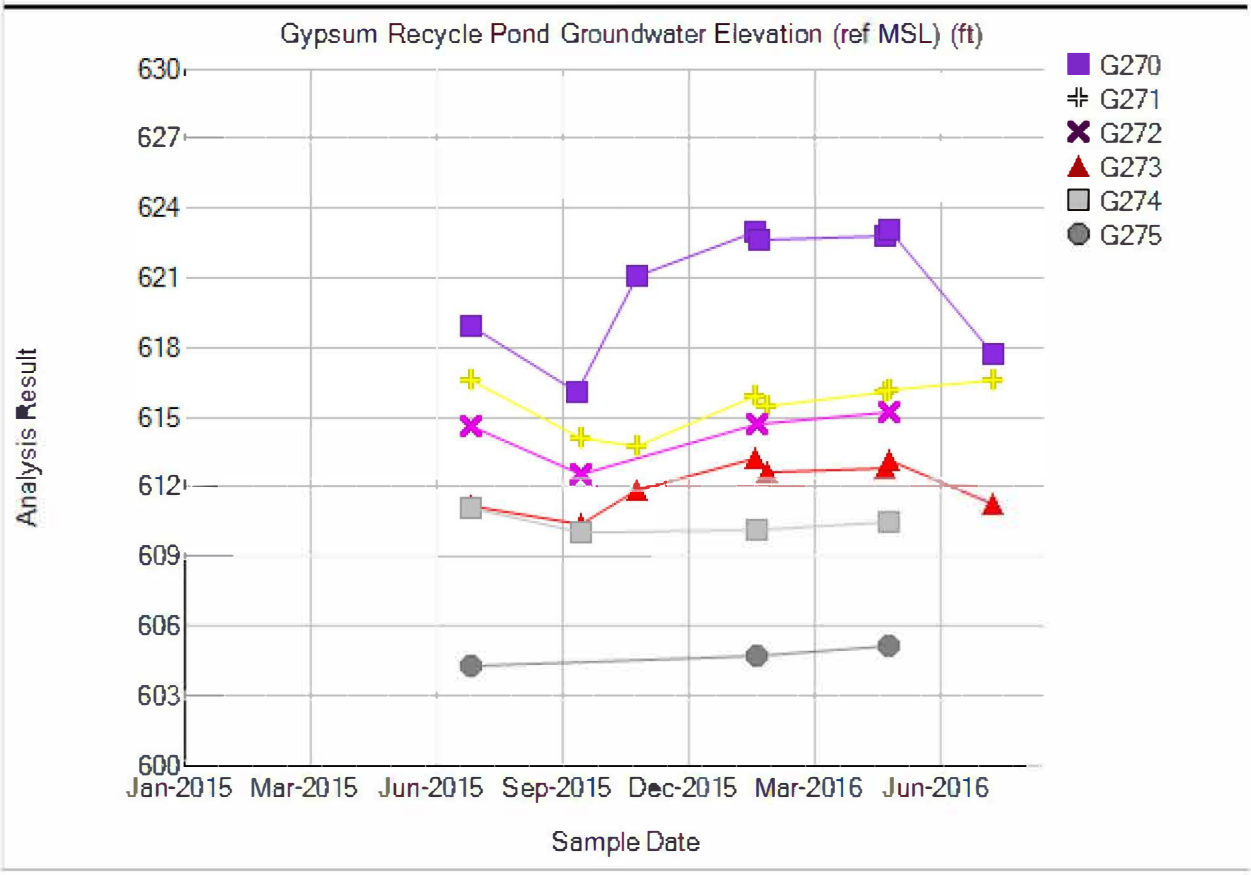
** Mean Ratio is Steady if 4 or more incremental readings are ±25% or better of the mean, or within ± 50% or better for k < 1 x 10^{-8} cm/sec.

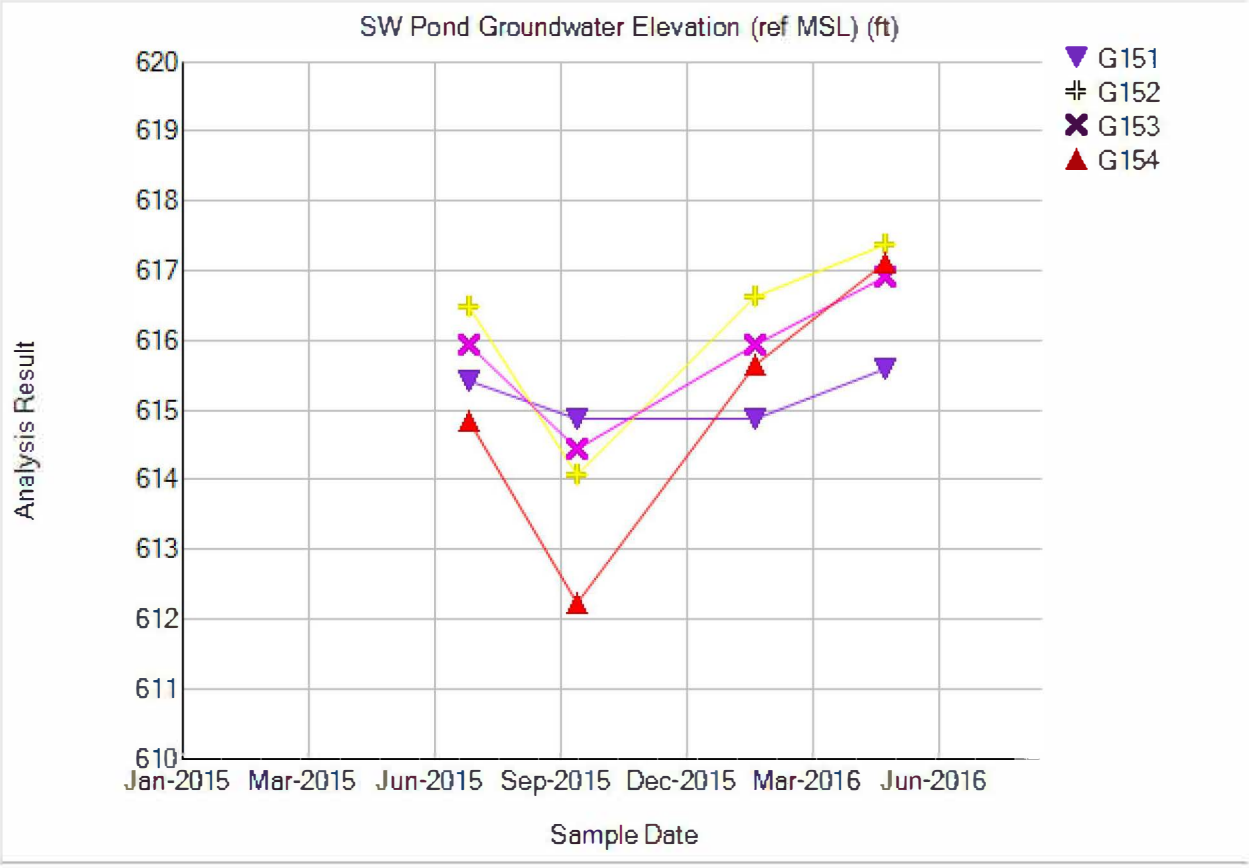


APPENDIX C

MONITORING WELL HYDROGRAPHS (2015-2016)


Ash Pond 2 Groundwater Elevation (ref MSL) (ft)
Analysis Result
635
630
625
620
615
610
605
600
Jan-2015
Mar-2015
Jun-2015
Sep-2015
Dec-2015
Mar-2016
Jun-2016
Sample Date
G281
G401
G402
G403
G404
G405


Gypsum Recycle Pond Groundwater Elevation (ref MSL) (ft)
Analysis Result
630
627
624
621
618
615
612
609
606
603
600
Jan-2015
Mar-2015
Jun-2015
Sep-2015
Dec-2015
Mar-2016
Jun-2016
Sample Date
G270
G271
G272
G273
G274
G275


SW Pond Groundwater Elevation (ref MSL) (ft)
G151
G152
G153
G154
620
619
618
617
616
615
614
613
612
611
610
Analysis Result
Jan-2015
Mar-2015
Jun-2015
Sep-2015
Dec-2015
Mar-2016
Jun-2016
Sample Date

APPENDIX D

DISCHARGE TO SURFACE WATER CALCULATIONS

CALCULATION SHEET

NATURAL RESOURCE TECHNOLOGY

Flux into Unnamed Creek

By: NRK Date: 12/19/16

Chkd by: EJT/SJC Date: 12/20/16

Revision: Date: By: App'd:

Client: Dynegy

NRT Project #: 2380

Coffeen Ash Pond No. 2
Closure Plan

Problem Statement:

Calculate the flux of impacted groundwater into the unnamed creek located east of Coffeen Ash Pond No. 2.

Assumptions:

1. Groundwater can enter the creek through the eastern berm as shown in conceptualized cross-sections.
2. Coal Combustion Residuals (CCR) are in contact with Hagarstown Formation within Ash Pond No. 2.
3. Groundwater flow is through Hagarstown Formation only:
   a. Hydraulic conductivity of Hagarstown Formation = $1x10^{-4}$ cm/s (Subsection 2.2.3)
   b. Hydraulic conductivity of Ash Pond No. 2 embankment fill = $5.4x10^{-8}$ cm/s (AECOM, 2015; from samples of embankment fill from Ash Pond No. 1)
4. Hagarstown Formation discharges directly to unnamed creek throughout 75% of eastern edge of Ash Pond No. 2 (as shown in conceptualized cross-section C-C') and Hagarstown Formation daylights to bottom of Ash Pond No. 2 with CCR in contact with Hagarstown Formation (absence of clay layer between bottom of Ash Pond No. 2 and Hagarstown Formation).

Calculations:

$$Conc_{(creek)} = \frac{Q_{(GW)}\ x\ Conc_{(GW)} + (Q_{(creek)} - Q_{(GW)})\ x\ Conc_{(creek)}}{Q_{(creek)}}$$

Where:

$$Q_{(GW)} = KIA$$

K = Hydraulic Conductivity of Hagarstown Formation (ft/min)
I = Hydraulic Gradient

$$I = \frac{Ash\ Pond\ No.2\ water\ elev - elev\ of\ top\ of\ Hagarstown\ Formation}{width\ of\ berm}$$

$$I = \frac{631\ ft - 601\ ft}{30\ ft}$$

$$I = 1$$

A = Area of Flow (ft^2)

$A = L\ x\ t$

L = length (ft)
t = thickness (ft)
$A = 1{,}400\ ft\ x\ 0.75\ x\ 2\ ft$
$A = 2{,}100\ ft^2$

$$Q_{(GW)} = 5x10^{-4}\ cm/sec\ x\ 1\ x\ 2{,}100\ ft^2$$
$$Q_{(GW)} = 0.000016\ ft/s\ x\ 2{,}100\ ft^2$$
$$Q_{(GW)} = 0.0336\ cfs\ or\ 0.95\ L/sec$$

CALCULATION SHEET

NATURAL RESOURCE TECHNOLOGY

Flux into Unnamed Creek

By: NRK Date: 12/19/16

Chkd by: EJT/SJC Date: 12/20/16

Revision: Date: By: App'd:

Client: Dynegy

NRT Project #: 2380

Coffeen Ash Pond No. 2
Closure Plan

$$Q_{(creek)} = \frac{1.49}{n} A\, R^{\frac{2}{3}} \sqrt{S}$$

A = Flow Area (ft²)
n = Manning's Roughness Coefficient (~0.05)
R = Hydraulic Radius (ft)
S = Channel Slope (ft/ft) (see attached Google Earth calculation)

$$Q_{(creek)} = \frac{1.49}{0.05} x 18\ ft^2\ x\ 1.44\ ft^{\frac{2}{3}} \sqrt{0.004}$$

$$Q_{(creek)} = 29.8\ x\ 18\ x\ 1.28\ x\ 0.063$$

$$Q_{(creek)} = 43.3\ cfs\ or\ 1{,}226\ L/sec$$

$$R = \frac{A}{P}$$

A = Flow Area of creek channel (ft²)
P = Wetted Perimeter of creek channel (ft)

$$R = \frac{18\ ft^2}{12.5\ ft}$$

$$R = 1.44\ ft$$

$$P = b + 2\sqrt{(\frac{T-b}{2})^2 + h^2}$$

b = channel width at base of creek (ft) (see assumed geometry at discharge to lake)
T = channel width at top of creek (ft) (see assumed geometry at discharge to lake)
h = depth of creek channel (ft) (see assumed geometry at discharge to lake)

$$P = 8\ ft + 2\sqrt{(\frac{10\ ft - 8\ ft}{2})^2 + 2\ ft^2}$$

$$P = 8\ ft + 2\sqrt{5 ft^2}$$

$$P = 12.5\ ft$$

CALCULATION SHEET	By: NRK	Date: 12/19/16
NATURAL RESOURCE TECHNOLOGY	Chkd by: EJT/SJC	Date: 12/20/16
Flux into Unnamed Creek	Revision:	Date: By: App'd:
Client: Dynegy NRT Project #: 2380	Coffeen Ash Pond No. 2 Closure Plan	

Boron

$$Conc_{(creek)} = \frac{0.95\ L/sec\ x\ 20\ mg/L + (1{,}226\ L/sec - 0.95\ L/sec)\ x\ 0.1\ mg/L}{1{,}226\ L/sec}$$

$$Conc_{(creek)} = \frac{19\ mg/sec + 122.5\ mg/sec}{1{,}226\ L/sec}$$

$$Conc_{(creek)} = 0.115\ mg/L$$

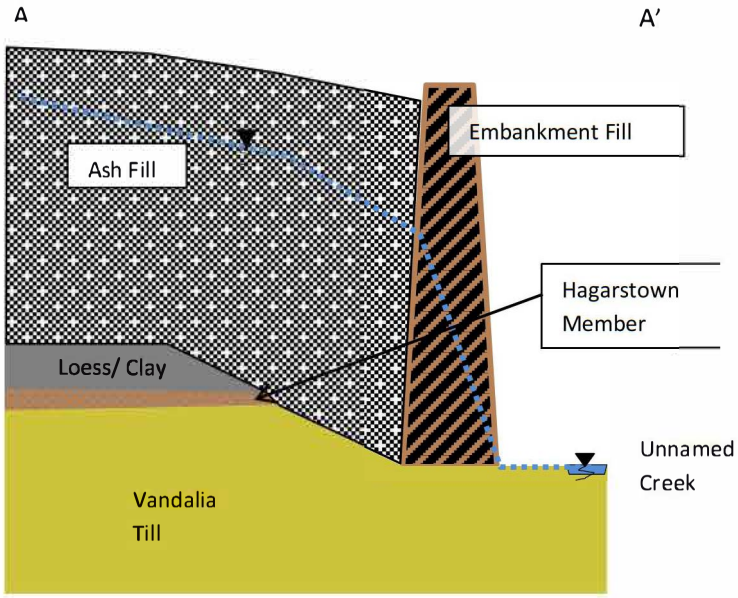
Sulfate

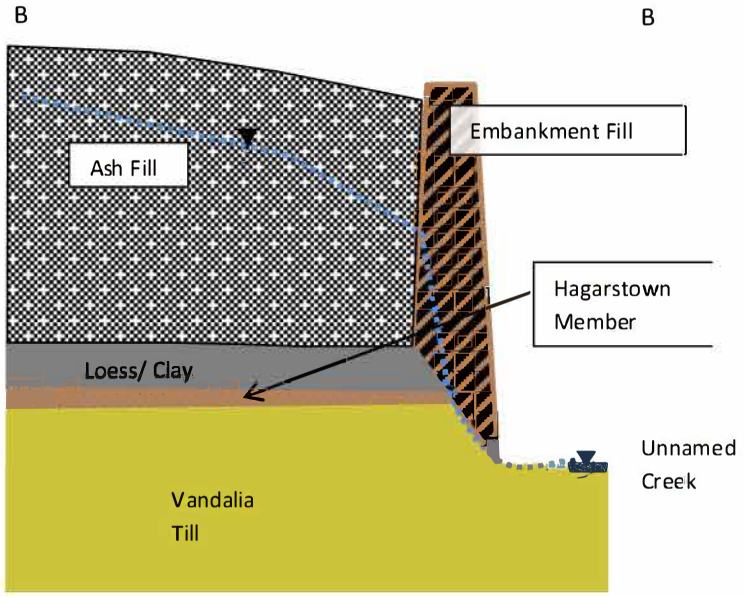
$$Conc_{(creek)} = \frac{0.95\ L/sec\ x\ 2{,}400\ mg/L + (1{,}226\ L/sec - 0.95\ L/sec)\ x\ 0.05\ mg/L}{1{,}226\ L/sec}$$

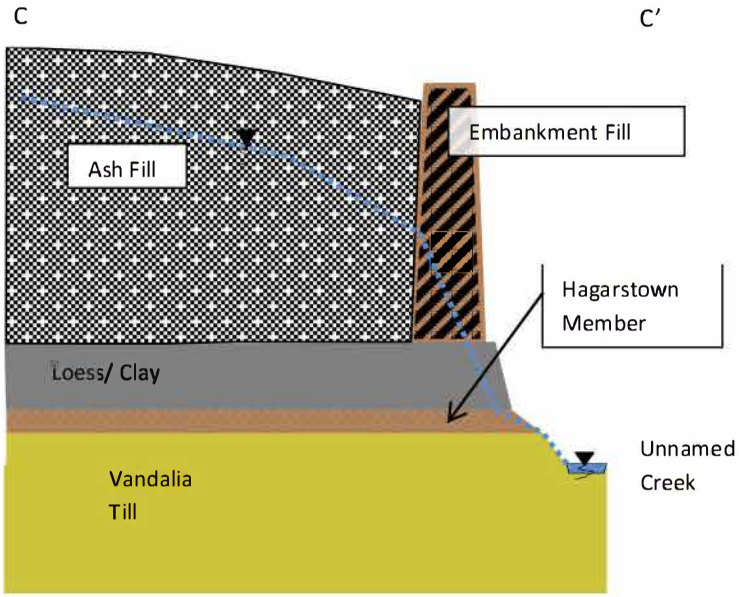
$$Conc_{(creek)} = \frac{2{,}280\ mg/sec + 61.3\ mg/sec}{1{,}226\ L/sec}$$

$$Conc_{(creek)} = 1.9\ mg/L$$

APPENDIX D – ASH POND 2 EAST BERM CONCEPTUAL CROSS SECTIONS







CALCULATION SHEET

NATURAL RESOURCE TECHNOLOGY

Flux into Condenser Cooling Water Discharge Flume

By: NRK Date: 12/19/16

Chkd by: EJT/SJC Date: 12/20/16

Revision:	Date:	By:	App'd:

Client: Dynegy

Coffeen Ash Pond No. 2
Closure Plan

NRT Project #: 2380

Problem Statement:

Calculate the flux of impacted groundwater into the Condenser Cooling Water Discharge Flume located south of Ash Pond No. 2.

Assumptions:

1. Average flow in flume per NPDES permit is ~500 MGD or approximately 21,900 L/sec.
2. Groundwater can enter the flume through the southern berm as shown in cross-section A-A'.
3. Coal Combustion Residuals (CCR) are in contact with Hagarstown Formation within Ash Pond No. 2.
4. Groundwater flow is through Hagarstown Formation only:
   a. Hydraulic conductivity of Hagarstown Formation = $1x10^{-4}$ cm/s (Subsection 2.2.3, this report)
   b. Hydraulic conductivity of Ash Pond No. 2 embankment fill = $5.4x10^{-8}$ cm/s (AECOM, 2015; from samples of embankment fill from Ash Pond No. 1)
5. Hagarstown Formation discharges directly to flume throughout entire southern edge of Ash Pond No. 2 (as shown in conceptualized cross-section C-C') and Hagarstown Formation daylights to bottom of Ash Pond No. 2 with CCR in contact with Hagarstown Formation (absence of clay layer between bottom of Ash Pond No. 2 and Hagarstown Formation).

Calculations:

$$Conc_{(flume)} = \frac{Q_{(GW)} \, x \, Conc_{(GW)} + (Q_{(flume)} - Q_{(GW)}) \, x \, Conc_{(flume)}}{Q_{(flume)}}$$

Where:

$$Q_{(GW)} = KIA$$

K = Hydraulic Conductivity of Hagarstown Formation (ft/min)
I = Hydraulic Gradient

$$I = \frac{Ash\ Pond\ No.2\ water\ elev - elev\ of\ top\ of\ Hagarstown\ Formation}{width\ of\ berm}$$

$$I = \frac{610\ ft - 600\ ft}{20\ ft}$$

$$I = 0.5$$

A = Area of Flow (ft^2)

$$A = L \, x \, t$$

L = length (ft)
t = thickness (ft)

$$A = 1{,}950\ ft \ x\ 2\ ft$$

$$A = 3{,}900\ ft^2$$

CALCULATION SHEET

NATURAL RESOURCE TECHNOLOGY

Flux into Condenser Cooling Water Discharge Flume

By: NRK Date: 12/19/16

Chkd by: EJT/SJC Date: 12/20/16

Revision:	Date:	By:	App'd:

Client: Dynegy

Coffeen Ash Pond No. 2
Closure Plan

NRT Project #: 2380

$$Q_{(GW)} = 5x10^{-4}\ cm/\sec x\ 0.5\ x\ 3{,}900\ ft^2$$
$$Q_{(GW)} = 1.6x10^{-5}\ ft/\sec x\ 1{,}950\ ft^2$$
$$Q_{(GW)} = 0.03\ ft^{3}/sec\ or\ 0.88\ L/sec$$

$$Q_{(flume)} = 21{,}900\ L/sec$$

$$SO_4\ Conc_{(flume)} = \frac{\frac{0.88L}{sec} x\ \frac{3{,}000mg}{L} + \left(\frac{21{,}900L}{sec} - \frac{0.88L}{sec}\right) x\ \frac{50mg}{L}}{21{,}900\ \frac{L}{sec}}$$

$$= \frac{2640\ mg/\sec\ +\ 1.1\ x\ 10^6\ mg/sec}{21{,}900\ \frac{L}{sec}}$$

$$= 50.1\ mg/L$$

Summary and Conclusions:

Since $Q_{(flume)}$ is so much larger in magnitude than $Q_{(GW)}$, the flux of impacted groundwater into the flume is negligible.

APPENDIX E

WATER WELL LOCATIONS AND RECORDS WITHIN 2,500-FOOT RADIUS OF COFFEEN ASH POND 2

E WELL SEARCH

E.1 Well Search Overview

The following sources of information were utilized in order to determine community water source and water well locations:

- Illinois State Geological Survey's Illinois Water Well (ILWATER) Internet Map Service
- Illinois State Water Survey Domestic Well Database
- Illinois EPA web-based Geographic Information System (GIS) files
- Illinois Department of Public Health
- Montgomery County Health Department

E.2 Illinois State Geological Survey (ISGS)

The ISGS website provided an ArcIMS View Map as well as a database query for water wells. ISGS database information including any boring logs and well construction information is provided in this Appendix.

E.3 Illinois State Water Survey (ISWS)

All of the wells found on-line through the ISWS Domestic Well Database were previously identified on the ISGS website. Hard copy records contained within the ISWS database, consisting of public, industrial, and commercial water wells, were not all received as of the date of this report. Since the ISWS database generally contains the same well information as the ISGS and Illinois EPA databases, some ISWS well entries on the Appendix E-1 Table were marked as pending. Should any new information be acquired from the ISWS including additional water wells not previously identified from the on-line sources of well information, it will be provided as an addendum to this report. Table E-2 lists wells located by RAPPS (2009) that were not located and identified in the on-line search for this report.

E.4 Illinois Environmental Protection Agency (IEPA)

The Illinois EPA database website provided ArcIMS Viewer Maps showing information on community, non-community, and public water supply wells as defined on the Illinois EPA website:

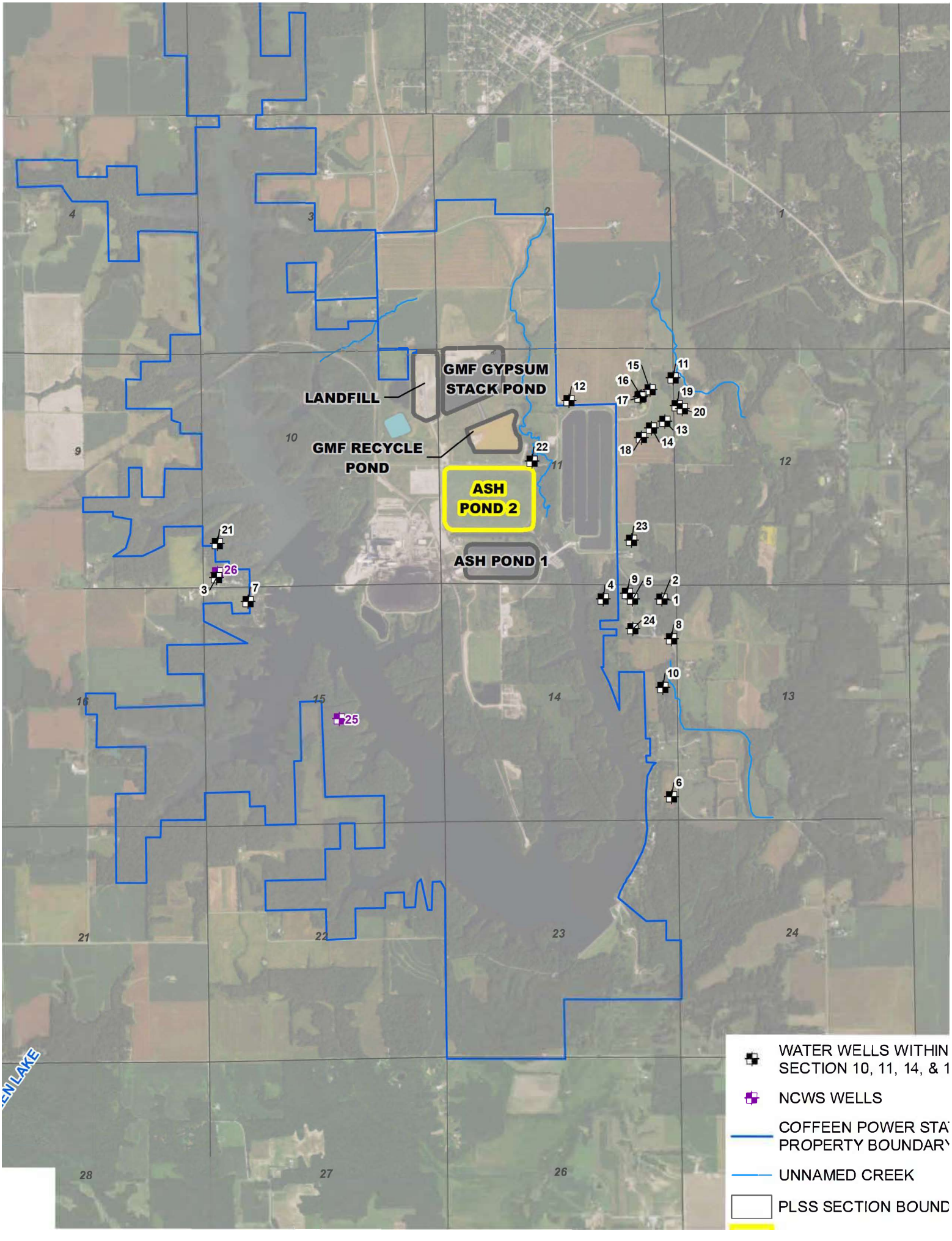
- Community Water Supply: a public water supply that serves or is intended to serve at least 15 service connections used by residents or regularly serves at least 25 residents.

- Non-Community Water Supply: a public water supply that is not a community water supply.
- Public Water Supply: all mains, pipes and structures through which water is obtained and distributed to the public, including wells and well structures, intakes and cribs, pumping stations, treatment plants, reservoirs, storage tanks and appurtenances, collectively or severally, actually used or intended for use for the purpose of furnishing water for drinking or general domestic use and which serve at least 15 service connections or which regularly serve at least 25 persons at least 60 days per year. A public water supply is either a community water supply or a non-community water supply.

Based on the IEPA maps, two non-CWS wells are located within Sections 10 and 15. Both non-CWS were identified in the ISGS records.

E.5 Montgomery County Health Department

Personnel from the Montgomery County Health Department confirmed the two non-CWS well systems were present within the area and noted that they were used at a campground and wildlife preserve. No additional information was provided about the area.


GMF GYPSUM STACK POND
LANDFILL
GMF RECYCLE POND
ASH POND 2
ASH POND 1
WATER WELLS WITHIN SECTION 10, 11, 14, & 1
NCWS WELLS
COFFEEN POWER STA PROPERTY BOUNDAR
UNNAMED CREEK
PLSS SECTION BOUND

R001641

Table E-1. Well Search Results
Hydrogeologic Characterization Report
Coffeen Energy Center

Map Well #	Source of Well Information ISGS	ISWS***	IEPA	Other	Location Name at Time of Well Completion	Well Depth	County	Location Township	Range	Section	Subsection	Year Drilled	Aquifer Type	Formation	Well Use*
1	121352182400	115230	21824	--	Hueitt, Bill	32	Montgomery	7N	3W	14	NE,NE,NE	1974	Unconsolidated	clay	FD
2	121352182500	115229	21825	--	Stahl, Louis	32	Montgomery	7N	3W	14	NE,NE,NE	1974	Unconsolidated	clay	FD
3	121350164400	115213	1644	--	Flori, Eugene	20	Montgomery	7N	3W	10	--	1969	Unconsolidated	sand	FD
4	121350171700	115228	1717	--	Marfield, Mac	29	Montgomery	7N	3W	14	NE,NW,NE	1970	Unconsolidated	clay	FD
5	121350172600	115224	1726	--	Schuler, Paul	32	Montgomery	7N	3W	14	NW,NE,NE	1971	Unconsolidated	sand	FD
6	121352300600	115226	23006	--	Jump, James	41	Montgomery	7N	3W	14	SE,SE,SE	1986	Unconsolidated	ground-clay	FD
7	121352310800	***	23108	--	Dept. of Conservation	70	Montgomery	7N	3W	15	NE,NW,NW	1987	Unconsolidated	sandy clay	IC
8	121352221300	115222	22213	--	Gadshlen, Clarence	156	Montgomery	7N	3W	14	SE,NE,NE	1977	Bedrock	sandstone	FD
9	121352221400	115223	22214	--	Warfield, William	151	Montgomery	7N	3W	14	NE	1978	Bedrock	sandstone	FD
10	121352334900	243174	23349	--	Monk, Lawrence & Anita	382	Montgomery	7N	3W	14	SE,SE,NE	1993	Bedrock	gray sandstone	FD
11	121352361400	***	23614	--	White & Brewer	40	Montgomery	7N	3W	11	SE,NE,NE	1993	Unconsolidated	silt	MW
12	121352361500	***	23615	--	White & Brewer	35	Montgomery	7N	3W	11	NE	1993	Unconsolidated	silt	MW
13	121352361600	***	23616	--	White & Brewer	17	Montgomery	7N	3W	11	--	--	Unconsolidated	silt	MW
14	121352361700	***	23617	--	White & Brewer	25	Montgomery	7N	3W	11	--	--	Unconsolidated	silty clay	MW
15	121352361800	***	23618	--	White & Brewer	23	Montgomery	7N	3W	11	--	--	Unconsolidated	silty clay	MW
16	121352361900	***	23619	--	White & Brewer	40	Montgomery	7N	3W	11	--	--	Unconsolidated	sandy silt	MW
17	121352362000	***	23620	--	White & Brewer	20	Montgomery	7N	3W	11	--	--	Unconsolidated	sandy silt	MW
18	121352362100	***	23621	--	White & Brewer	33	Montgomery	7N	3W	11	--	--	Unconsolidated	sandy silt	MW
19	121352362300	***	23623	--	White & Brewer	48	Montgomery	7N	3W	12	--	--	Unconsolidated	clay and silt	MW
20	121352362400	***		--	White & Brewer	24	Montgomery	7N	3W	12	--	--	Unconsolidated	sandy silt	MW
21	121352283100	115350	22831	--	Sidner, Joe	50	Montgomery	7N	3W	10	NW,SW,SW	1984	Unconsolidated	gravel	FD
22	121352283200	115215	22832	--	Wibel, William	39	Montgomery	7N	3W	11	SE,SE,NW (A)	1981	Unconsolidated	sand and gravel	FD
23	121352380200	290232	23802	--	O'Dell, Kenneth & Chong	363	Montgomery	7N	3W	11	NW,SE,SE	1996	Bedrock	light gray sandstone	FD
24	121352380300	290231	23803	--	Childers, Joe	401	Montgomery	7N	3W	14	SW,NE,NE	1996	Bedrock	light gray sandstone	FD
25	121352396900	***	13500061	--	Coffeen Lake Fish & Wildlife	--	Montgomery	7N	3W	15	NW,NW,SE	--	--	--	NCWS
26	121352400700	***	13500012	--	Indian Grove Campground	--	Montgomery	7N	3W	10	SW,SW,SW	--	--	--	NCWS

Sources of Information

IEPA	Illinois Environmental Protection Agency
ISGS	Illinois State Geological Survey
ISWS	Illinois State Water Survey (Private Well Database)
SWA	IEPA Source Water Assessment

*Well Use

FD	Farm and/or Domestic Water Well
IC	Industrial/Commercial Water Well
CWS	Community Water Supply
NCWS	Non-Community Water Supply
MW	Monitoring well

Notes

--	Not applicable or no information available
***	ISWS data pending
(A)	Well is mislocated in ISGS and/or IEPA databases

Table E-2. Other Water Wells, Precise Location Not Available
Hydrogeologic Characterization Report
Coffeen Energy Center

Well ID	Depth	Location			Well Use	Driller	Date Drilled
		Township	Range	Section			
400397		7N	3W	10	IC		//
43308	16	7N	3W	10	IC	DAN KOHNEN	//
433123	20	7N	3W	10	IC	DAN KOHNEN	//
115214	500	7N	3W	11	IC		7/14/1996
250603	40	7N	3W	11	MO	FOX DRILLING INC.	11/17/1993
250604	35	7N	3W	11	MO	FOX DRILLING INC.	11/18/1993
250605	17	7N	3W	11	MO	FOX DRILLING INC.	1/28/1994
250610	25	7N	3W	11	MO	FOX DRILLING INC.	1/28/1994
250611	23	7N	3W	11	MO	FOX DRILLING INC.	1/28/1994
250612	40	7N	3W	11	MO	FOX DRILLING INC.	1/28/1994
250613	20	7N	3W	11	MO	FOX DRILLING INC.	1/28/1994
250614	33	7N	3W	11	MO	FOX DRILLING INC.	2/3/1994
433009	15	7N	3W	11	MO	DAN KOHNEN	//
290231	401	7N	3W	14	IC	KOHEN CONCR.	8/5/1996
377373	483	7N	3W	14	IC	SCWHARTZ	1997
377374	504	7N	3W	14	IC	SCWHARTZ	1997
377375	490	7N	3W	14	IC	SCWHARTZ	1997
377376	408	7N	3W	14	IC	SCWHARTZ	1997
377377	417	7N	3W	14	IC	SCWHARTZ	1997
377378	418	7N	3W	14	IC	SCWHARTZ	1997
377380	416	7N	3W	14	IC	SCWHARTZ	1997
403162		7N	3W	14			//
403163		7N	3W	14			//
115231	70	7N	3W	15	ST	H LINK	6/23/1987

Well Use

DO	Domestic
MO	not specified
IC	not specified
ST	not specified

These wells are listed in RAPPS (2009). NRT has ordered but not yet received these records from the ISWS Domestic Wells Database.

APPENDIX F

GROUNDWATER QUALITY DATA

R001644

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.0218								< 0.002			0.257				
0.057	< 0.001		0.026	< 0.001		50	< 0.004	< 0.002	0.691		< 0.001			< 0.0002		0.0021	
0.069	< 0.001		0.019	< 0.001		67	< 0.004	< 0.002	0.486		< 0.001			< 0.0002		0.0029	
		0.052								< 0.001			0.11				
0.067	< 0.001		0.01	< 0.001		58	< 0.004	< 0.002	0.649		< 0.001			< 0.0002		0.0024	
		0.013								< 0.001			0.091				
		< 0.02								< 0.001			0.071				
		< 0.005								< 0.001			0.031				
		0.02								< 0.001			0.12				
		0.014								< 0.001			0.072				
		0.024								< 0.001			0.069				
		< 0.01								< 0.001			0.14				
		< 0.01								< 0.001			0.031				
		< 0.01								< 0.001			0.066				
		< 0.02								< 0.002			0.19				
		0.018								< 0.001			0.093				
		0.036								< 0.001			0.56				
		< 0.01								< 0.001			0.18				
		< 0.02								< 0.002			0.011				
		0.0513								< 0.002			0.927				
0.13	< 0.001		0.047	< 0.001		40	0.008	0.0023	0.642		0.0026			< 0.0002		0.003	
0.13	< 0.001		0.036	< 0.001		42	< 0.004	< 0.002	0.422		< 0.001			< 0.0002		0.0043	
		0.044								< 0.001			0.21				
0.1	< 0.001		0.032	< 0.001		45	< 0.004	< 0.002	0.587		< 0.001			< 0.0002		0.0035	
		0.031								< 0.001			0.14				
		0.033								< 0.001			0.14				
		0.015								< 0.001			0.034				
		0.024								0.0014			0.21				
		0.038								< 0.001			0.12				
		0.044								< 0.001			0.05				
		0.044								< 0.001			0.31				
		0.034								< 0.001			0.15				
		0.03								< 0.001			0.15				
		0.025								< 0.002			0.07				
		0.079								< 0.001			0.89				
		0.11								< 0.001			0.53				
		0.082								< 0.001			0.47				
		0.066								< 0.002			0.31				
0.073			0.017			51			0.509								
		0.0575								< 0.002			1.02				
0.036	< 0.001		0.064	< 0.001		130	0.0053	0.0068	0.369		< 0.001			< 0.0002		0.021	
0.022	< 0.001		0.036	< 0.001		160	0.0041	0.0034	0.293		< 0.001			< 0.0002		0.027	
		0.032								< 0.001			0.42				
0.016	< 0.001		0.031	< 0.001		130	0.0041	< 0.002	0.341		< 0.001			< 0.0002		0.021	
		0.04								< 0.001			0.19				
		0.039								< 0.001			0.28				
		0.012								< 0.001			0.13				

R001645

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.026								< 0.001			0.24				
		0.028								< 0.001			0.51				
		0.02								< 0.001			0.2				
		0.02								< 0.002			0.024				
		0.015								< 0.001			0.16				
		0.03								< 0.001			0.19				
		0.016								< 0.001			0.046				
		0.026								< 0.002			0.037				
0.017			0.013			230			0.491								
		0.0452								< 0.002			0.462				
0.037	< 0.001		0.031	< 0.001		10	< 0.004	< 0.002	1.01		< 0.001			< 0.0002		0.0042	
0.032	< 0.001		0.021	< 0.001		4.6	< 0.004	< 0.002	0.971		< 0.001			< 0.0002		0.0062	
		0.025								< 0.001			0.038				
0.033	< 0.001		0.038	< 0.001		4.9	< 0.004	< 0.002	1.06		< 0.001			< 0.0002		0.0058	
		0.04								< 0.001			0.043				
		0.043								< 0.001			0.032				
		0.021								< 0.001			0.046				
		0.035								< 0.001			0.045				
		0.043								< 0.001			0.018				
		0.044								< 0.001			0.014				
		0.035								< 0.001			0.081				
		0.035								< 0.001			0.0077				
		0.037								< 0.001			0.0092				
		0.023								< 0.002			0.003				
		0.024								< 0.001			0.14				
		0.044								< 0.001			0.01				
		0.041								< 0.001			0.041				
		0.037								< 0.002			0.0085				
0.076	< 0.005	< 0.25	< 0.25	< 0.0025	77	9.5	< 0.025	< 0.005	0.36	< 0.0025	< 0.0025		0.19	< 0.0002		< 0.012	
0.076	< 0.001	0.078	0.071	< 0.0005	72	11	< 0.005	0.0017	0.36	< 0.0005	0.0021		0.21	< 0.0002		< 0.0025	
0.072	< 0.001	< 0.05	< 0.05	< 0.0005	70	< 10	< 0.005	0.001	0.33	< 0.0005	0.0021		0.21	< 0.0002		< 0.0025	
0.069	< 0.001	0.052	< 0.05	< 0.0005	67	8.9	< 0.005	< 0.001	0.38	< 0.0005	< 0.0005		0.26	< 0.0002		< 0.0025	
0.068	< 0.001	0.073	< 0.05	< 0.0005	71	9.4	< 0.005	< 0.001	0.35	< 0.0005	< 0.0005		0.22	< 0.0002		< 0.0025	
0.068	< 0.001	0.052	0.051	< 0.0005	69	9.6	< 0.005	< 0.001	0.31	< 0.0005	0.00054		0.22	< 0.0002		< 0.0025	
		0.054	0.058	< 0.0005	77	9.4				< 0.0005	0.0011		0.26				
		0.054	0.057	< 0.0005	75	11				< 0.0005	0.0011		0.23				
		0.053	0.052	< 0.0005	74	19				< 0.0005	0.0031		0.14				
0.056	< 0.001						< 0.005	< 0.001	0.3					< 0.0002		< 0.0025	
		< 0.01	< 0.01	< 0.001	61	39				< 0.001	< 0.001		0.058				
		0.011	< 0.01	< 0.001	58	40				< 0.001	< 0.001		0.062				
		0.013	0.016	< 0.001	60	40				< 0.001	0.0021		0.069				
0.064	< 0.001	< 0.01	0.012	< 0.001	80	45	< 0.004	0.002	0.36	< 0.001	0.0041		0.032	< 0.0002		0.002	
		0.01	< 0.01	< 0.001	57	57				< 0.001	< 0.001		0.023				
		< 0.01	< 0.01	< 0.001	59	57				< 0.001	< 0.001		0.046				
		< 0.01	< 0.01	< 0.001	61	64				< 0.001	< 0.001		0.05				
0.049	< 0.001	< 0.01	< 0.01	< 0.001	64	73	< 0.004	< 0.002	0.363	< 0.001	< 0.001		0.0094	< 0.0002		0.0046	
		< 0.01	< 0.01	< 0.001	67	83				< 0.001	< 0.001		0.04				
		0.092	0.018	< 0.001	73	66				< 0.001	< 0.001		0.045				
		< 0.01	< 0.01	< 0.001	65	76				< 0.001	< 0.001		0.017				
0.062	< 0.001	< 0.01	< 0.01	< 0.001	65	91	< 0.004	< 0.002	0.372	< 0.001	< 0.001		0.011	< 0.0002		0.0078	
		< 0.01	< 0.01	< 0.001	72	85				< 0.001	< 0.001		0.025				

R001646

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.041	< 0.001	< 0.01	< 0.01	< 0.001	67	56	< 0.004	< 0.002	0.279	< 0.001	< 0.001		0.0029	< 0.0002		0.0022	
		0.026	0.025	< 0.001	68	30				< 0.001	< 0.001		0.016				
		< 0.01	< 0.01	< 0.001	62	34				< 0.001	< 0.001		0.04				
		0.12	0.057	0.008	67	21				< 0.001	0.0073		0.04				
		0.011	< 0.01	< 0.001	70	18				< 0.001	< 0.001		0.011				
0.05	< 0.001	0.025	0.047	< 0.001	70	20	< 0.004	< 0.002	0.334	< 0.002	< 0.001		0.0055	< 0.0002		0.0016	
0.049	< 0.001	< 0.01	< 0.01	< 0.001		15	< 0.004	< 0.002	0.427	< 0.001	0.0018		0.47	< 0.0002	0.0011	< 0.001	
0.037	< 0.001	0.013	< 0.01	< 0.001		11	< 0.004	< 0.002	0.411	< 0.001	< 0.001		0.056	< 0.0002	< 0.001	< 0.001	
0.045	< 0.001		< 0.01	< 0.001	59	12	< 0.004	< 0.002	0.362		0.0015	< 0.01		< 0.0002	0.001	< 0.001	
0.037	< 0.001	0.02	< 0.01	< 0.001	49	16	< 0.004	< 0.002	0.472	< 0.001	< 0.001	< 0.01	0.012	< 0.0002	< 0.001	0.0013	
0.034	< 0.001	< 0.02	< 0.01	< 0.001	57	15	< 0.004	< 0.002	0.504	< 0.002	< 0.001	< 0.01	0.029	< 0.0002	< 0.001	< 0.001	
0.037	< 0.001		< 0.01	< 0.001	50	15	< 0.004	< 0.002	0.397		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.08	< 0.001		0.33	< 0.0005	110	37	0.0064	0.0023	0.46		0.0054			< 0.0002		0.0038	
0.11	< 0.001		0.33	< 0.0005	140	34	0.014	0.0047	0.41		0.011			< 0.0002		0.0034	
		0.34								< 0.0005			0.11				
0.055	< 0.001	0.18	0.24	< 0.0005	110	33	< 0.005	< 0.001	0.34	< 0.0005	0.0018		0.007	< 0.0002		0.0035	
0.055	< 0.001	0.25	0.23	< 0.0005	120	36	< 0.005	< 0.001	0.39	0.00061	0.0023		< 0.0025	< 0.0002		0.0053	
0.053	< 0.001	0.26	0.16	< 0.001	130	40	0.0056	< 0.002	0.42	< 0.001	0.0029		0.028	< 0.0002		0.0051	
0.041	< 0.001	0.24	0.15	< 0.001	120	40	< 0.004	< 0.002	0.34	< 0.001	< 0.001		0.016	< 0.0002		0.005	
		0.16								< 0.001			0.0015				
		0.14	0.15	< 0.001	110	44				< 0.001	< 0.001		< 0.001				
0.05	< 0.001	0.17	0.14	< 0.001	110	44	< 0.004	< 0.002	0.48	< 0.001	0.0035		0.0013	< 0.0002		0.0079	
		0.16	0.11	< 0.001	100	53				< 0.001	< 0.001		< 0.001				
		0.13	0.17	< 0.001	96	49				< 0.001	< 0.001		< 0.001				
		0.15	0.21	< 0.001	110	50				< 0.001	< 0.001		< 0.001				
0.034	< 0.001	0.19	0.18	< 0.001	110	44	< 0.004	< 0.002	0.393	< 0.001	< 0.001		< 0.001	< 0.0002		0.0099	
		0.16	0.14	< 0.001	110	5.1				< 0.001	< 0.001		< 0.001				
		0.18	0.13	< 0.001	110	45				< 0.001	< 0.001		< 0.001				
		0.28	0.19	< 0.001	130	50				< 0.001	0.0012		0.0021				
0.063	< 0.001	0.32	0.32	< 0.001	150	58	0.0066	0.0026	0.458	< 0.001	0.005		0.024	< 0.0002		0.005	
		0.17	0.19	< 0.001	120	47				< 0.001	< 0.001		< 0.001				
		0.16	0.15	< 0.001	99	49				< 0.001	< 0.001		< 0.001				
		0.3	0.18	< 0.001	120	47				< 0.001	< 0.001		< 0.001				
0.062	< 0.001	0.26	0.24	< 0.001	150	51	0.0087	0.0023	0.298	< 0.001	0.0056		< 0.001	< 0.0002		0.0045	
		0.45	0.33	< 0.001	140	47				0.15	0.0018		0.22				
		0.39	0.44	< 0.001	140	42				< 0.001	0.0061		< 0.001				
		0.44	0.5	< 0.001	150	45				< 0.001	0.0062		0.0021				
		0.42	0.51	< 0.001	120	39				< 0.001	0.0014		< 0.001				
0.029	< 0.001	0.37	0.31	< 0.001	130	45	< 0.004	< 0.002	0.406	< 0.002	< 0.001		< 0.002	< 0.0002		0.0035	
0.028	< 0.001	0.32	0.24	< 0.001		35	< 0.004	< 0.002	0.406	0.0017	0.0036		0.001	< 0.0002	< 0.001	0.0026	
0.03	< 0.001	0.44	0.33	< 0.001		38	< 0.004	< 0.002	0.402	< 0.001	< 0.001		< 0.001	< 0.0002	0.0036	0.0035	
0.031	< 0.001		0.5	< 0.001	130	38	< 0.004	< 0.002	0.347		0.0012	< 0.01		< 0.0002	0.0012	0.0024	
0.029	< 0.001	0.51	0.61	< 0.001	130	38	< 0.004	< 0.002	0.481	< 0.001	< 0.001	< 0.01	< 0.001	< 0.0002	< 0.001	0.0032	
0.028	< 0.001	0.61	0.98	< 0.001	170	39	< 0.004	< 0.002	0.562	< 0.002	< 0.001	< 0.01	< 0.002	< 0.0002	< 0.001	0.0021	
0.032	< 0.001		0.63	< 0.001	110	37	< 0.004	< 0.002	0.414		0.0027	< 0.01		< 0.0002	< 0.001	0.0022	
0.031	< 0.001		0.4	< 0.001		29	< 0.004	< 0.002	0.484		< 0.001	< 0.01		< 0.0002	< 0.001	0.0029	
0.079	< 0.001		0.06	< 0.0005	84	53	< 0.005	0.0017	0.48		0.0039			< 0.0002		< 0.0025	
0.073	< 0.001	0.057	< 0.05	< 0.0005	88	46	< 0.005	0.0012	0.5	< 0.0005	0.0025		0.056	< 0.0002		< 0.0025	
0.068	< 0.001	< 0.05	0.051	< 0.0005	85	45	< 0.005	< 0.001	0.42	< 0.0005	0.002		0.006	< 0.0002		< 0.0025	
0.061	< 0.001	< 0.05	0.05	< 0.0005	93	44	< 0.005	< 0.001	0.41	< 0.0005	0.00058		< 0.0025	< 0.0002		< 0.0025	

R001647

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		< 0.01								< 0.001			< 0.001				
		< 0.01	< 0.01	< 0.001	84	42				< 0.001	< 0.001		< 0.001				
0.07	< 0.001	< 0.01	0.013	< 0.001	98	43	< 0.004	< 0.002	0.48	< 0.001	< 0.001		< 0.001	< 0.0002		0.0042	
		< 0.01	< 0.01	< 0.001	92	42				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	99	< 100				< 0.001	< 0.001		< 0.001				
		< 0.01	0.01	< 0.001	98	41				< 0.001	< 0.001		< 0.001				
0.068	< 0.001	< 0.01	< 0.01	< 0.001	98	43	< 0.004	< 0.002	0.459	< 0.001	< 0.001		< 0.001	< 0.0002		0.0021	
		< 0.01	< 0.01	< 0.001	82	42				< 0.001	< 0.001		< 0.001				
		0.032	< 0.01	< 0.001	100	43				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	110	40				< 0.001	0.0011		0.0012				
0.072	< 0.001	< 0.01	< 0.01	< 0.001	110	44	< 0.004	< 0.002	0.461	< 0.001	< 0.001		< 0.001	< 0.0002		0.0029	
		< 0.01	< 0.01	< 0.001	98	37				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	100	35				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	100	32				< 0.001	< 0.001		< 0.001				
0.06	< 0.001	< 0.01	< 0.01	< 0.001	110	40	< 0.004	< 0.002	0.355	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		0.27	0.015	< 0.001	93	36				0.15	< 0.001		0.23				
		< 0.01	< 0.01	< 0.001	110	34				< 0.001	0.0014		< 0.001				
		0.036	0.022	< 0.001	110	37				< 0.001	0.0026		< 0.001				
		< 0.01	< 0.01	< 0.001	99	31				< 0.001	0.0022		< 0.001				
0.059	< 0.001	< 0.02	< 0.01	< 0.001	110	37	< 0.004	< 0.002	0.399	< 0.002	< 0.001		< 0.002	< 0.0002		0.0012	
0.06	< 0.001	< 0.01	0.031	< 0.001		29	< 0.004	< 0.002	0.493	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.058	< 0.001	< 0.01	0.046	< 0.001		33	< 0.004	< 0.002	0.361	< 0.001	< 0.001		< 0.001	< 0.0002	0.0024	0.0016	
0.099	< 0.001	< 0.01	< 0.01	< 0.001		29	0.011	0.0022	0.516	< 0.001	0.0049		0.0013	< 0.0002	0.0013	< 0.001	
0.059	< 0.001	< 0.01	< 0.01	< 0.001		29	< 0.004	< 0.002	0.561	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.094	< 0.001		< 0.05	< 0.0005	120	35	< 0.005	< 0.001	0.38		< 0.0005			< 0.0002		< 0.0025	
0.09	< 0.001	< 0.05	0.051	< 0.0005	140	28	< 0.005	< 0.001	0.33	< 0.0005	0.00093		0.097	< 0.0002		< 0.0025	
0.085	< 0.001	0.054	< 0.05	< 0.0005	150	30	< 0.005	< 0.001	0.29	< 0.0005	< 0.0005		0.063	< 0.0002		< 0.0025	
0.079	< 0.001	< 0.05	< 0.05	< 0.0005	190	25	< 0.005	< 0.001	0.26	< 0.0005	< 0.0005		0.055	< 0.0002		< 0.0025	
0.055	< 0.001	0.019	0.016	< 0.001	180	31	0.034	< 0.002	0.33	< 0.001	< 0.001		0.041	< 0.0002		0.0016	
0.048	< 0.001	0.023	0.023	< 0.001	160	30	< 0.004	< 0.002	0.37	< 0.001	< 0.001		0.048	< 0.0002		< 0.001	
		0.024								< 0.001			0.052				
		0.035	0.039	< 0.001	130	27				< 0.001	< 0.001		0.058				
0.05	< 0.001	0.16	0.21	< 0.001	170	33	< 0.004	< 0.002	0.38	< 0.001	< 0.001		0.047	< 0.0002		< 0.001	
		0.16	0.14	< 0.001	160	59				< 0.001	< 0.001		0.042				
		0.097	0.12	< 0.001	150	29				< 0.001	< 0.001		0.029				
		0.13	0.15	< 0.001	150	29				< 0.001	< 0.001		0.041				
0.043	< 0.001	0.27	0.26	< 0.001	180	27	< 0.004	< 0.002	0.359	< 0.001	< 0.001		0.033	< 0.0002		0.0012	
		0.21	0.2	< 0.001	160	27				< 0.001	< 0.001		0.028				
		0.12	0.094	< 0.001	140	32				< 0.001	< 0.001		0.022				
		0.27	0.2	< 0.001	160	33				< 0.001	0.0037		0.026				
0.046	< 0.001	0.48	0.46	< 0.001	180	37	< 0.004	< 0.002	0.33	< 0.001	< 0.001		0.03	< 0.0002		< 0.002	
		0.18	0.29	< 0.001	180	4				< 0.001	< 0.001		0.013				
		0.21	0.25	< 0.001	160	35				< 0.001	< 0.001		0.022				
		0.18	0.18	< 0.001	140	37				< 0.001	< 0.001		0.015				
0.039	< 0.001	0.52	0.36	< 0.001	150	38	< 0.004	< 0.002	0.286	< 0.001	< 0.001		0.015	< 0.0002		< 0.001	
		0.62	0.35	< 0.001	160	47				0.22	< 0.001		0.33				
		0.25	0.26	< 0.001	140	37				< 0.001	< 0.001		0.01				
		0.32	0.29	< 0.001	150	37				< 0.001	0.0011		0.013				
		0.58	0.45	< 0.001	150	46				< 0.001	< 0.001		0.018				
0.028	< 0.001	0.29	0.48	< 0.001	200	41	< 0.004	< 0.002	0.32	< 0.002	< 0.001		0.019	< 0.0002		< 0.001	
0.044	< 0.001	0.4	0.12	< 0.001		39	< 0.004	< 0.002	0.382	< 0.001	< 0.001		0.0011	< 0.0002	< 0.001	< 0.001	

R001648

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.043	< 0.001	0.43	0.42	< 0.001	150	45	< 0.004	< 0.002	0.401	< 0.001	< 0.001	< 0.01	0.01	< 0.0002	< 0.001	< 0.001	
0.031	< 0.001	0.31	0.29	< 0.001	170	44	< 0.004	< 0.002	0.537	< 0.001	< 0.001	< 0.01	0.012	< 0.0002	< 0.001	< 0.001	
0.032	< 0.001		0.17	< 0.001	120	46	< 0.004	< 0.002	0.294		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.036	< 0.001		0.15	< 0.001		48	< 0.004	< 0.002	0.39		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.12	< 0.001		0.053	< 0.0005	100	55	0.0059	0.0028	0.34		0.0091			< 0.0002		< 0.0025	
0.092	< 0.001	0.057	< 0.05	< 0.0005	100	54	< 0.005	< 0.001	0.35	< 0.0005	0.0012		0.007	< 0.0002		< 0.0025	
0.09	< 0.001	< 0.05	< 0.05	< 0.0005	100	50	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.0039	< 0.0002		< 0.0025	
0.091	< 0.001	< 0.05	< 0.05	< 0.0005	110	49	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.0056	< 0.0002		< 0.0025	
0.09	< 0.001	< 0.01	< 0.01	< 0.001	110	45	< 0.004	< 0.002	0.32	< 0.001	0.0015		< 0.001	< 0.0002		0.0022	
0.08	< 0.001	< 0.01	< 0.01	< 0.001	110	44	< 0.004	< 0.002	0.35	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		< 0.01								< 0.001			< 0.001				
		< 0.01	0.012	< 0.001	120	38				< 0.001	< 0.001		< 0.001				
0.077	0.0018	< 0.01	0.012	0.0014	110	39	< 0.004	< 0.002	0.36	< 0.001	0.0018		< 0.001	< 0.0002		< 0.001	
		< 0.01	< 0.01	< 0.001	120	36				< 0.001	< 0.001		< 0.001				
		0.013	< 0.01	< 0.001	120	37				< 0.001	< 0.001		< 0.001				
		0.035	0.039	< 0.001	120	37				< 0.001	< 0.001		< 0.001				
0.068	< 0.001	0.076	0.052	< 0.001	110	34	< 0.004	< 0.002	0.379	< 0.001	< 0.001		0.001	< 0.0002		0.0014	
		0.12	0.11	< 0.001	120	36				< 0.001	< 0.001		< 0.001				
		0.15	0.13	< 0.001	120	40				< 0.001	< 0.001		< 0.001				
		0.18	0.16	< 0.001	120	37				< 0.001	0.0031		< 0.001				
0.059	< 0.001	0.26	0.25	< 0.001	130	36	< 0.004	< 0.002	0.382	< 0.001	< 0.001		< 0.001	< 0.0002		0.0015	
		0.25	0.27	< 0.001	120	3.6				< 0.001	< 0.001		0.0073				
		0.31	0.31	< 0.001	110	32				< 0.001	0.0015		< 0.001				
		0.52	0.46	< 0.001	110	31				< 0.001	< 0.001		< 0.001				
0.063	< 0.001	0.79	0.47	< 0.001	110	32	< 0.004	< 0.002	0.262	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		0.52	0.52	< 0.001	98	27				0.0034	< 0.001		0.0059				
		0.57	0.61	< 0.001	120	25				< 0.001	< 0.001		< 0.001				
		0.62	0.55	< 0.001	100	23				< 0.001	0.01		< 0.001				
		0.68	0.5	< 0.001	110	19				< 0.001	0.0029		0.0036				
0.052	< 0.001	0.57	0.53	< 0.001	110	24	< 0.004	< 0.002	0.341	< 0.002	< 0.001		< 0.002	< 0.0002		< 0.001	
0.068	< 0.001	0.48	0.49	< 0.001		24	< 0.004	< 0.002	0.403	< 0.001	0.0018		0.0015	< 0.0002	< 0.001	0.0014	
0.061	< 0.001	0.43	0.74	< 0.001		22	< 0.004	< 0.002	0.265	< 0.001	< 0.001		< 0.001	< 0.0002	0.0012	< 0.001	
0.07	< 0.001	0.87	0.65	< 0.001		22	< 0.004	< 0.002	0.455	< 0.001	0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.057	< 0.001	0.97	0.63	< 0.001		22	< 0.004	< 0.002	0.417	< 0.001	< 0.001		0.046	< 0.0002	< 0.001	< 0.001	
0.12	< 0.001		4.5	< 0.0005	300	14	< 0.025	< 0.005	0.22		0.01			< 0.0002		< 0.012	
0.032	< 0.001	2.4	2.5	< 0.0005	140	12	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.032	< 0.0002		< 0.0025	
0.032	< 0.001	1.2	1.2	< 0.0005	120	13	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.023	< 0.0002		< 0.0025	
0.035	< 0.001	1.3	1.3	< 0.0005	160	23	< 0.005	< 0.001	0.27	< 0.0005	0.00053		0.029	< 0.0002		< 0.0025	
0.047	< 0.001	2.9	2.9	< 0.001	180	18	0.0087	< 0.002	0.33	< 0.001	0.0017		0.018	< 0.0002		0.0014	
0.038	< 0.001	2.9	2.8	< 0.001	180	9.9	< 0.004	< 0.002	0.4	< 0.001	< 0.001		0.019	< 0.0002		< 0.001	
		2.6								< 0.001			0.026				
		3.7	4.1	< 0.001	260	9.7				< 0.001	0.0045		0.16				
0.046	< 0.001	3.6	3.6	< 0.001	230	11	< 0.004	< 0.002	0.34	< 0.001	< 0.001		0.016	< 0.0002		< 0.001	
		3.6	3.8	< 0.001	240	13				< 0.001	< 0.001		0.04				
		4.3	4.2	< 0.001	200	9.2				< 0.001	< 0.001		0.03				
		4.3	4.4	< 0.001	260	17				< 0.001	0.0059		0.09				
0.039	< 0.001	3.8	3.6	< 0.001	310	15	0.0047	< 0.002	0.281	< 0.001	< 0.001		0.0081	< 0.0002		0.0015	
		3.7	3.4	< 0.001	240	11				< 0.001	0.0015		0.01				
		4.6	4.2	< 0.001	260	13				< 0.001	0.0024		0.09				
		3.7	3.9	< 0.001	270	19				< 0.001	0.0037		0.28				
		3.4	3.8	< 0.001	250	24				< 0.001	0.0015		< 0.001				

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Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		4.2	4.1	< 0.001	240	20				< 0.001	0.0078		< 0.001				
		1.9	3.5	< 0.001	200	16				< 0.001	0.0012		0.003				
		4.6	4.6	< 0.001	230	20				< 0.001	0.0079		0.025				
0.056	< 0.001	0.91	1.8	< 0.001	180	22	< 0.004	< 0.002	< 0.25	< 0.002	< 0.001		0.0024	< 0.0002		0.0012	
0.035	< 0.001	3	4	< 0.001		30	< 0.004	< 0.002	0.307	< 0.001	0.001		0.012	< 0.0002	0.0014	0.0014	
0.042	< 0.001	4	2.3	< 0.001		26	< 0.004	< 0.002	0.349	0.0044	0.0016		0.0064	< 0.0002	< 0.001	< 0.001	
0.039	< 0.001	2.5	2.4	< 0.001		14	< 0.004	< 0.002	0.452	< 0.001	< 0.001		0.0036	< 0.0002	< 0.001	< 0.001	
0.16	0.0026		0.087	< 0.0025	94	38	< 0.025	< 0.005	0.75		0.035			< 0.0002		< 0.012	
0.079	< 0.001	0.057	0.062	< 0.0005	91	40	0.0059	< 0.001	0.57	< 0.0005	0.0037		0.03	< 0.0002		< 0.0025	
0.075	< 0.001	0.057	0.052	< 0.0005	91	36	< 0.005	< 0.001	0.53	< 0.0005	0.00079		0.0093	< 0.0002		< 0.0025	
						38			0.51								
0.083	< 0.001	0.057	0.058	< 0.0005	110		< 0.005	< 0.001		< 0.0005	0.0016		0.01	< 0.0002		< 0.0025	
0.067	< 0.001	0.035	0.033	< 0.001	100	40	0.0051	< 0.002	0.49	< 0.001	< 0.001		0.012	< 0.0002		0.0014	
0.063	< 0.001	0.023	0.022	< 0.001	93	40	< 0.004	< 0.002	0.54	< 0.001	< 0.001		0.0054	< 0.0002		< 0.001	
		0.024								< 0.001			0.005				
		0.013	0.044	< 0.001	96	35				< 0.001	< 0.001		0.0018				
0.078	< 0.001	0.036	0.052	< 0.001	96	36	< 0.004	< 0.002	0.53	< 0.001	0.001		0.0041	< 0.0002		< 0.001	
		0.043	0.039	< 0.001	95	36				< 0.001	< 0.001		0.0016				
		0.011	< 0.01	< 0.001	96	37				< 0.001	< 0.001		0.001				
		0.081	0.08	< 0.001	94	35				< 0.001	< 0.001		< 0.001				
0.075	< 0.001	< 0.01	0.06	< 0.001	130	32	0.0052	< 0.002	0.501	< 0.001	< 0.001		< 0.001	< 0.0002		0.0022	
		0.066	0.073	< 0.001	97	38				< 0.001	< 0.001		0.0014				
		< 0.01	< 0.01	< 0.001	100	38				< 0.001	< 0.001		< 0.001				
		0.012	0.083	< 0.001	100	36				< 0.001	< 0.001		< 0.001				
0.081	< 0.001	0.014	0.023	< 0.001	110	35	< 0.004	< 0.002	0.51	< 0.001	0.0011		< 0.001	< 0.0002		0.0031	
		0.036	0.031	< 0.001	99	3.8				< 0.001	< 0.001		< 0.001				
		0.022	< 0.01	< 0.001	100	32				< 0.001	< 0.001		< 0.001				
		< 0.01	0.021	< 0.001	130	31				< 0.001	< 0.001		< 0.001				
		0.018	0.027	< 0.001	120	29				< 0.001	0.006		< 0.001				
		0.028	0.019	< 0.001	100	28				< 0.001	0.0024		< 0.001				
		0.015	0.021	< 0.001	100	30				< 0.001	< 0.001		< 0.001				
0.34	0.0016	< 0.02	0.036	< 0.001	170	34	0.043	0.0047	0.486	< 0.002	0.022		< 0.002	< 0.0002		0.0034	
0.096	< 0.001	0.037	0.015	< 0.001		26	< 0.004	< 0.002	0.377	< 0.001	0.0012		< 0.001	< 0.0002	0.0012	0.001	
0.077	< 0.001		0.043	< 0.001	120	28	< 0.004	< 0.002	0.345		< 0.001	0.013		< 0.0002	0.0017	< 0.001	
0.09	< 0.001		0.021	< 0.001	120	23	< 0.004	< 0.002	0.456		0.0014	0.015		< 0.0002	0.0013	0.0018	
0.089	< 0.001	0.027	0.029	< 0.001		28	< 0.004	< 0.002	0.456	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.079	< 0.001	0.013	< 0.01	< 0.001	130	22	< 0.004	< 0.002	0.549	< 0.001	< 0.001	0.012	< 0.001	< 0.0002	< 0.001	0.0017	
0.085	< 0.001		0.019	< 0.001	110	23	< 0.004	< 0.002	0.443		< 0.001	< 0.01		< 0.0002	< 0.001	0.0017	
0.081	< 0.001		< 0.01	< 0.001		23	< 0.004	< 0.002	0.445		< 0.001	0.011		< 0.0002	< 0.001	0.002	
0.61	0.0027		0.11	< 0.0025	190	41	0.052	0.04	0.79		0.072			0.00023		< 0.012	
0.22	0.0011	< 0.05	0.074	< 0.0005	110	43	0.037	0.017	0.47	0.028	0.029		1.6	< 0.0002		< 0.0025	
0.093	< 0.001	< 0.05	0.062	< 0.0005	92	39	0.0094	0.0019	0.41	< 0.0005	0.0037		0.02	< 0.0002		< 0.0025	
0.075	< 0.001		0.065	< 0.0005	93	43	< 0.005	< 0.001	0.4		0.00092			< 0.0002		< 0.0025	
		0.073								< 0.0005			0.0037				
0.092	< 0.001	0.02	0.021	< 0.001	100	46	0.033	< 0.002	0.4	< 0.001	0.0031		0.0011	< 0.0002		0.0032	
0.085	< 0.001	0.015	0.019	< 0.001	85	46	0.0092	< 0.002	0.42	< 0.001	0.0029		0.003	< 0.0002		0.0021	
		0.012								< 0.001			0.0055				
		< 0.01	< 0.01	< 0.001	86					< 0.001	< 0.001		0.0021				
0.085	< 0.001	0.016	0.025	< 0.001	97	40	< 0.004	< 0.002	0.38	< 0.001	0.0024		0.0031	< 0.0002		0.003	

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Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.031	0.044	< 0.001	110	36				< 0.001	0.0056		0.0054				
0.12	< 0.001		0.027	< 0.001	160	37	0.012	0.0022	0.326		0.0035			< 0.0002		0.0014	
		0.021	0.026	< 0.001	110	30				< 0.001	< 0.001		0.0052				
						34											
		< 0.01	< 0.01	< 0.001	110					< 0.001	0.0011		0.013				
			< 0.01	< 0.001	120	11					0.0012						
		0.022	0.018	< 0.001	110	3.3				< 0.001	< 0.001		< 0.001				
		0.02	0.021	< 0.001	93	18				< 0.001	< 0.001		< 0.001				
		0.012	0.053	< 0.001	130	30				< 0.001	0.0019		< 0.001				
			0.024	< 0.001	84	3.6					0.0033						
		0.032								< 0.001			0.003				
0.09	< 0.001	0.047	0.025	< 0.001		1.2	< 0.004	< 0.002	0.495	< 0.001	0.0013		0.0017	< 0.0002	0.001	< 0.001	
0.078	< 0.001		0.026	< 0.001	93	82	0.016	< 0.002	0.41		< 0.001			< 0.0002		0.0058	
		0.012								< 0.001			0.052				
0.069	< 0.001	0.014	0.014	< 0.001	90	55	0.0063	< 0.002	0.55	< 0.001	0.0025		0.1	< 0.0002		0.0019	
0.15	< 0.001	< 0.01	0.026	< 0.001	97	60	0.022	0.0055	0.43	< 0.001	0.013		0.027	< 0.0002		0.0032	
0.34	0.0018	< 0.01	0.023	< 0.001	170	62	0.034	0.018	0.42	< 0.001	0.033		0.032	< 0.0002		0.0029	
0.086	< 0.001	0.093	0.023	< 0.001	100	85	0.048	< 0.002	0.51	< 0.001	0.0031		0.04	< 0.0002		0.012	
0.098	< 0.001	0.017	0.017	< 0.001	110	82	0.007	0.0028	0.359	< 0.001	0.0059		0.46	< 0.0002		0.0025	
0.11	< 0.001	0.54	0.54	< 0.001		310	0.0092	0.0034	0.336	< 0.001	0.008		0.14	< 0.0002	0.0014	0.041	
0.19	< 0.001	0.5	0.2	< 0.001		180	0.017	0.0066	0.441	< 0.001	0.015		0.39	< 0.0002	0.0026	0.014	
0.095	< 0.001		0.062	< 0.0005	90	59	0.01	0.0059	0.5		0.0092			< 0.0002		< 0.0025	
0.065	< 0.001	0.062	0.056	< 0.0005	81	50	< 0.005	< 0.001	0.5	< 0.0005	0.00068		0.26	< 0.0002		< 0.0025	
0.067	< 0.001	< 0.05	0.057	< 0.0005	80	54	< 0.005	< 0.001	0.43	< 0.0005	0.0013		0.094	< 0.0002		< 0.0025	
0.065	< 0.001	< 0.05	< 0.05	< 0.0005	85	57	< 0.005	< 0.001	0.42	< 0.0005	0.00068		0.059	< 0.0002		< 0.0025	
0.068	< 0.001	< 0.01	0.01	< 0.001	89	69	0.011	< 0.002	0.42	< 0.001	< 0.001		0.022	< 0.0002		0.005	
0.062	< 0.001	< 0.01	< 0.01	< 0.001	91	64	< 0.004	< 0.002	0.43	< 0.001	< 0.001		0.019	< 0.0002		0.0015	
		< 0.01								< 0.001			0.014				
		< 0.01	< 0.01	< 0.001	89	52				< 0.001	< 0.001		0.0088				
0.098	< 0.001	< 0.01	0.016	< 0.001	100	50	< 0.004	0.0029	0.44	< 0.001	0.0052		0.014	< 0.0002		0.0038	
		< 0.01	< 0.01	< 0.001	130	49				< 0.001	< 0.001		0.0033				
		< 0.01	< 0.01	< 0.001	83	51				< 0.001	< 0.001		0.0071				
		0.017	0.019	< 0.001	84	53				< 0.001	< 0.001		0.0035				
0.05	< 0.001	< 0.01	< 0.01	< 0.001	120	51	< 0.004	< 0.002	0.54	< 0.001	< 0.001		0.0049	< 0.0002		0.0041	
		< 0.01	< 0.01	< 0.001	69	54				< 0.001	< 0.001		0.042				
		< 0.01	< 0.01	< 0.001	98	71				< 0.001	< 0.001		0.002				
		< 0.01	< 0.01	< 0.001	97	62				< 0.001	0.001		0.019				
0.06	< 0.001	< 0.01	< 0.01	< 0.001	120	60	< 0.004	< 0.002	0.418	< 0.001	< 0.001		0.0019	< 0.0002		0.0034	
		0.01	0.011	< 0.001	87	56				< 0.001	< 0.001		0.0011				
		< 0.01	< 0.01	< 0.001	88	55				< 0.001	< 0.001		0.0078				
		0.015	0.011	< 0.001	97	55				< 0.001	< 0.001		0.078				
0.058	< 0.001	0.022	0.015	< 0.001	86	54	< 0.004	< 0.002	0.331	< 0.001	< 0.001		0.029	< 0.0002		< 0.001	
		0.038	0.016	< 0.001	94	50				0.022	< 0.001		0.034				
		0.015	0.11	< 0.001	97	56				< 0.001	< 0.001		0.024				
		0.025	0.012	< 0.001	92	63				< 0.001	< 0.001		0.026				
		0.032	0.031	< 0.001	100	74				< 0.001	< 0.001		0.017				
0.029	< 0.001	0.047	0.016	< 0.001	170	46	< 0.004	< 0.002	0.518	< 0.002	< 0.001		0.0033	0.00024		0.0056	
0.11	< 0.001	0.031	0.065	< 0.001		96	0.0042	0.0025	0.361	< 0.001	0.0041		0.013	< 0.0002	0.0015	0.02	
0.096	< 0.001	1.3	1.4	< 0.001		120	0.0047	0.0033	< 0.25	< 0.001	0.0025		0.032	< 0.0002	0.0015	0.017	
0.053	< 0.001		0.63	< 0.001	140	61	< 0.004	< 0.002	0.334		0.0015	0.014		< 0.0002	< 0.001	0.0041	
0.082	< 0.001	0.29	0.26	< 0.001	180	130	< 0.004	< 0.002	0.392	< 0.001	< 0.001	0.012	0.011	< 0.0002	0.043	0.017	

	Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
	0.057	< 0.001		0.49	< 0.001		130	< 0.004	< 0.002	0.272		< 0.001	0.011		< 0.0002	< 0.001	0.017	
	0.049	< 0.01	< 0.5	< 0.5	< 0.005	63	47	< 0.05	< 0.01	0.37	< 0.005	< 0.005		0.11	< 0.0002		< 0.025	
	0.058	< 0.001	0.06	0.062	< 0.0005	59	51	< 0.005	< 0.001	0.37	< 0.0005	0.00055		0.18	< 0.0002		0.0028	
	0.052	< 0.001	< 0.05	< 0.05	< 0.0005	66	43	< 0.005	< 0.001	0.33	< 0.0005	< 0.0005		0.13	< 0.0002		0.0027	
	0.053	< 0.001	0.05	< 0.05	< 0.0005	63	44	< 0.005	< 0.001	0.39	< 0.0005	< 0.0005		0.13	< 0.0002		0.0026	
	0.05	< 0.001	< 0.05	< 0.05	< 0.0005	69	45	< 0.005	< 0.001	0.35	< 0.0005	< 0.0005		0.078	< 0.0002		< 0.0025	
	0.11	< 0.001	< 0.05	< 0.05	< 0.0005	120	110	< 0.005	< 0.001	0.26	< 0.0005	0.0007		0.24	< 0.0002		< 0.0025	
			< 0.05	< 0.05	< 0.0005	59	40				< 0.0005	< 0.0005		0.012				
			< 0.05	< 0.05	< 0.0005	61	40				< 0.0005	< 0.0005		0.019				
			< 0.05	< 0.05	< 0.0005	60	41				< 0.0005	0.0006		0.0069				
	0.039	< 0.001						< 0.005	< 0.001	0.32					< 0.0002		0.0042	
			< 0.01	< 0.01	< 0.001	66	65				< 0.001	< 0.001		0.0031				
			0.01	< 0.01	< 0.001	60	60				< 0.001	< 0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	58	35				< 0.001	< 0.001		0.018				
	0.082	< 0.001	< 0.01	0.012	< 0.001	100	57	< 0.004	0.0024	0.36	< 0.001	0.0055		< 0.001	< 0.0002		0.0051	
			< 0.01	< 0.01	< 0.001	< 0.1	87				< 0.001	< 0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	63	45				< 0.001	< 0.001		0.015				
			< 0.01	< 0.01	< 0.001	60	51				< 0.001	< 0.001		0.0033				
	0.047	< 0.001	< 0.01	< 0.01	< 0.001	81	54	< 0.004	< 0.002	0.44	< 0.001	< 0.001		< 0.001	< 0.0002		0.0055	
			< 0.01	< 0.01	< 0.001	65	67				< 0.001	< 0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	72	48				< 0.001	0.0026		0.0073				
			< 0.01	< 0.01	< 0.001	63	46				< 0.001	0.0014		0.0081				
	0.036	< 0.001	< 0.01	< 0.01	< 0.001	63	46	< 0.004	< 0.002	0.423	< 0.001	< 0.001		< 0.001	< 0.0002		0.0042	
			< 0.01	< 0.01	< 0.001	67	59				< 0.001	< 0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	73	52				< 0.001	< 0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	72	51				< 0.001	< 0.001		< 0.001				
	0.041	< 0.001	< 0.01	< 0.01	< 0.001	69	56	< 0.004	< 0.002	0.338	< 0.001	< 0.001		< 0.001	< 0.0002		0.0031	
			0.017	0.029	< 0.001	73	55				< 0.001	0.001		< 0.001				
			< 0.01	< 0.01	< 0.001	75	55				< 0.001	< 0.001		< 0.001				
			0.013	< 0.01	< 0.001	76	60				< 0.001	0.002		< 0.001				
			< 0.01	< 0.01	< 0.001	74	62				< 0.001	< 0.001		< 0.001				
	0.045	< 0.001	0.025	< 0.01	< 0.001	71	67	< 0.004	< 0.002	0.358	< 0.002	< 0.001		0.026	< 0.0002		0.0037	
	0.049	< 0.001	0.01	< 0.01	< 0.001		53	< 0.004	< 0.002	0.415	< 0.001	< 0.001		0.074	< 0.0002	0.0019	0.0033	
	0.056	< 0.001	0.025	0.024	< 0.001		54	< 0.004	< 0.002	0.318	< 0.001	< 0.001		0.0035	< 0.0002	0.0074	0.0017	
	0.11	< 0.001		0.029	< 0.001	120	54	0.019	0.0059	0.343		0.012	0.019		< 0.0002	0.0045	0.0032	
	0.048	< 0.001	0.012	< 0.01	< 0.001	60	55	< 0.004	< 0.002	0.466	< 0.001	0.0019	< 0.01	< 0.001	< 0.0002	0.0016	0.0033	
	0.045	< 0.001		< 0.01	< 0.001	63	50	< 0.004	< 0.002	0.429		< 0.001	< 0.01		< 0.0002	0.0014	0.0044	
	0.044	< 0.001	< 0.01	< 0.01	< 0.001		45	< 0.004	< 0.002	0.497	< 0.001	0.0014		< 0.001	< 0.0002	0.0014	0.0035	
	0.045	< 0.001		< 0.01	< 0.001	65	46	< 0.004	< 0.002	0.397		0.0014	< 0.01		< 0.0002	0.0016	0.0048	
	0.044	< 0.001		< 0.01	< 0.001		49	< 0.004	< 0.002	0.473		< 0.001	< 0.01		< 0.0002	0.0014	0.0034	
	0.14	< 0.001		< 0.01	< 0.001	150	74	0.011	0.0056	0.349		0.0063	0.013		< 0.0002	0.0015	< 0.001	
	0.067	< 0.001		0.01	< 0.001	120	55	< 0.004	< 0.002	0.411		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
	0.072	< 0.001		< 0.01	< 0.001	130	72	< 0.004	< 0.002	0.405		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
	0.078	< 0.001		0.012	< 0.001	140	70	< 0.004	< 0.002	0.368		0.0011	< 0.01		< 0.0002	< 0.001	< 0.001	
			< 0.01								< 0.001			0.48				
	0.037	< 0.001		3.3	< 0.001	440	3.6	0.0053	0.25	< 0.25		0.0031	0.055		< 0.0002	< 0.001	0.002	
	0.015	< 0.001		3.4	< 0.001	330	6	< 0.004	0.24	< 0.25		< 0.001	0.05		< 0.0002	< 0.001	< 0.002	
	0.014	< 0.001		3.5	< 0.001	380	3	< 0.004	0.27	0.758		< 0.001	0.046		< 0.0002	< 0.001	< 0.001	
	0.053	< 0.001		4.1	0.0012	450	5.3	0.0096	0.28	< 0.25		0.0048	0.051		0.00093	< 0.001	0.0055	
	0.021	< 0.001		4	0.0013		< 5	< 0.004	0.27	< 0.25		0.0029	0.054		< 0.0002	< 0.001	0.001	
	0.082	< 0.001		6.6	0.001	270	2.8	0.019	0.014	< 0.25		0.015	0.054		< 0.0002	0.006	0.002	

R001651

R001652

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.047	< 0.001		7.4	< 0.001	240	2.2	0.0085	0.0074	0.33		0.0072	0.033		< 0.0002	0.0033	< 0.001	
0.054	< 0.001		6.9	< 0.001		2.6	0.011	0.007	0.463		0.0079	0.047		< 0.0002	0.0034	0.0012	
0.14	< 0.001		0.039	< 0.001	78	6.8	0.0062	< 0.002	0.442		0.0021	< 0.01		< 0.0002	0.004	< 0.001	
0.13	< 0.001		0.064	< 0.001	69	4.1	< 0.004	< 0.002	0.518		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.16	< 0.001		0.014	< 0.001	71	2.7	< 0.004	< 0.002	0.478		< 0.001	< 0.01		< 0.0002	0.0012	< 0.001	
0.24	< 0.001		0.027	< 0.001	140	4.5	0.0073	0.0029	0.485		0.0021	< 0.01		< 0.0002	0.0055	0.0068	
0.2	< 0.001		0.042	< 0.001		4	< 0.004	0.0024	0.539		< 0.001	< 0.01		< 0.0002	0.001	< 0.001	
0.05	< 0.001		2.1	< 0.001	110	53	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.043	< 0.001		1.6	< 0.001	110	49	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.041	< 0.001		1.4	< 0.001	89	46	< 0.004	< 0.002	0.287		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.055	< 0.001		3.2	< 0.001	120	62	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.052	< 0.001		3.4	< 0.001		61	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.051	< 0.001		17	0.0012	330	14	0.0051	0.0034	0.454		0.0085	< 0.01		< 0.0002	0.001	< 0.001	
0.018	< 0.001		16	< 0.001	320	11	< 0.004	< 0.002	0.459		0.0023	< 0.01		< 0.0002	< 0.001	< 0.001	
0.02	< 0.001		15	< 0.001	320	9.3	< 0.004	< 0.002	0.544		0.0011	< 0.01		< 0.0002	< 0.001	< 0.001	
0.028	< 0.001		17	< 0.001	280	3.4	< 0.004	0.0038	< 0.25		0.0018	< 0.01		< 0.0002	0.0016	< 0.001	
0.022	< 0.001		13	< 0.001		19	< 0.004	0.0021	0.525		0.0023	< 0.01		< 0.0002	0.0011	< 0.001	
		1.6								< 0.001			5.5				
0.024			1.9			4.4			0.345								
		0.052								< 0.001			0.21				
0.024			0.078			14			0.289								
		0.35								< 0.001			0.035				
		0.14								< 0.001			0.094				

R001653

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**

Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405

Location Type Class

APW-2

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
B, diss	mg/L	8	7.245	7.180	8.100	6.300	0.626	0.27	Yes / Yes	0.00
Mn, diss	mg/L	8	0.432	0.414	0.730	0.130	0.166	0.01	Yes / No	0.00
SO4, diss	mg/L	8	805.375	840.000	1,100.000	500.000	173.105	5.17	Yes / Yes	12.50
TDS	mg/L	8	1,651.250	1,600.000	1,810.000	1,600.000	78.456	0.00	No / No	0.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001654

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G151

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	3	0.0007	0.0005	0.0012	0.0005	0.0004	0.00	No / No	66.67
B, diss	mg/L	16	0.016	0.012	0.052	0.003	0.013	0.00	No / Yes	50.00
B, tot	mg/L	3	0.0183	0.0190	0.0260	0.0100	0.0080	-0.03	Yes / Yes	0.00
Ba, tot	mg/L	3	0.0643	0.0670	0.0690	0.0570	0.0064	0.02	Yes / Yes	0.00
Be, tot	mg/L	3	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Cd,tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	3	58.333	58.000	67.000	50.000	8.505	16.23	Yes / Yes	0.00
Co, tot	mg/L	3	0.0010	0.0010	0.0010	0.0010	0.0000	0.00	No / No	100.00
Cr, tot	mg/L	3	0.0020	0.0020	0.0020	0.0020	0.0000	0.00	No / No	100.00
F, tot	mg/L	3	0.609	0.649	0.691	0.486	0.108	-0.09	Yes / Yes	0.00
Hg, tot	mg/L	3	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	16	0.131	0.092	0.560	0.011	0.131	0.00	No / Yes	0.00
Mn, tot	mg/L	3	0.225	0.230	0.360	0.086	0.137	0.56	Yes / Yes	0.00
Pb, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Sb, tot	mg/L	3	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	3	0.0025	0.0024	0.0029	0.0021	0.0004	0.00	Yes / Yes	0.00
SO4, diss	mg/L	16	111.563	110.000	140.000	100.000	11.213	4.79	No / No	0.00
SO4, tot	mg/L	3	104.333	98.000	120.000	95.000	13.650	6.09	Yes / Yes	0.00
TDS	mg/L	17	551.176	560.000	660.000	500.000	44.424	0.00	Yes / Yes	0.00
Tl, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001655

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G152

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	3	0.0016	0.0014	0.0023	0.0011	0.0006	0.00	Yes / Yes	0.00
B, diss	mg/L	16	0.047	0.041	0.110	0.015	0.025	0.01	No / Yes	0.00
B, tot	mg/L	3	0.0383	0.0360	0.0470	0.0320	0.0078	-0.03	Yes / Yes	0.00
Ba, tot	mg/L	3	0.1200	0.1300	0.1300	0.1000	0.0173	-0.06	No / No	0.00
Be, tot	mg/L	3	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Cd,tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	3	42.333	42.000	45.000	40.000	2.517	10.15	Yes / Yes	0.00
Co, tot	mg/L	3	0.0014	0.0010	0.0023	0.0010	0.0008	0.00	No / No	66.67
Cr, tot	mg/L	3	0.0040	0.0020	0.0080	0.0020	0.0035	-0.01	No / No	66.67
F, tot	mg/L	3	0.550	0.587	0.642	0.422	0.114	-0.11	Yes / Yes	0.00
Hg, tot	mg/L	3	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	16	0.294	0.180	0.927	0.034	0.277	0.07	No / Yes	0.00
Mn, tot	mg/L	3	0.317	0.310	0.370	0.270	0.050	0.12	Yes / Yes	0.00
Pb, tot	mg/L	3	0.0012	0.0005	0.0026	0.0005	0.0012	0.00	No / No	66.67
Sb, tot	mg/L	3	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	3	0.0036	0.0035	0.0043	0.0030	0.0007	0.00	Yes / Yes	0.00
SO4, diss	mg/L	16	161.063	135.000	300.000	107.000	61.151	26.31	No / No	0.00
SO4, tot	mg/L	3	120.000	120.000	130.000	110.000	10.000	20.29	Yes / Yes	0.00
TDS	mg/L	17	676.706	620.000	1,100.000	494.000	156.107	72.77	No / Yes	0.00
Tl, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001656

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G153

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	3	0.0056	0.0056	0.0059	0.0052	0.0004	0.00	Yes / Yes	0.00
B, diss	mg/L	16	0.028	0.027	0.058	0.012	0.012	-0.01	Yes / Yes	0.00
B, tot	mg/L	3	0.0437	0.0360	0.0640	0.0310	0.0178	-0.07	Yes / Yes	0.00
Ba, tot	mg/L	3	0.0247	0.0220	0.0360	0.0160	0.0103	-0.04	Yes / Yes	0.00
Be, tot	mg/L	3	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Cd,tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	3	140.000	130.000	160.000	130.000	17.321	0.00	No / No	0.00
Co, tot	mg/L	3	0.0037	0.0034	0.0068	0.0010	0.0029	-0.01	Yes / Yes	33.33
Cr, tot	mg/L	3	0.0045	0.0041	0.0053	0.0041	0.0007	0.00	No / No	0.00
F, tot	mg/L	5	0.363	0.369	0.410	0.293	0.047	-0.01	Yes / Yes	0.00
Hg, tot	mg/L	3	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	16	0.235	0.175	1.020	0.024	0.249	-0.12	No / Yes	0.00
Mn, tot	mg/L	3	0.673	0.510	1.300	0.210	0.563	-2.21	Yes / Yes	0.00
Pb, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Sb, tot	mg/L	3	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	3	0.0230	0.0210	0.0270	0.0210	0.0035	0.00	No / No	0.00
SO4, diss	mg/L	16	1,823.750	1,800.000	2,100.000	1,500.000	206.458	184.47	Yes / Yes	0.00
SO4, tot	mg/L	3	1,633.333	1,500.000	1,900.000	1,500.000	230.940	0.00	No / No	0.00
TDS	mg/L	17	3,361.765	3,300.000	3,900.000	2,800.000	340.739	42.47	Yes / Yes	0.00
Tl, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001657

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G154

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	3	0.0008	0.0005	0.0014	0.0005	0.0005	0.00	No / No	66.67
B, diss	mg/L	16	0.036	0.037	0.045	0.021	0.008	0.00	No / No	0.00
B, tot	mg/L	3	0.0300	0.0310	0.0380	0.0210	0.0085	0.01	Yes / Yes	0.00
Ba, tot	mg/L	3	0.0340	0.0330	0.0370	0.0320	0.0026	-0.01	Yes / Yes	0.00
Be, tot	mg/L	3	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Cd,tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	3	6.500	4.900	10.000	4.600	3.035	-10.35	Yes / Yes	0.00
Co, tot	mg/L	3	0.0010	0.0010	0.0010	0.0010	0.0000	0.00	No / No	100.00
Cr, tot	mg/L	3	0.0020	0.0020	0.0020	0.0020	0.0000	0.00	No / No	100.00
F, tot	mg/L	3	1.014	1.010	1.060	0.971	0.045	0.10	Yes / Yes	0.00
Hg, tot	mg/L	3	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	16	0.062	0.035	0.462	0.003	0.112	0.00	No / Yes	0.00
Mn, tot	mg/L	3	0.157	0.160	0.160	0.150	0.006	0.02	No / No	0.00
Pb, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Sb, tot	mg/L	3	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	3	0.0054	0.0058	0.0062	0.0042	0.0011	0.00	Yes / Yes	0.00
SO4, diss	mg/L	16	110.250	105.000	175.000	82.000	23.601	-11.96	No / Yes	0.00
SO4, tot	mg/L	3	98.667	93.000	110.000	93.000	9.815	34.50	No / No	0.00
TDS	mg/L	17	476.118	460.000	624.000	410.000	52.309	17.11	No / No	0.00
Tl, tot	mg/L	3	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001658

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G270

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	38	0.0010	0.0005	0.0110	0.0005	0.0018	0.00	No / No	73.68
B, diss	mg/L	34	0.029	0.012	0.125	0.005	0.034	0.00	No / No	47.06
B, tot	mg/L	38	0.0207	0.0050	0.1250	0.0050	0.0264	0.00	No / No	68.42
Ba, tot	mg/L	20	0.0527	0.0495	0.0760	0.0320	0.0155	0.00	Yes / Yes	0.00
Be, tot	mg/L	20	0.00060	0.00050	0.00250	0.00050	0.00045	0.00	No / No	100.00
Ca, tot	mg/L	34	66.588	67.000	81.000	49.000	7.785	-0.34	Yes / Yes	0.00
Cd,tot	mg/L	38	0.0007	0.0005	0.0080	0.0003	0.0012	0.00	No / No	97.37
Cl, tot	mg/L	38	35.521	20.500	91.000	5.000	27.343	2.03	No / No	2.63
Co, tot	mg/L	20	0.0011	0.0010	0.0025	0.0005	0.0005	0.00	No / No	85.00
Cr, tot	mg/L	20	0.0027	0.0020	0.0125	0.0020	0.0023	0.00	No / No	100.00
F, tot	mg/L	20	0.373	0.361	0.504	0.279	0.058	0.00	Yes / Yes	0.00
Hg, tot	mg/L	20	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mn, diss	mg/L	34	0.094	0.045	0.470	0.003	0.108	-0.02	No / Yes	0.00
Mn, tot	mg/L	34	0.146	0.083	0.620	0.021	0.134	-0.03	No / No	0.00
Mo, tot	mg/L	8	0.0007	0.0005	0.0011	0.0005	0.0003	0.00	No / No	62.50
Pb, tot	mg/L	38	0.0011	0.0005	0.0073	0.0003	0.0013	0.00	No / No	68.42
Ra-226,228, tot	pCi/L	4	0.5815	0.5340	0.9970	0.2610	0.3415	0.82	Yes / Yes	25.00
Sb, tot	mg/L	20	0.0013	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	20	0.0019	0.0013	0.0078	0.0005	0.0020	0.00	No / No	60.00
SO4, diss	mg/L	34	54.312	42.500	140.000	2.100	50.372	15.70	No / No	0.00
SO4, tot	mg/L	38	58.747	65.000	140.000	2.300	50.239	15.58	No / No	0.00
TDS	mg/L	37	453.514	460.000	550.000	340.000	52.769	10.59	Yes / Yes	0.00
Tl, tot	mg/L	20	0.0007	0.0005	0.0010	0.0005	0.0002	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001659

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G271

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	33	0.0012	0.0005	0.0049	0.0005	0.0011	0.00	No / No	60.61
B, diss	mg/L	29	0.281	0.260	0.610	0.130	0.128	0.05	No / Yes	0.00
B, tot	mg/L	33	0.3088	0.2400	0.9800	0.1100	0.1904	0.03	No / Yes	0.00
Ba, tot	mg/L	19	0.0456	0.0340	0.1100	0.0280	0.0220	0.00	No / No	0.00
Be, tot	mg/L	19	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	29	123.276	120.000	170.000	96.000	17.834	2.68	Yes / Yes	0.00
Cd,tot	mg/L	33	0.0005	0.0005	0.0005	0.0003	0.0001	0.00	No / No	100.00
Cl, tot	mg/L	33	41.427	42.000	58.000	5.100	9.067	0.00	No / No	0.00
Co, tot	mg/L	19	0.0014	0.0010	0.0047	0.0005	0.0010	0.00	No / No	78.95
Cr, tot	mg/L	19	0.0037	0.0020	0.0140	0.0020	0.0032	0.00	No / No	73.68
F, tot	mg/L	19	0.415	0.410	0.562	0.298	0.062	0.01	Yes / Yes	0.00
Hg, tot	mg/L	19	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mn, diss	mg/L	29	0.015	0.001	0.220	0.001	0.045	0.00	No / No	62.07
Mn, tot	mg/L	29	0.058	0.021	0.270	0.001	0.075	-0.01	No / Yes	0.00
Mo, tot	mg/L	8	0.0010	0.0005	0.0036	0.0005	0.0011	0.00	No / No	62.50
Pb, tot	mg/L	33	0.0022	0.0012	0.0110	0.0005	0.0024	0.00	No / No	45.45
Ra-226,228, tot	pCi/L	4	0.5905	0.5785	1.0200	0.1850	0.4251	-1.19	Yes / Yes	0.00
Sb, tot	mg/L	19	0.0014	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	19	0.0040	0.0035	0.0099	0.0018	0.0021	0.00	No / Yes	0.00
SO4, diss	mg/L	29	354.483	360.000	520.000	220.000	87.447	35.77	Yes / Yes	0.00
SO4, tot	mg/L	33	356.970	350.000	540.000	230.000	87.446	28.25	Yes / Yes	0.00
TDS	mg/L	31	861.935	860.000	1,000.000	710.000	96.035	29.19	No / No	0.00
Tl, tot	mg/L	19	0.0006	0.0005	0.0010	0.0005	0.0002	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001660

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**

Locations: **APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405**

Location	Type	Class
G272	Groundwater	

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	29	0.0006	0.0005	0.0013	0.0005	0.0002	0.00	No / No	86.21
B, diss	mg/L	29	0.019	0.005	0.270	0.005	0.050	0.00	No / No	86.21
B, tot	mg/L	29	0.0144	0.0050	0.0600	0.0050	0.0167	0.00	No / No	68.97
Ba, tot	mg/L	15	0.0673	0.0620	0.0990	0.0580	0.0108	0.00	No / No	0.00
Be, tot	mg/L	15	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	25	97.400	98.000	110.000	82.000	9.000	3.90	No / No	0.00
Cd,tot	mg/L	29	0.0005	0.0005	0.0005	0.0003	0.0001	0.00	No / No	100.00
Cl, tot	mg/L	29	39.552	41.000	53.000	29.000	6.294	-2.64	Yes / Yes	3.45
Co, tot	mg/L	15	0.0011	0.0010	0.0022	0.0005	0.0004	0.00	No / No	80.00
Cr, tot	mg/L	15	0.0029	0.0020	0.0110	0.0020	0.0024	0.00	No / No	86.67
F, tot	mg/L	15	0.449	0.459	0.561	0.355	0.058	0.00	Yes / Yes	0.00
Hg, tot	mg/L	15	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	29	0.011	0.001	0.230	0.001	0.043	0.00	No / No	75.86
Mn, tot	mg/L	29	0.029	0.011	0.150	0.002	0.040	0.00	No / Yes	0.00
Mo, tot	mg/L	4	0.0012	0.0009	0.0024	0.0005	0.0009	0.00	Yes / Yes	50.00
Pb, tot	mg/L	29	0.0011	0.0005	0.0049	0.0005	0.0011	0.00	No / No	65.52
Sb, tot	mg/L	15	0.0014	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	15	0.0017	0.0013	0.0042	0.0005	0.0012	0.00	No / Yes	53.33
SO4, diss	mg/L	29	264.483	270.000	380.000	140.000	62.996	28.10	Yes / Yes	0.00
SO4, tot	mg/L	29	253.448	250.000	380.000	120.000	68.935	30.52	Yes / Yes	0.00
TDS	mg/L	27	702.963	680.000	840.000	570.000	68.770	25.54	Yes / Yes	0.00
Tl, tot	mg/L	15	0.0006	0.0005	0.0010	0.0005	0.0002	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001661

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G273

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	33	0.0008	0.0005	0.0045	0.0005	0.0009	0.00	No / No	75.76
B, diss	mg/L	29	0.224	0.180	0.620	0.019	0.176	0.06	No / No	6.90
B, tot	mg/L	33	0.2084	0.2000	0.4800	0.0160	0.1368	0.05	Yes / No	9.09
Ba, tot	mg/L	19	0.0503	0.0440	0.0940	0.0280	0.0210	-0.01	No / Yes	0.00
Be, tot	mg/L	19	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	29	156.207	150.000	200.000	120.000	19.533	0.00	Yes / Yes	0.00
Cd,tot	mg/L	33	0.0005	0.0005	0.0005	0.0003	0.0001	0.00	No / No	100.00
Cl, tot	mg/L	33	35.788	37.000	59.000	4.000	9.591	2.49	Yes / No	0.00
Co, tot	mg/L	19	0.0009	0.0010	0.0010	0.0005	0.0002	0.00	No / No	100.00
Cr, tot	mg/L	19	0.0038	0.0020	0.0340	0.0020	0.0073	0.00	No / No	94.74
F, tot	mg/L	19	0.335	0.330	0.537	0.125	0.099	0.01	Yes / No	10.53
Hg, tot	mg/L	19	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mn, diss	mg/L	29	0.042	0.028	0.330	0.001	0.059	-0.01	No / No	0.00
Mn, tot	mg/L	29	0.057	0.043	0.190	0.019	0.043	-0.01	No / Yes	0.00
Mo, tot	mg/L	8	0.0007	0.0005	0.0019	0.0005	0.0005	0.00	No / No	87.50
Pb, tot	mg/L	33	0.0006	0.0005	0.0037	0.0003	0.0006	0.00	No / No	87.88
Ra-226,228, tot	pCi/L	4	1.2503	1.1420	2.0600	0.6570	0.6588	-2.20	Yes / Yes	0.00
Sb, tot	mg/L	19	0.0014	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	19	0.0010	0.0005	0.0051	0.0005	0.0011	0.00	No / No	84.21
SO4, diss	mg/L	29	524.000	520.000	700.000	46.000	131.055	8.97	No / No	0.00
SO4, tot	mg/L	33	529.697	520.000	750.000	340.000	105.874	6.45	Yes / Yes	0.00
TDS	mg/L	31	1,085.484	1,100.000	1,300.000	840.000	140.139	0.00	No / No	0.00
Tl, tot	mg/L	19	0.0006	0.0005	0.0010	0.0005	0.0002	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001662

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**

Locations: **APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405**

Location	Type	Class
G274	Groundwater	

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	29	0.0008	0.0005	0.0040	0.0005	0.0008	0.00	No / No	82.76
B, diss	mg/L	29	0.295	0.180	0.970	0.005	0.302	0.13	No / No	27.59
B, tot	mg/L	29	0.2636	0.1600	0.7400	0.0050	0.2533	0.11	No / No	24.14
Ba, tot	mg/L	15	0.0759	0.0700	0.1200	0.0520	0.0181	-0.01	Yes / Yes	0.00
Be, tot	mg/L	15	0.00059	0.00050	0.00180	0.00050	0.00034	0.00	No / No	93.33
Ca, tot	mg/L	25	112.320	110.000	130.000	98.000	8.440	0.00	No / No	0.00
Cd,tot	mg/L	29	0.0005	0.0005	0.0014	0.0003	0.0002	0.00	No / No	96.55
Cl, tot	mg/L	29	33.572	36.000	55.000	3.600	11.500	-4.55	Yes / No	0.00
Co, tot	mg/L	15	0.0010	0.0010	0.0028	0.0005	0.0005	0.00	No / No	93.33
Cr, tot	mg/L	15	0.0024	0.0020	0.0059	0.0020	0.0010	0.00	No / No	93.33
F, tot	mg/L	15	0.351	0.350	0.455	0.262	0.052	0.01	Yes / Yes	0.00
Hg, tot	mg/L	15	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	29	0.003	0.001	0.046	0.001	0.009	0.00	No / No	68.97
Mn, tot	mg/L	29	0.049	0.022	0.370	0.003	0.087	0.00	No / Yes	0.00
Mo, tot	mg/L	4	0.0007	0.0005	0.0012	0.0005	0.0003	0.00	No / No	75.00
Pb, tot	mg/L	29	0.0015	0.0005	0.0100	0.0003	0.0024	0.00	No / No	65.52
Sb, tot	mg/L	15	0.0014	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	15	0.0010	0.0013	0.0022	0.0005	0.0005	0.00	No / No	73.33
SO4, diss	mg/L	29	340.000	350.000	400.000	240.000	41.748	0.00	No / No	0.00
SO4, tot	mg/L	29	336.552	330.000	460.000	230.000	54.725	6.69	Yes / Yes	0.00
TDS	mg/L	27	862.593	870.000	980.000	770.000	64.307	-16.05	Yes / Yes	0.00
Tl, tot	mg/L	15	0.0007	0.0005	0.0013	0.0005	0.0003	0.00	No / No	93.33

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001663

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**

Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405

Location	Type	Class
G275	Groundwater	

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	25	0.0016	0.0011	0.0043	0.0005	0.0013	0.00	No / No	48.00
B, diss	mg/L	25	3.176	3.500	4.600	0.910	1.040	0.10	Yes / No	0.00
B, tot	mg/L	25	3.3360	3.6000	4.6000	1.2000	0.9652	0.04	No / No	0.00
Ba, tot	mg/L	12	0.0468	0.0390	0.1200	0.0320	0.0241	0.00	No / No	0.00
Be, tot	mg/L	12	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	22	221.364	230.000	310.000	120.000	48.726	5.01	Yes / Yes	0.00
Cd,tot	mg/L	25	0.0005	0.0005	0.0005	0.0003	0.0001	0.00	No / No	100.00
Cl, tot	mg/L	25	16.752	16.000	30.000	9.200	5.504	1.57	Yes / Yes	0.00
Co, tot	mg/L	12	0.0010	0.0010	0.0025	0.0005	0.0005	0.00	No / No	100.00
Cr, tot	mg/L	12	0.0038	0.0023	0.0125	0.0020	0.0034	0.00	No / No	83.33
F, tot	mg/L	12	0.310	0.320	0.452	0.125	0.083	0.01	Yes / No	8.33
Hg, tot	mg/L	12	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Mn, diss	mg/L	25	0.051	0.019	0.340	0.001	0.086	0.00	No / Yes	8.00
Mn, tot	mg/L	25	0.168	0.085	0.780	0.012	0.203	0.01	No / Yes	0.00
Mo, tot	mg/L	3	0.0008	0.0005	0.0014	0.0005	0.0005	0.00	No / No	66.67
Pb, tot	mg/L	25	0.0024	0.0013	0.0100	0.0003	0.0028	0.00	No / Yes	36.00
Sb, tot	mg/L	12	0.0014	0.0015	0.0015	0.0010	0.0002	0.00	No / No	100.00
Se, tot	mg/L	12	0.0014	0.0013	0.0060	0.0005	0.0015	0.00	No / No	66.67
SO4, diss	mg/L	25	677.600	720.000	920.000	280.000	183.627	30.33	No / No	0.00
SO4, tot	mg/L	25	684.000	720.000	990.000	310.000	213.288	0.84	Yes / No	0.00
TDS	mg/L	24	1,388.333	1,500.000	2,000.000	840.000	270.373	0.00	Yes / No	0.00
Tl, tot	mg/L	12	0.0007	0.0005	0.0010	0.0005	0.0002	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001664

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G281

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0015	0.0005	0.0043	0.0005	0.0019	0.00	No / No	75.00
B, tot	mg/L	4	0.0080	0.0075	0.0120	0.0050	0.0036	0.01	Yes / Yes	50.00
Ba, tot	mg/L	4	0.0893	0.0750	0.1400	0.0670	0.0341	-0.03	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	135.000	135.000	150.000	120.000	12.910	13.36	Yes / Yes	0.00
Cd,tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	4	67.750	71.000	74.000	55.000	8.655	-4.99	Yes / Yes	0.00
Co, tot	mg/L	4	0.0022	0.0010	0.0056	0.0010	0.0023	0.00	No / No	75.00
Cr, tot	mg/L	4	0.0043	0.0020	0.0110	0.0020	0.0045	-0.01	No / No	75.00
F, tot	mg/L	4	0.383	0.387	0.411	0.349	0.030	0.00	Yes / Yes	0.00
Hg, tot	mg/L	4	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0070	0.0050	0.0130	0.0050	0.0040	-0.01	No / No	75.00
Mo, tot	mg/L	4	0.0008	0.0005	0.0015	0.0005	0.0005	0.00	No / No	75.00
Pb, tot	mg/L	4	0.0021	0.0008	0.0063	0.0005	0.0028	0.00	No / Yes	50.00
Ra-226,228, tot	pCi/L	4	0.7225	0.5910	1.4900	0.2180	0.5416	0.80	Yes / Yes	25.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
SO4, tot	mg/L	4	330.000	325.000	370.000	300.000	31.623	68.72	Yes / Yes	0.00
TDS	mg/L	4	770.000	760.000	820.000	740.000	38.297	-28.65	Yes / Yes	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001665

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G401

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0028	0.0028	0.0046	0.0010	0.0018	0.00	Yes / Yes	25.00
B, tot	mg/L	4	3.5750	3.4500	4.1000	3.3000	0.3594	0.79	Yes / Yes	0.00
Ba, tot	mg/L	4	0.0298	0.0260	0.0530	0.0140	0.0188	0.01	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	400.000	410.000	450.000	330.000	55.976	112.15	Yes / Yes	0.00
Cd,tot	mg/L	4	0.0007	0.0005	0.0012	0.0005	0.0003	0.00	No / No	75.00
Cl, tot	mg/L	4	4.475	4.450	6.000	3.000	1.408	0.61	Yes / Yes	0.00
Co, tot	mg/L	4	0.2600	0.2600	0.2800	0.2400	0.0183	0.05	Yes / Yes	0.00
Cr, tot	mg/L	4	0.0047	0.0037	0.0096	0.0020	0.0036	0.00	Yes / Yes	50.00
F, tot	mg/L	4	0.283	0.125	0.758	0.125	0.317	0.00	No / No	75.00
Hg, tot	mg/L	4	0.00031	0.00010	0.00093	0.00010	0.00042	0.00	No / No	75.00
Li, tot	mg/L	4	0.0505	0.0505	0.0550	0.0460	0.0037	-0.01	Yes / Yes	0.00
Mo, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Pb, tot	mg/L	4	0.0022	0.0018	0.0048	0.0005	0.0021	0.00	Yes / Yes	50.00
Ra-226,228, tot	pCi/L	4	1.3010	1.3150	1.6300	0.9440	0.3593	-0.17	Yes / Yes	0.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0023	0.0015	0.0055	0.0005	0.0023	0.00	Yes / Yes	50.00
SO4, tot	mg/L	4	2,275.000	2,250.000	2,500.000	2,100.000	170.783	-390.59	Yes / Yes	0.00
TDS	mg/L	4	2,925.000	2,950.000	3,000.000	2,800.000	95.743	-185.33	Yes / Yes	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001666

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G402

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0210	0.0235	0.0270	0.0100	0.0075	-0.02	Yes / Yes	0.00
B, tot	mg/L	4	6.5000	6.4500	7.4000	5.7000	0.7071	1.83	Yes / Yes	0.00
Ba, tot	mg/L	4	0.0810	0.0835	0.1100	0.0470	0.0259	-0.08	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	250.000	255.000	270.000	220.000	24.495	-21.49	Yes / Yes	0.00
Cd,tot	mg/L	4	0.0006	0.0005	0.0010	0.0005	0.0003	0.00	No / No	75.00
Cl, tot	mg/L	4	2.325	2.500	2.800	1.500	0.618	-1.11	Yes / Yes	0.00
Co, tot	mg/L	4	0.0139	0.0145	0.0190	0.0074	0.0048	0.00	Yes / Yes	0.00
Cr, tot	mg/L	4	0.0201	0.0205	0.0310	0.0085	0.0093	-0.03	Yes / Yes	0.00
F, tot	mg/L	4	0.294	0.343	0.367	0.125	0.114	0.17	No / No	25.00
Hg, tot	mg/L	4	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0450	0.0450	0.0570	0.0330	0.0122	-0.03	Yes / Yes	0.00
Mo, tot	mg/L	4	0.0047	0.0047	0.0060	0.0033	0.0011	0.00	Yes / Yes	0.00
Pb, tot	mg/L	4	0.0138	0.0150	0.0180	0.0072	0.0046	-0.01	Yes / Yes	0.00
Ra-226,228, tot	pCi/L	4	3.1500	3.5500	4.4600	1.0400	1.5553	-2.49	Yes / Yes	0.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0019	0.0018	0.0033	0.0005	0.0012	0.00	Yes / Yes	25.00
SO4, tot	mg/L	4	1,012.500	980.000	1,200.000	890.000	133.010	-392.46	Yes / Yes	0.00
TDS	mg/L	4	1,600.000	1,600.000	1,700.000	1,500.000	115.470	-346.15	No / No	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001667

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G403

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0015	0.0011	0.0033	0.0005	0.0013	0.00	Yes / Yes	50.00
B, tot	mg/L	4	0.0360	0.0330	0.0640	0.0140	0.0213	-0.03	Yes / Yes	0.00
Ba, tot	mg/L	4	0.1675	0.1500	0.2400	0.1300	0.0499	0.14	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	89.500	74.500	140.000	69.000	33.887	49.18	No / Yes	0.00
Cd,tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	4	4.525	4.300	6.800	2.700	1.702	-4.64	Yes / Yes	0.00
Co, tot	mg/L	4	0.0015	0.0010	0.0029	0.0010	0.0010	0.00	No / No	75.00
Cr, tot	mg/L	4	0.0044	0.0041	0.0073	0.0020	0.0028	0.00	Yes / Yes	50.00
F, tot	mg/L	4	0.481	0.482	0.518	0.442	0.031	0.05	Yes / Yes	0.00
Hg, tot	mg/L	4	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mo, tot	mg/L	4	0.0028	0.0026	0.0055	0.0005	0.0024	0.00	Yes / Yes	25.00
Pb, tot	mg/L	4	0.0013	0.0013	0.0021	0.0005	0.0009	0.00	No / No	50.00
Ra-226,228, tot	pCi/L	4	0.3674	0.1973	0.9680	0.1070	0.4057	0.85	Yes / Yes	25.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0021	0.0005	0.0068	0.0005	0.0032	0.00	No / No	75.00
SO4, tot	mg/L	4	18.225	14.000	35.000	9.900	11.610	-30.93	Yes / Yes	0.00
TDS	mg/L	4	325.000	320.000	340.000	320.000	10.000	0.00	No / No	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001668

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**
Locations: APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405
Location Type Class
G404

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
B, tot	mg/L	4	2.0750	1.8500	3.2000	1.4000	0.8057	0.40	Yes / Yes	0.00
Ba, tot	mg/L	4	0.0473	0.0465	0.0550	0.0410	0.0064	0.00	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	107.250	110.000	120.000	89.000	13.048	7.16	Yes / Yes	0.00
Cd,tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Cl, tot	mg/L	4	52.500	51.000	62.000	46.000	6.952	0.62	Yes / Yes	0.00
Co, tot	mg/L	4	0.0010	0.0010	0.0010	0.0010	0.0000	0.00	No / No	100.00
Cr, tot	mg/L	4	0.0020	0.0020	0.0020	0.0020	0.0000	0.00	No / No	100.00
F, tot	mg/L	4	0.166	0.125	0.287	0.125	0.081	0.00	No / No	75.00
Hg, tot	mg/L	4	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mo, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Pb, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
Ra-226,228, tot	pCi/L	4	1.1275	1.0655	2.0700	0.3090	0.8526	2.14	Yes / Yes	25.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
SO4, tot	mg/L	4	165.000	165.000	190.000	140.000	23.805	-12.27	Yes / Yes	0.00
TDS	mg/L	4	555.000	570.000	620.000	460.000	68.069	-13.82	Yes / Yes	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

R001669

Coffeen
Ash Pond 2 - Statistical Summary for Select Monitoring Wells

User Supplied Information

Date Range: 03/11/2008 to 08/16/2016 **Option for LT Pts: x 0.5**

Locations: **APW-2,G151,G152,G153,G154,G270,G271,G272,G273,G274,G275,G281,G401,G402,G403,G404,G405**

Location **Type** **Class**

G405

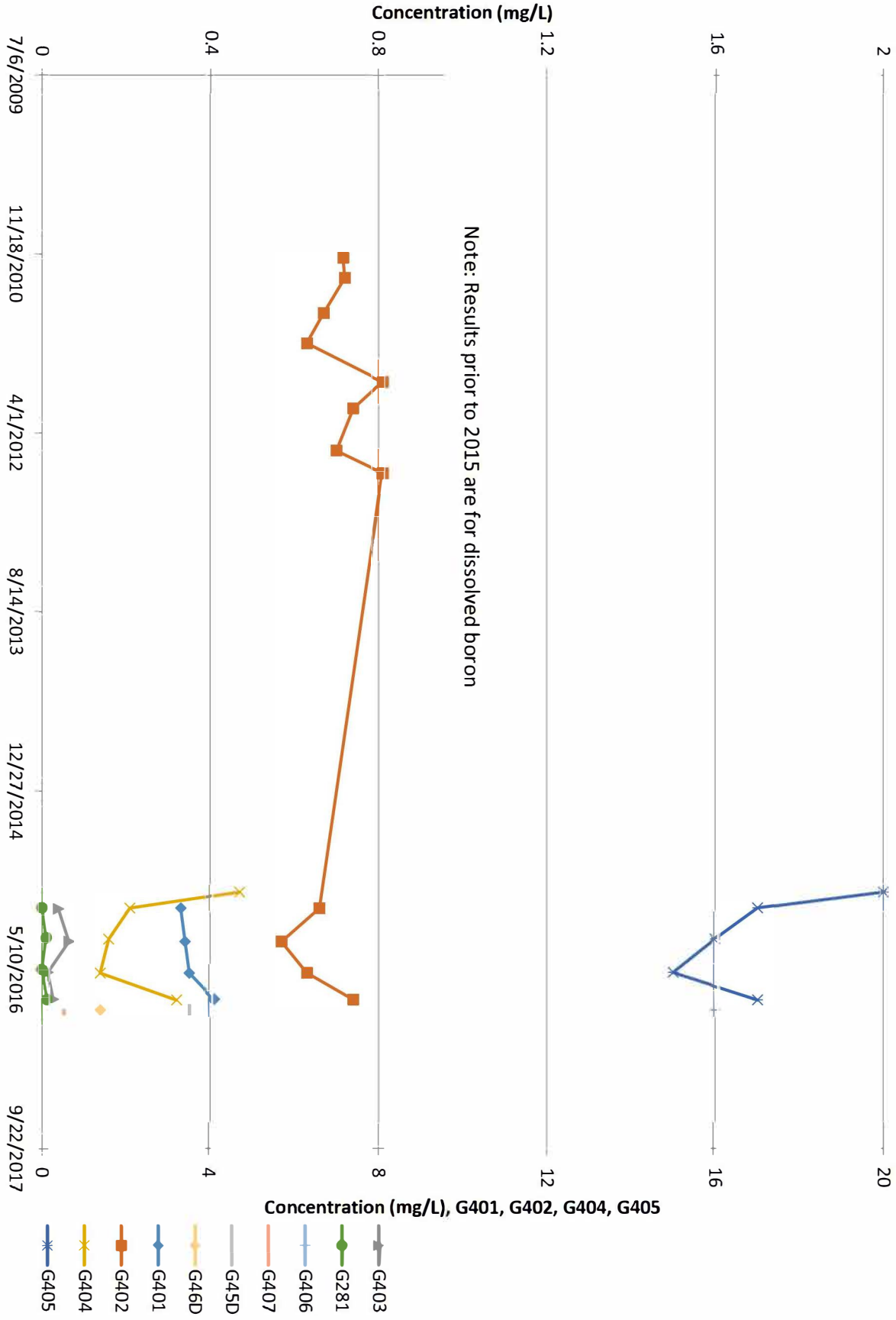
Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, tot	mg/L	4	0.0064	0.0046	0.0140	0.0025	0.0054	-0.01	Yes / Yes	0.00
B, tot	mg/L	4	16.2500	16.5000	17.0000	15.0000	0.9574	-1.96	Yes / Yes	0.00
Ba, tot	mg/L	4	0.0293	0.0240	0.0510	0.0180	0.0151	-0.01	Yes / Yes	0.00
Be, tot	mg/L	4	0.00050	0.00050	0.00050	0.00050	0.00000	0.00	No / No	100.00
Ca, tot	mg/L	4	312.500	320.000	330.000	280.000	22.174	-57.04	Yes / Yes	0.00
Cd,tot	mg/L	4	0.0007	0.0005	0.0012	0.0005	0.0003	0.00	No / No	75.00
Cl, tot	mg/L	4	9.425	10.150	14.000	3.400	4.462	-13.96	Yes / Yes	0.00
Co, tot	mg/L	4	0.0023	0.0022	0.0038	0.0010	0.0015	0.00	Yes / Yes	50.00
Cr, tot	mg/L	4	0.0028	0.0020	0.0051	0.0020	0.0016	0.00	No / No	75.00
F, tot	mg/L	4	0.396	0.457	0.544	0.125	0.185	-0.23	Yes / No	25.00
Hg, tot	mg/L	4	0.00010	0.00010	0.00010	0.00010	0.00000	0.00	No / No	100.00
Li, tot	mg/L	4	0.0050	0.0050	0.0050	0.0050	0.0000	0.00	No / No	100.00
Mo, tot	mg/L	4	0.0009	0.0008	0.0016	0.0005	0.0005	0.00	Yes / Yes	50.00
Pb, tot	mg/L	4	0.0034	0.0021	0.0085	0.0011	0.0034	-0.01	Yes / Yes	0.00
Ra-226,228, tot	pCi/L	4	0.6429	0.4678	1.3700	0.2660	0.4976	1.01	Yes / Yes	25.00
Sb, tot	mg/L	4	0.0015	0.0015	0.0015	0.0015	0.0000	0.00	No / No	100.00
Se, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00
SO4, tot	mg/L	4	1,700.000	1,700.000	1,800.000	1,600.000	81.650	-71.62	Yes / Yes	0.00
TDS	mg/L	4	2,325.000	2,300.000	2,500.000	2,200.000	150.000	-347.29	Yes / Yes	0.00
Tl, tot	mg/L	4	0.0005	0.0005	0.0005	0.0005	0.0000	0.00	No / No	100.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

APPENDIX G

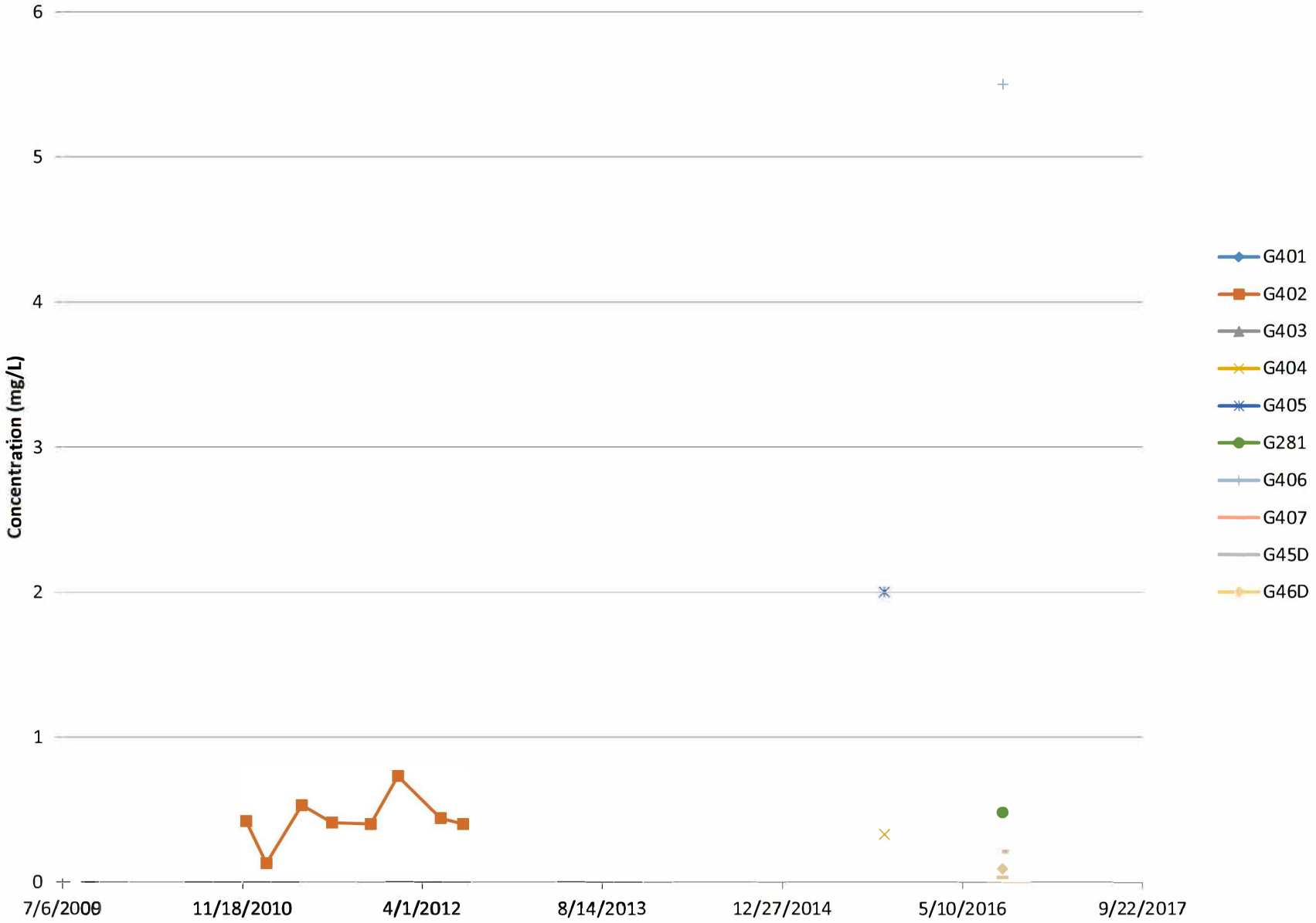
WATER QUALITY TREND GRAPHS

Ash Pond 2 Boron Concentrations



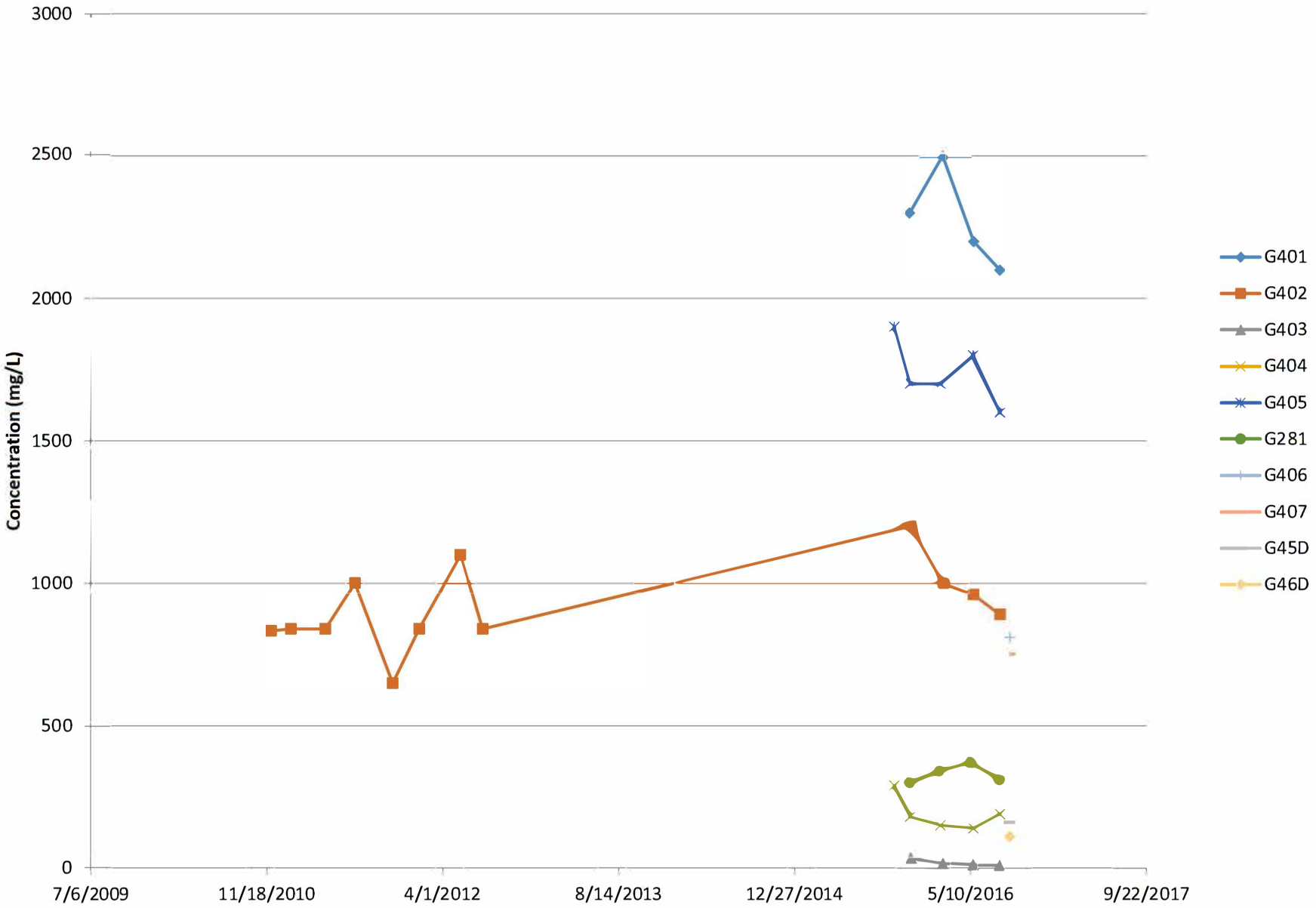
R001672

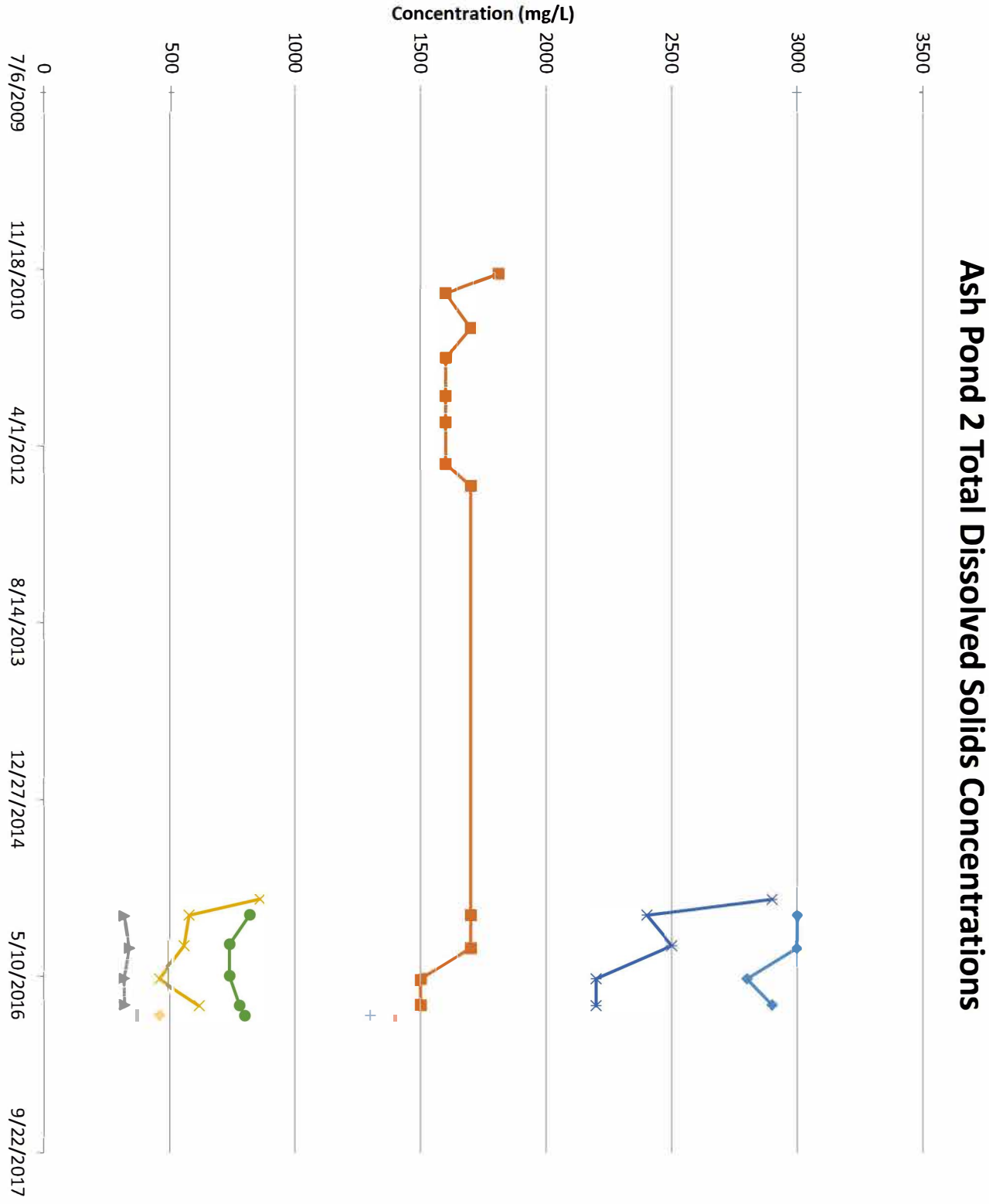
Ash Pond 2 Manganese Concentrations

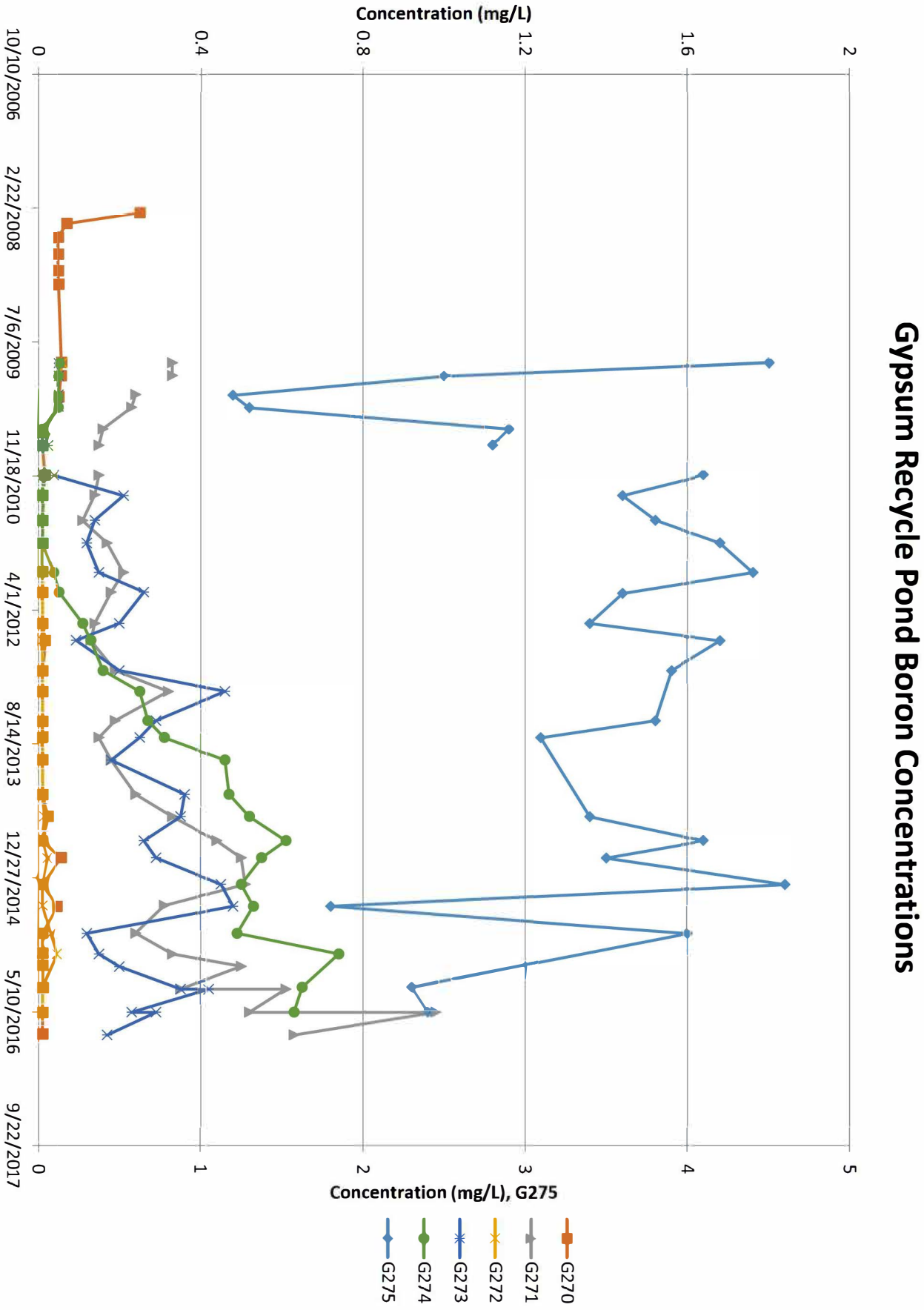


R001673

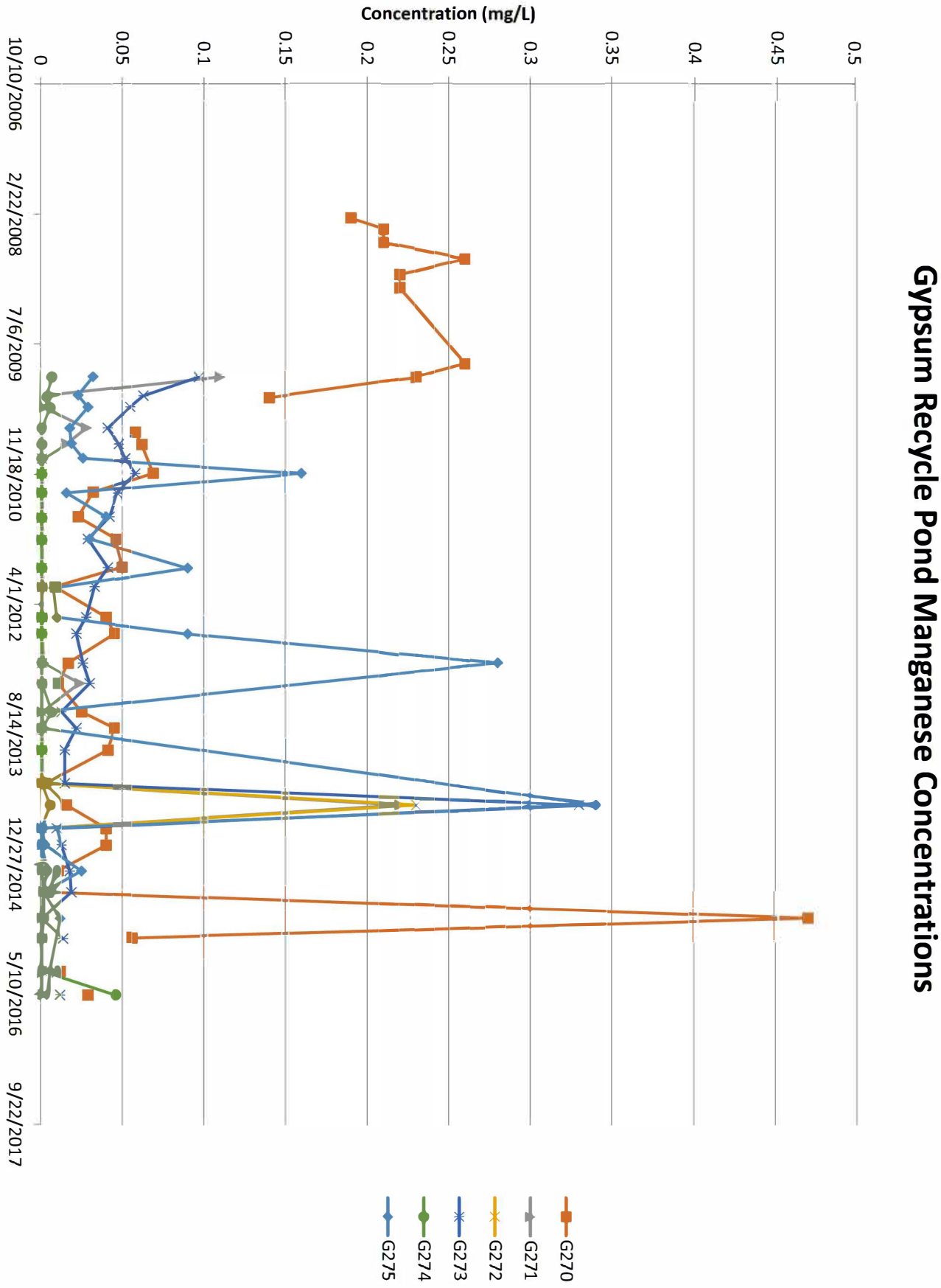
Ash Pond 2 Sulfate Concentrations



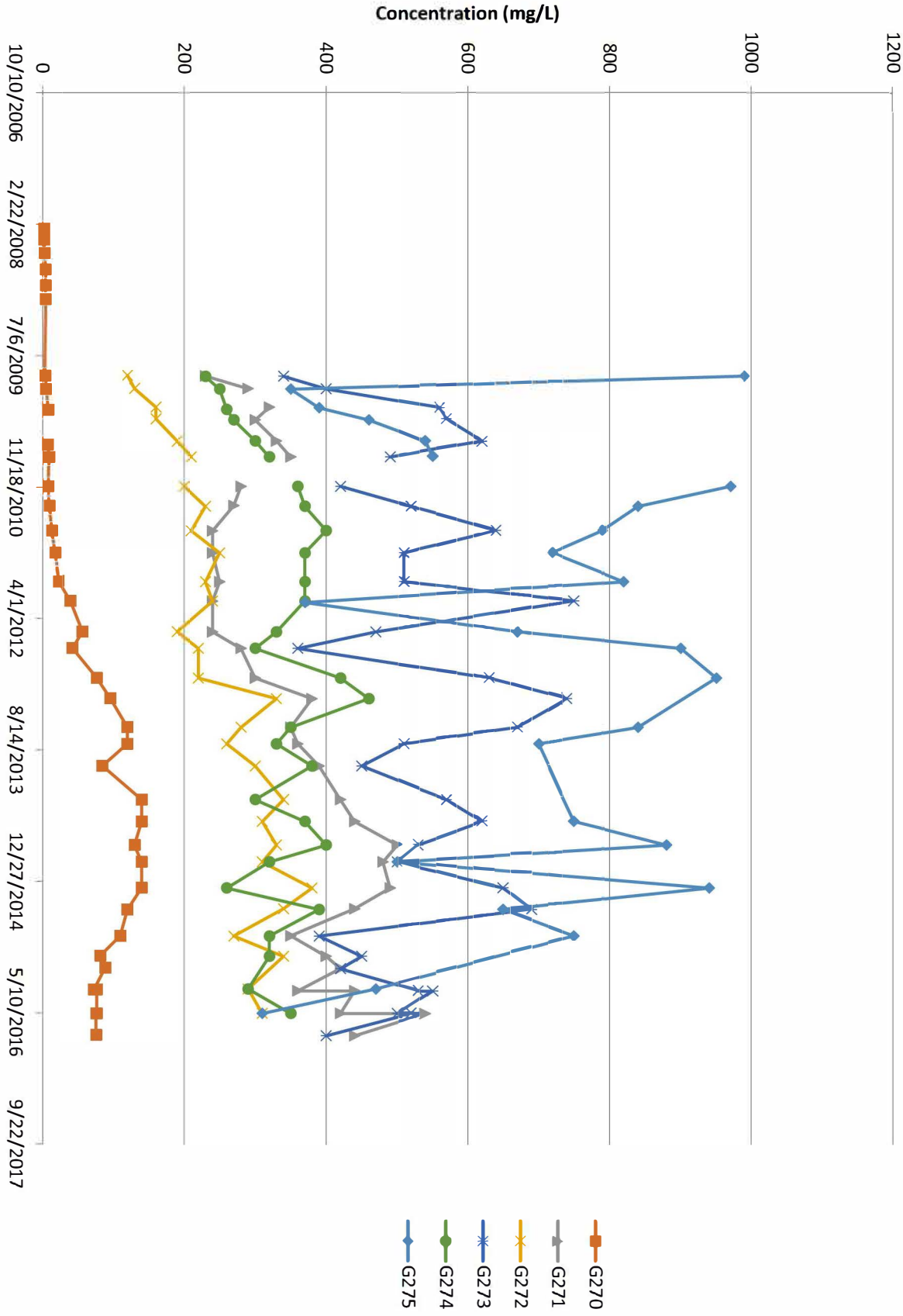

Ash Pond 2 Total Dissolved Solids Concentrations
Concentration (mg/L)
3500
3000
2500
2000
1500
1000
500
0
7/6/2009
11/18/2010
4/1/2012
8/14/2013
12/27/2014
5/10/2016
9/22/2017
G401
G402
G403
G404
G405
G281
G406
G407
G45D
G46D


Gypsum Recycle Pond Boron Concentrations
Concentration (mg/L)
0
0.4
0.8
1.2
1.6
2
10/10/2006
2/22/2008
7/6/2009
11/18/2010
4/1/2012
8/14/2013
12/27/2014
5/10/2016
9/22/2017
Concentration (mg/L), G275
0
1
2
3
4
5
G275
G274
G273
G272
G271
G270

Gypsum Recycle Pond Manganese Concentrations

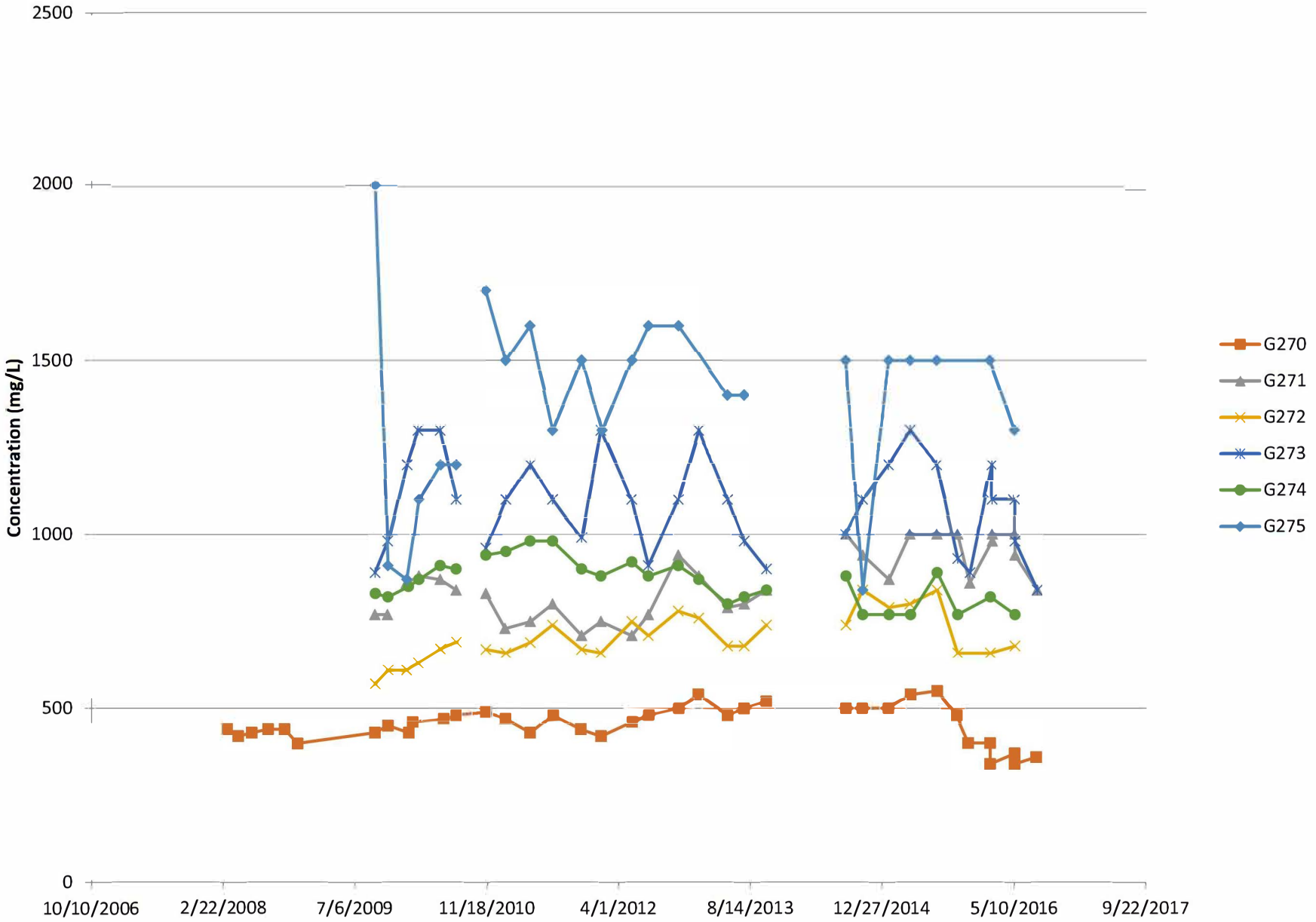


Gypsum Recycle Pond Sulfate Concentrations



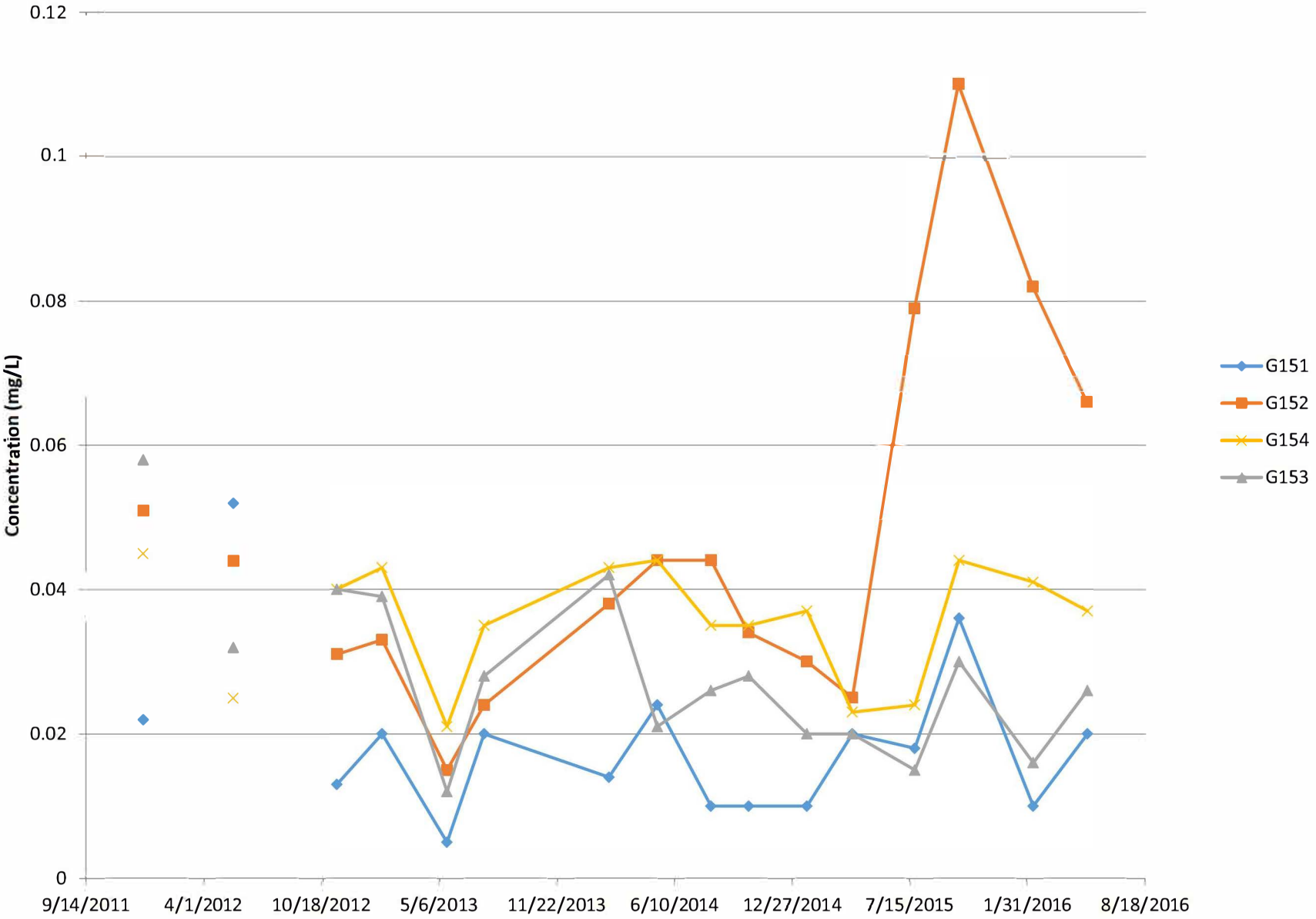
R001678

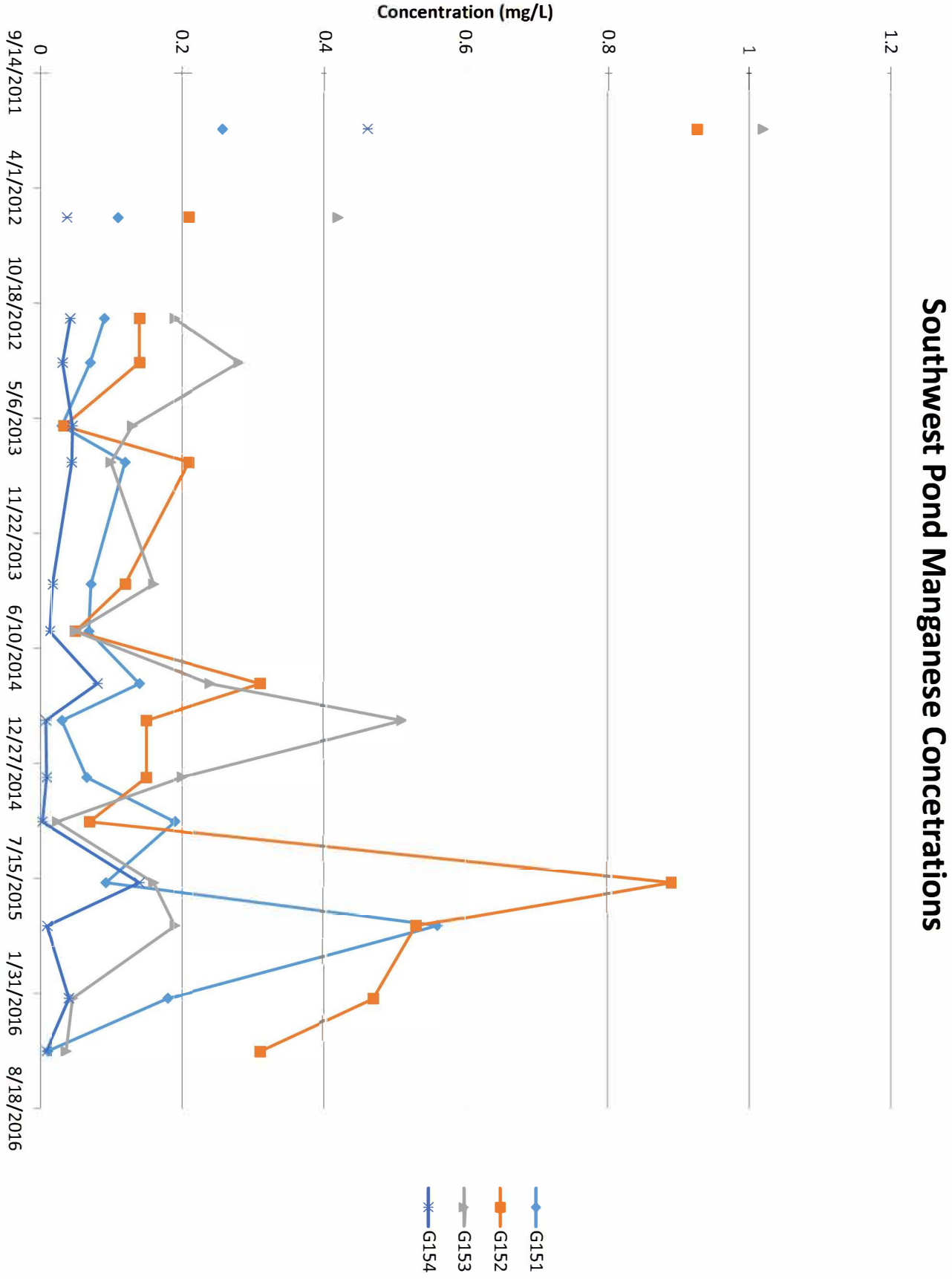
Gypsum Recycle Pond Total Dissolved Solids Concentration

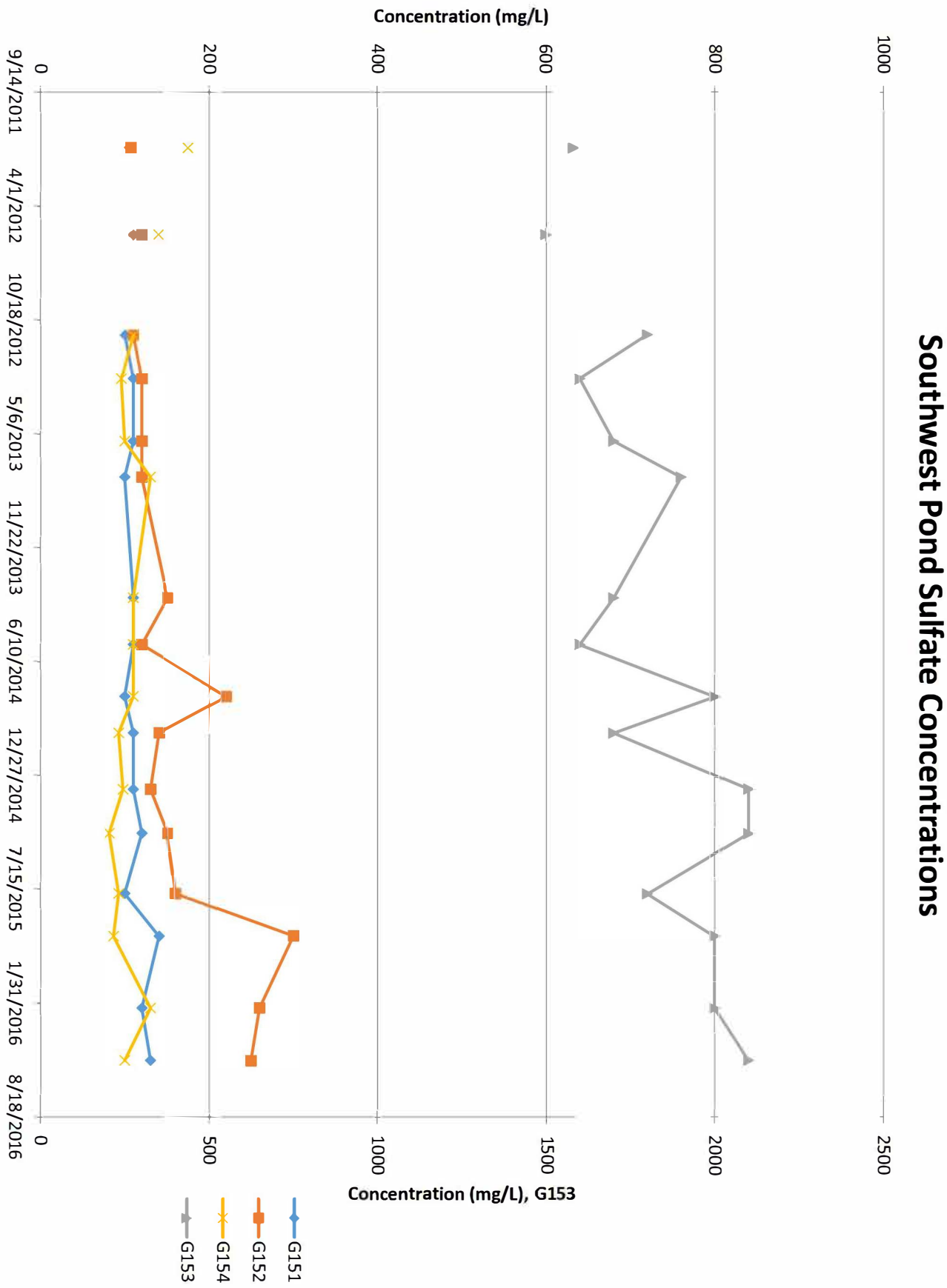


R001679

Southwest Pond Boron Concentrations




Southwest Pond Manganese Concetrations
Concentration (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
9/14/2011
4/1/2012
10/18/2012
5/6/2013
11/22/2013
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
G151
G152
G153
G154


Southwest Pond Sulfate Concentrations
Concentration (mg/L)
Concentration (mg/L), G153
0
200
400
600
800
1000
0
500
1000
1500
2000
2500
9/14/2011
4/1/2012
10/18/2012
5/6/2013
11/22/2013
6/10/2014
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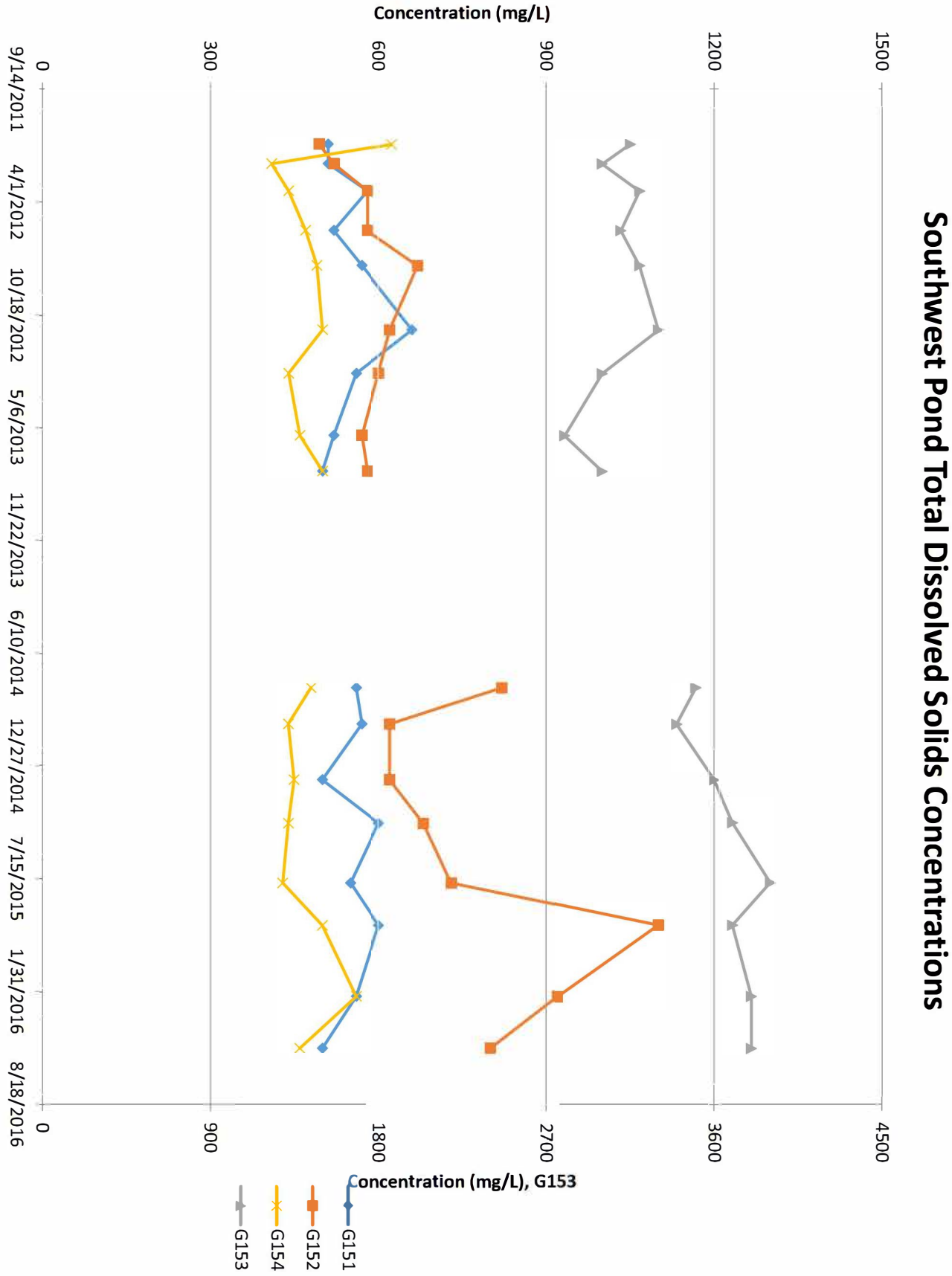
7/15/2015
1/31/2016
8/18/2016
G151
G152
G154
G153


Southwest Pond Total Dissolved Solids Concentrations
Concentration (mg/L)
Concentration (mg/L), G153
0
300
600
900
1500
0
900
1800
2700
3600
4500
9/14/2011
4/1/2012
10/18/2012
5/6/2013
11/22/2013
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
G151
G152
G154
G153

ATTACHMENT I

RAMBOLL

ENVIRONMENT
& HEALTH

Illinois Power Generating Company
134 CIPS Lane
Coffeen, IL 62017

Groundwater Monitoring Plan Addendum for Ash Pond No. 2
Coffeen Power Plant, Coffeen, IL

October 25, 2021

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Ramboll Americas Engineering Solutions, Inc. (Ramboll) is providing the attached Addendum to the Groundwater Monitoring Plan (GMP) for inclusion in the Operating Permit Applications as required under Title 35 of the Illinois Administrative Code (35 I.A.C.), § 845.230 and allowed under 35 I.A.C. § 845.210(d)(1). The GMP was previously submitted to and approved by Illinois Environmental Protection Agency (IEPA) as part of the *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2* (Closure Plan; AECOM, 2017) submitted for Coffeen Power Plant (CPP) Ash Pond Number (No.) 2 (AP2), Vistra Identification (ID) No. 102, IEPA ID No. W1350150004-02, National Inventory of Dams (NID) No. IL50723.

In addition to the historical documents, Ramboll is providing an Addendum to the CPP AP2 GMP (Attachment 1), that modifies the existing monitoring program and network to align with Part 845. Upon issuance of the Operating Permit, groundwater monitoring will be performed as specified in the Addendum.

BACKGROUND

AECOM submitted the Closure Plan, dated January 26, 2017. Included in Appendix A and B of the Closure Plan were the Hydrogeologic Site Characterization Report and GMP. IEPA provided comments on the Closure Plan in a letter dated October 27, 2017. A response to comment letter submitted by Illinois Power Generating Company (IPGC) dated November 27, 2017 included revisions to the GMP, which defined groundwater monitoring for AP2 following approval of the Closure Plan (Attachment 2). The Closure Plan was approved by IEPA in a letter dated January 30, 2018. Closure of AP2 was completed on November 17, 2020.

On April 21, 2021, 35 I.A.C. § 845 became effective, and 35 I.A.C. § 845.100(i) provides the following with respect to certain CCR units closed prior to the effective date:

> *i) If a CCR surface impoundment has completed an Agency-approved closure before April 21, 2021, this Part does not require the owner or operator of the CCR surface impoundment to resubmit to the Agency any closure plan, closure report, or closure certification for that completed closure.*

SUBMITTALS

The attached documents are being provided to address requirements of 35 I.A.C. § 845.230 as follows:

- Addendum to the CPP AP2 Groundwater Monitoring Plan (new submittal, Attachment 1). This Addendum includes revisions to the monitoring well network, analytical parameters, and statistical procedures included in the previously submitted Groundwater Monitoring Plan (Natural Resource Technology, Inc. [NRT], 2016). These modifications are proposed to meet and fulfill the requirements in 35 I.A.C. § 845.630 and 35 I.A.C. § 845.640 (Groundwater Monitoring Systems and Statistical Procedures); and 35 I.A.C. § 845.650(b) (background samples). The proposed modifications were identified and developed using existing and previously approved documents, but additional information has been provided where necessary.
- Groundwater Monitoring Plan, dated January 24, 2017, and subsequent Response to Comments (Attachment 2). This attachment provides a copy of the existing groundwater monitoring plan as it was approved by IEPA.

Sincerely,

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ATTACHMENTS:

Attachment 1	Addendum to the Groundwater Monitoring Plan
Attachment 2	Groundwater Monitoring Plan, dated January 24, 2017 and Response to Comment Letter dated November 27, 2017

ATTACHMENT 1
ADDENDUM TO THE GROUNDWATER MONITORING PLAN

Intended for
Illinois Power Generating Company

Date
October 25, 2021

Project No.
1940100806-002

ADDENDUM TO THE GROUNDWATER MONITORING PLAN

ASH POND NO. 2
COFFEEN POWER PLANT
COFFEEN, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

ADDENDUM TO THE GROUNDWATER MONITORING PLAN COFFEEN POWER PLANT ASH POND NO. 2

Project name	**Coffeen Power Plant Ash Pond No. 2**
Project no.	**1940100806-002**
Recipient	**Illinois Power Generating Company**
Document type	**Addendum to the Groundwater Monitoring Plan**
Revision	**FINAL**
Date	**October 25, 2021**
Prepared by	**Kristen L. Theesfeld**

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LICENSED PROFESSIONAL CERTIFICATIONS

35 I.A.C. § 845.630 Groundwater Monitoring Systems (PE)

I, Eric J. Tlachac, a qualified professional engineer in good standing in the State of Illinois, certify that the groundwater monitoring system described in this document (Addendum to the Groundwater Monitoring Plan, Coffeen Power Plant Ash Pond No. 2), meets the intent of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the IEPA approved Hydrogeologic Site Characterization Report submitted with the IEPA approved Closure and Post Closure Care Plan.

Eric J. Tlachac
Qualified Professional Engineer
062-063091
Illinois
Date: October 25, 2021

35 I.A.C. § 845.630 Groundwater Monitoring Systems (PG)

I, Brian G. Hennings, a qualified professional geologist in good standing in the State of Illinois, certify that the groundwater monitoring system described in this document (Addendum to the Groundwater Monitoring Plan, Coffeen Power Plant Ash Pond No. 2), meets the intent of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the IEPA approved Hydrogeologic Site Characterization Report submitted with the IEPA approved Closure and Post Closure Care Plan.

Brian G. Hennings
Professional Geologist
196.001482
Illinois
Date: October 25, 2021

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APPENDICES

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ACRONYMS AND ABBREVIATIONS

§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
77 I.A.C.	Title 77 of the Illinois Administrative Code
40 C.F.R.	Title 40 of the Code of Federal Regulations
AP2	Ash Pond No. 2
ASD	Alternate Source Demonstration
bgs	below ground surface
CCR	coal combustion residuals
Closure Plan	*Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2*
cm/s	centimeters per second
CPP	Coffeen Power Plant
GMF	Gypsum Management Facility
GMP	Groundwater Monitoring Plan
GWPS	Groundwater Protection Standard
ID	Identification
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
LCU	lower confining unit
mg/L	milligrams per liter
NA	not applicable
NID	National Inventory of Dams
No.	Number
NRT	Natural Resource Technology, Inc.
Part 845	Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
QA/QC	quality assurance/quality control
Ramboll	Ramboll Americas Engineering Solutions, Inc.
RL	Reporting Limit
SI	Surface Impoundment
SW	surface water
TDS	total dissolved solids
UA	uppermost aquifer
USEPA	United States Environmental Protection Agency
WLO	water level only

1. INTRODUCTION

1.1 Overview

In accordance with requirements of the Standards for the Disposal of Coal Combustion Residuals (CCR) in Surface Impoundments (SIs): Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845 (Part 845) (Illinois Environmental Protection Agency [IEPA], April 15 2021), Ramboll Americas Engineering Solutions, Inc. (Ramboll) has prepared this Addendum to the Groundwater Monitoring Plan (GMP) on behalf of Coffeen Power Plant (CPP) (**Figure 1-1**), operated by Illinois Power Generating Company (IPGC). This Addendum applies specifically to the CCR Unit referred to as Ash Pond Number (No.) 2 (AP2; Vistra identification [ID] No. 102, IEPA ID No. W1350150004-02, and National Inventory of Dams [NID] No. IL50723) (**Figure 1-2**). AP2 is a closed, unlined CCR SI that was previously used to manage CCR and non-CCR waste streams at the CPP.

AECOM submitted the *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2* (Closure Plan) dated January 26, 2017, which was approved by the IEPA on January 30, 2018. The Groundwater Monitoring Plan (Natural Resource Technology, Inc. [NRT], 2017a) defined groundwater monitoring for AP2 following approval of the Closure Plan. Closure of AP2 was completed on November 17, 2020.

On April 21, 2021, Part 845 became effective, and for CCR units closed prior to the effective date the following section was included (35 I.A.C. § 845.100(i)):

> *If a CCR surface impoundment has completed an Agency-approved closure before April 21, 2021, this Part does not require the owner or operator of the CCR surface impoundment to resubmit to the Agency any closure plan, closure report, or closure certification for that completed closure.*

This Addendum includes modifications to the previously approved GMP to provide content required by 35 I.A.C. § 845.630 (Groundwater Monitoring System), 35 I.A.C. 845.640 (Groundwater Sampling and Analysis), and 35 I.A.C. 845.650 (Groundwater Monitoring Program) for AP2. Specifically, this Addendum incorporates additional monitoring wells and monitoring parameters specified in 35 I.A.C. § 845.600.

1.2 Purpose and Scope

The purpose of this Addendum is to provide updated GMP text, tables, and figures to incorporate modifications made to the existing monitoring program to comply with Part 845. Following issuance of the Part 845 Operating Permit, the application for which this Addendum is attached, groundwater monitoring at AP2 will include the following:

- Monitoring required by Title 40 of the Code of Federal Regulations (40 C.F.R.) § 257 Subpart D (pre-existing with no modifications)
- Part 845 Monitoring (proposed)

Details of the monitoring programs (schedules and parameters), monitoring well networks, and analysis (statistical methods) are included in this Addendum. No changes are proposed to the monitoring networks utilized for the current 40 C.F.R. § 257 Subpart D monitoring; however, those details have been included for completeness. Additional information regarding the

hydrogeology and groundwater quality were included with the Closure Plan and are not reproduced in this Addendum.

2. GROUNDWATER MONITORING SYSTEMS

The Part 845 groundwater monitoring network for AP2 was developed to monitor post-closure groundwater quality and trends and demonstrate compliance with the applicable groundwater quality standards identified in **Section 3**. The existing and proposed groundwater monitoring well networks consist of a sufficient number of wells, installed at appropriate locations and depths, to monitor post-closure compliance with groundwater quality standards for 40 C.F.R. § 257 and 35 I.A.C. § 845.600.

The monitoring wells are designed and constructed in a manner consistent with the standards of 40 C.F.R. § 257 and Title 77 of the Illinois Administrative Code (77 I.A.C.) § 920.170, as required by 35 I.A.C. § 845.630(e), including the following:

- All monitoring wells are cased in a manner that maintains the integrity of the boreholes.
- Wells are screened to allow sampling only at the specified interval.
- All wells are covered with vented caps, unless located in flood-prone areas, and equipped with devices to protect against tampering and damage.

Consistent with applicable standards, the monitoring well networks described below fulfill the following goals:

- Enable the collection of groundwater samples that represent the quality of background water that has not been affected by AP2.
- Enable the collection of groundwater samples that represent the quality of downgradient groundwater.
- Include wells that are located within the stratigraphic unit(s) that may serve as potential chemical migration pathways.

Groundwater monitoring at AP2 is currently being performed in accordance with the GMP that was approved in the Closure Plan. The Closure Plan specified one monitoring network, that complies with both the IEPA Closure Plan monitoring requirements and the 40 C.F.R. § 257 monitoring requirements. This Addendum proposes additions to that network which were developed to comply with the requirements of Part 845. It is anticipated that upon acceptance and approval of the Operating Permit application (and by extension the GMP) for the CPP and upon acceptance and approval of Part 845 by the United States Environmental Protection Agency (USEPA) as a State CCR Permit Program, the Part 845 monitoring program will supersede the Closure Plan and 40 C.F.R. § 257 monitoring program.

2.1 IEPA Closure Plan Monitoring Program

The approved IEPA Closure Plan monitoring well network consists of fourteen groundwater monitoring wells used to monitor the uppermost aquifer, including three background wells (G270, G280, and G281) and eleven compliance wells (G154, G279, G401, G402, G403, G404, G405, G406, G407, G410, and G411). These wells are monitored in accordance with Water Pollution Control Permit 2020-EA-65027-1 Special Condition No. 6. The well locations are shown on **Figure 2-1**.

The GMP established a monitoring program that meets the requirements of 35 I.A.C. § 620.410 and groundwater samples are collected quarterly and analyzed for the parameters listed in **Table A** below.

Table A. IEPA Closure Plan Groundwater Monitoring Program Parameters

Field Parameters		
pH	Temperature	Turbidity
Dissolved Oxygen	Oxidation/Reduction Potential	Specific Conductance
Static Water Elevation	Depth of Well	Depth to Water
Elevation of Groundwater Surface		
Inorganics (Total, except Total Dissolved Solids [TDS])		
Chloride	Fluoride	Sulfate
Cyanide	Nitrate-Nitrogen	TDS
Metals (Total)		
Antimony	Cadmium	Lithium
Arsenic	Calcium	Mercury
Barium	Chromium	Molybdenum
Beryllium	Cobalt	Selenium
Boron	Lead	Thallium
Metals (Dissolved)		
Aluminum	Iron	Silver
Arsenic	Lead	Vanadium
Boron	Manganese	Zinc
Copper	Nickel	
Other (Total)		
Radium 226 and 228 combined		

2.2 40 C.F.R. § 257 Monitoring Program

The 40 C.F.R. § 257 monitoring well network consists of seven of the same groundwater monitoring wells used to monitor the uppermost aquifer, including two background wells (G270 and G281) and five compliance wells (G401, G402, G403, G404, and G405).

Assessment monitoring in accordance with 40 C.F.R. § 257.95 was initiated on April 9, 2018. Details on the procedures and techniques used to fulfill the groundwater sampling and analysis program requirements are found in the Sampling and Analysis Plan for AP2 (NRT, 2017b).

Groundwater samples are collected semi-annually and analyzed for the following laboratory and field parameters from Appendix III and Appendix IV of 40 C.F.R. § 257, summarized in **Table B** below.

Table B. 40 C.F.R. § 257 Groundwater Monitoring Program Parameters

Field Parameters[1]			
Groundwater Elevation	pH		
Appendix III Parameters (Total, except TDS)			
Boron	Chloride	Sulfate	
Calcium	Fluoride	TDS	
Appendix IV Parameters (Total)			
Antimony	Cadmium	Lithium	Selenium
Arsenic	Chromium	Mercury	Thallium
Barium	Cobalt	Molybdenum	Radium 226 and 228 combined
Beryllium	Lead		

[1]Dissolved oxygen, temperature, specific conductance, oxidation/reduction potential, and turbidity are recorded during sample collection.

2.3 Proposed Part 845 Monitoring Well Network

2.3.1 Proposed Additional Wells to the Current IEPA Closure Plan Monitoring

The land between AP2 and the Unnamed Tributary underwent significant improvement during closure construction which made areas, that were previously inaccessible, available for monitoring well construction. In 2021, additional monitoring wells G1001 and G1003 were completed between the eastern edge of AP2 and the Unnamed Tributary (**Figure 2-1**) targeting the uppermost aquifer (Hagarstown Member), which is classified as primarily sandy to gravelly silts and clays with thin beds of sands. No sand layers were observed in the soil boring at G1001 (**Appendix A**); however, a well was screened from 6 to 11 feet below ground surface (bgs) within the LCU and yields water. Sand layers were observed in the soil boring at G1003 (**Appendix A**) and the well was screened across sandy deposits from 8 to 12 feet bgs; however, this well has not yielded water (no measurable groundwater) since construction in May of 2021. Well G1001 is proposed as an additional well to the network for monitoring groundwater downgradient of AP2. Well G1003 will continue to be monitored for the presence of groundwater.

2.3.2 Proposed Reduction of Wells from Current IEPA Closure Plan Monitoring

Monitoring wells G154, G279, G407, G410, and G411 were included in the IEPA groundwater monitoring plan to monitor sulfate in groundwater that could be attributed to AP2. With the exception of well G407, these wells are proposed for removal from the AP2 monitoring well network as described below:

- Monitoring wells G154, G410, and G411. Groundwater elevation measurements collected from these wells confirm the presence of a groundwater divide located west of AP2 (**Figure 2-2**). Groundwater on the east side of the divide flows toward the Unnamed Tributary while groundwater on the west side of the divide flows toward the western lobe of Coffeen Lake. AP2 is located on the eastern side of the divide; therefore, these wells on the west side of the divide are not downgradient of AP2. Additionally, minimum, maximum, and median sulfate concentrations observed from March 2018 to August 2021 in wells (G154, G410, and G411) have not had concentrations greater than the groundwater protection standard (GWPS) of 400 milligrams per liter (mg/L) as presented in **Table C** below.

- Monitoring well G279. This well is located along the eastern edge of another CCR unit, the Gypsum Management Facility [GMF] Recycle Pond (Vistra ID No. 104, IEPA ID No. W1350150004-04, and NID No. IL50578). G279 is part of the 40 C.F.R. § 257 monitoring well network and the proposed Part 845 monitoring well network for the GMF Recycle Pond; therefore, this well will be removed from the AP2 monitoring network.

Table C. Summary of Sulfate Concentrations for Wells G154, G407, G410, and G411 from March 2018 through August 2021.

Location	Count	Minimum (mg/L)	Maximum (mg/L)	Median (mg/L)
G154	16	74	160	79
G407	16	400	1600	1100
G410	16	31	55	41
G411	16	110	300	250

Groundwater monitoring well G407 is also located on the east side of the groundwater divide and sulfate concentrations have been steadily decreasing since the well was installed; however, this well will be retained in the proposed monitoring network to continue to monitor potential sulfate exceedances consistent with the existing permit.

2.3.3 Proposed Monitoring Network

The groundwater monitoring network proposed in this plan will include eleven wells screened in the uppermost aquifer, or the LCU where the uppermost aquifer is absent (G270, G280, G281, G401, G402, G403, G404, G405, G406, G407, and G1001). The proposed network is summarized in **Table D** below and displayed on **Figure 2-3**. Eleven wells (three background and eight compliance) will be used to monitor groundwater concentrations within the uppermost aquifer, or the LCU where the uppermost aquifer is absent. Surface water elevations will be monitored at three staff gauges: SG02, monitoring the former discharge flume; SG03, monitoring the eastern lobe of Coffeen Lake; and SG04, monitoring the Unnamed Tributary.

The groundwater samples collected from the eleven wells will be used to monitor and evaluate groundwater quality and demonstrate compliance with the groundwater quality standards listed in 35 I.A.C. § 845.600(a). The proposed monitoring wells will yield groundwater samples that represent the quality of downgradient groundwater at the CCR boundary (as required in 35 I.A.C. § 845.630(a)(2)). Monitoring well depths and construction details are listed in **Table 2-1** and summarized in **Table D** below.

Table D. Proposed Part 845 Monitoring Well Network

Well ID	Monitored Unit	Well Screen Interval (feet bgs)	Well Type [1]
G270	UA	13.1-17.9	Background
G280	UA	12.8-17.6	Background
G281	UA	15.5-20.2	Background
G401	UA	14.4-18.8	Compliance
G402	UA	10-20	Compliance
G403	UA	13.1-17.8	Compliance
G404	UA	6.4-11.2	Compliance
G405	UA	9.0-13.8	Compliance
G406	UA	13.6-18.4	Compliance
G407	UA	13.8-18.6	Compliance
G1001	LCU	6-11	Compliance
SG02	SW	NA	WLO
SG03	SW	NA	WLO
SG04	SW	NA	WLO

[1] Well type refers to the role of the well in the monitoring network.
bgs = below ground surface
LCU = lower confining unit
NA = not applicable
SW = surface water
UA = uppermost aquifer
WLO = water level only

2.4 Well Abandonment

No wells are currently proposed for abandonment.

3. APPLICABLE GROUNDWATER QUALITY STANDARDS

3.1 Groundwater Classification

The 35 I.A.C. § 620 groundwater classification at AP2 was presented in the GMP (NRT, 2017a) and is summarized here. Groundwater at AP2 meets the definition of Class I - Potable Resource Groundwater (35 I.A.C. § 620.210) based on the following criteria:

- Groundwater in the uppermost aquifer is located 10 feet or more below the land surface and within,
- A geologic material which is capable of a hydraulic conductivity of 1 x 10^{-4} centimeters per second (cm/s) or greater using a slug test.

3.2 Statistical Evaluation of Background Groundwater Data

A Statistical Analysis Plan (**Appendix B**) has been developed to describe procedures that will be used to establish background conditions and implement compliance monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. The Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in USEPA's *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance,* March 2009), and is intended to provide a logical process and framework for conducting the statistical analysis of the data obtained during groundwater monitoring.

In accordance with 35 I.A.C. § 845.640(f)(1), the statistical method chosen for analysis of background groundwater quality was either the tolerance interval or the prediction interval procedure for each constituent listed in 35 I.A.C. § 845.600(a)(1) at this CCR unit per 35 I.A.C. § 845.640(f)(1)(C). A comparison of the statistical background concentrations and groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1) and the resulting GWPSs are summarized in **Table 3-1**.

3.3 Applicable Groundwater Protection Standards

The applicable GWPS will be established in accordance with 35 I.A.C. § 845.600(a) (greater of the background concentration or numerical limit specified in 35 I.A.C. § 845.600(a)(1)). The results of the statistical analysis of background groundwater data (**Table 3-1**) indicate that background concentrations in the uppermost aquifer are less than the groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1) with the exception of lead. Therefore, for these parameters, the groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1) will be applied to the results from the proposed groundwater monitoring network. The background concentration for lead will be applied to the lead results from the proposed groundwater monitoring network.

Under most circumstances, the GWPS will be compared to the lower confidence limit for the observed concentrations for each constituent in each compliance well. Exceptions are when there are high percentages (greater than 50 percent) of non-detects in compliance well data, for which a future mean (for 50 to 70 percent non-detects) or median (for greater than 70 percent non-detects) will be compared to the GWPS. Consistent with the *Unified Guidance*, the same general statistical method of confidence interval testing against a fixed GWPS is recommended in compliance and corrective action programs. Confidence intervals provide a flexible and statistically accurate method to test how a parameter estimated from a single sample compares

to a fixed numerical limit. Confidence intervals explicitly account for variation and uncertainty in the sample data used to construct them.

Evaluation of the applicable standards will occur in conjunction with the analysis of groundwater quality results. Background calculations and the resulting concentrations may be updated as appropriate, in accordance with the Statistical Analysis Plan included in **Appendix B**.

4. GROUNDWATER MONITORING PLAN

The groundwater monitoring plan will monitor and evaluate groundwater quality to demonstrate compliance with the groundwater quality standards included in 40 C.F.R. § 257.94(e), 40 C.F.R. § 257.95(h), and 35 I.A.C. § 845.600(a). The groundwater monitoring program will include sampling and analysis procedures that are consistent and provide an accurate representation of groundwater quality at the background and compliance wells as required by 35 I.A.C. § 845.630. As discussed within **Section 2**, three monitoring programs specific to AP2 exist, the Closure Plan monitoring program, the 40 C.F.R. § 257 monitoring program, and the proposed Part 845 monitoring program. It is expected that upon acceptance and approval of the Operating Permit applications (and by extension the GMPs) for the CPP and upon acceptance and approval of Part 845 by the USEPA as a State CCR Permit Program, the proposed Part 845 monitoring program will supersede the Closure Plan and 40 C.F.R. § 257 monitoring programs.

4.1 Monitoring Networks and Parameters

4.1.1 IEPA Closure Plan Monitoring

The existing IEPA-approved Closure Plan monitoring program was discussed in detail in **Section 2.1**. Fourteen groundwater monitoring wells are used to monitor the uppermost aquifer, including three background wells (G270, G280, and G281) and eleven compliance wells (G154, G279, G401, G402, G403, G404, G405, G406, G407, G410, and G411), and are sampled on a quarterly frequency for the parameters listed in the GMP (NRT, 2017a). Well locations and parameters will continue to be monitored and reported as required by the Closure Plan until IEPA approves the proposed Part 845 monitoring network.

4.1.2 40 C.F.R. § 257 Monitoring

The existing 40 C.F.R. § 257 monitoring program was discussed in detail in **Section 2.2**. Seven groundwater monitoring wells, including two background wells (G270 and G281) and five compliance wells (G401, G402, G403, G404, and G405) are sampled for Appendix III and Appendix IV parameters on a semi-annual frequency. Well locations and parameters will continue to be monitored and reported as required by 40 C.F.R. § 257 until USEPA approves Part 845.

4.1.3 Part 845 Groundwater Monitoring

The proposed Part 845 Monitoring Network will consist of eleven monitoring wells, three background monitoring wells (G270, G280, and G281), eight compliance wells (G401, G402, G403, G404, G405, G406, G407, and G1001), to monitor potential impacts from AP2 (**Figure 2-2**). These monitoring wells are screened within the uppermost aquifer, or the LCU where the uppermost aquifer is absent, along the perimeter of or near AP2 and include G407, located west of AP2, which is retained to continue monitoring sulfate as described in **Sections 2.3.1** and **2.3.2**. Three staff gauges (SG02, SG03, and SG04) will be used to monitor surface water elevations adjacent to AP2. Groundwater samples will be collected and analyzed for the laboratory and field parameters summarized in **Table E** below.

Table E. Part 845 Groundwater Monitoring Program Parameters

Field Parameters[1]			
Groundwater Elevation	pH	Turbidity	
Metals (Total)			
Antimony	Boron	Cobalt	Molybdenum
Arsenic	Cadmium	Lead	Selenium
Barium	Calcium	Lithium	Thallium
Beryllium	Chromium	Mercury	
Inorganics (Total)			
Chloride	Fluoride	Sulfate	TDS
Other (Total)			
Radium 226 and 228 combined			

[1] Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential will be recorded during sample collection.

4.2 Sampling Schedule

Groundwater sampling for the approved Closure Plan will be maintained until IEPA approval of the Part 845 GMP. Groundwater sampling for the Part 845 monitoring well network will initially be performed quarterly according to the following schedule:

Table F. Part 845 Sampling Schedule

Frequency	Duration
Monthly (groundwater elevations only)	Begins: the quarter following approval of this plan and issuance of the Operating Permit. Ends: Following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii).
Quarterly (groundwater quality)	Begins: the quarter following approval of this plan and issuance of the Operating Permit. Ends: Following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii), or upon IEPA approval of an alternate schedule as allowed by 35 I.A.C. § 845.650(b)(4).
Semi-annual (groundwater quality)	Begins: Following 5 years of quarterly groundwater monitoring and IEPA approval of a demonstration that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and not exhibiting statistically-significant increasing trends, monitoring effectiveness is not compromised by a semi-annual schedule, and sufficient data has been collected to characterize groundwater. Ends: Following detection of a statistically-significant increasing trend in groundwater concentrations or an exceedance of the standards in 35 I.A.C. § 845.600 (quarterly monitoring shall be resumed in these circumstances), or following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii).

Groundwater monitoring for the 40 C.F.R. § 257.94 well network will continue to follow a schedule in accordance with the requirements of 40 C.F.R. § 257.94 and 40 C.F.R. § 257.95. Upon USEPA approval of Part 845 as a State CCR Permit Program, the 40 C.F.R. § 257.94 monitoring will be discontinued, and replaced by the Part 845 monitoring.

4.3 Groundwater Sample Collection

Groundwater sampling procedures have been developed and the collection of groundwater samples is being implemented to meet the requirements of 35 I.A.C. § 845.640. In addition to groundwater well samples, quality assurance samples will be collected as described in **Section 4.5** (**Table 4-1**).

4.4 Laboratory Analysis

Laboratory analysis will be performed consistent with the requirements of 35 I.A.C. § 845.640(j) by a state-certified laboratory using methods approved by IEPA and USEPA. Laboratory methods may be modified based on laboratory equipment availability or procedures, but the Reporting Limit (RL) for all parameters analyzed, regardless of method, will be lower than the applicable groundwater quality standard. RLs for the applicable parameters are summarized in **Table 4-2**. Concentrations lower than the RL will be reported as less than the RL.

4.5 Quality Assurance Program

Consistent with the requirements of 35 I.A.C. § 845.640(a)(5), the sampling and analysis program includes procedures and techniques for quality assurance/quality control (QA/QC). Additional quality assurance samples to be collected will include the following:

- Field duplicates will be collected at a frequency of one per group of ten or fewer investigative water samples.
- One equipment blank sample will be collected and analyzed for each day of sampling. If dedicated sampling equipment is used, then equipment blank samples will not be collected.
- The duplicate and equipment blank quality assurance samples will be supplemented by the laboratory QA/QC program, which typically includes:
  - Regular generation of instrument calibration curves to assure instrument reliability
  - Laboratory control samples and/or quality control check standards that have been spiked, and analyses to monitor the performance of the analytical method
  - Matrix spike/matrix spike duplicate analyses to determine percent recoveries and relative percent differences for each of the parameters detected
  - Analysis of replicate samples to check the precision of the instrumentation and/or methodology employed for all analytical methods
  - Analysis of method blanks to assure that the system is free of contamination

Water quality meters used to measure pH and turbidity will be calibrated according to manufacturer's specifications. At a minimum, it is recommended that calibration of pH occur daily prior to sampling and checked for accuracy at the end of each day. Unusual or suspect pH measurements during sampling events will be flagged, evaluated, and additional calibration may be performed throughout the sampling events. Turbidity meters will be checked daily, prior to

and following sampling. Unusual measurements or erratic meter performance will be flagged and evaluated for overall effects on the data prior to reporting.

4.6 Groundwater Monitoring System Maintenance Plan

Consistent with the requirements of 35 I.A.C. § 845.630(e)(2), maintenance will be performed as needed to assure that the monitoring wells provide representative groundwater samples. Monitoring wells will be inspected during each groundwater sampling event; inspections will consist of the following:

- Visual inspection, clearing of vegetation, replacement of markers, and painting of protective casings as needed to assure that monitoring wells are clearly marked and accessible.
- Visual inspection and repair or replacement of well aprons as needed to assure that they are intact, drain water away from the well, and have not heaved.
- Visual inspection and repair or replacement of protective casings as needed to assure that they are undamaged, and that locks are present and functional.
- Checks to assure that well caps are intact and vented, unless in flood-prone areas in which case caps will not be vented.
- Annual measurement of monitoring well depths to determine the degree of siltation within the wells. Wells will be redeveloped as needed to remove siltation from the screened interval if it impedes flow of water into the well.
- Checks to assure that wells are clear of internal obstructions, and flow freely.

If maintenance of a monitoring well cannot address an identified deficiency, a replacement well will be installed.

4.7 Statistical Analysis

Statistical analysis will be consistent with procedures listed in 35 I.A.C. § 845.640(f). A Statistical Analysis Plan, provided in **Appendix B**, has been developed to summarize the statistical procedures that will be used to evaluate the groundwater results.

4.8 Data Reporting

Data reporting for the 40 C.F.R. § 257 monitoring program will be consistent with recordkeeping, notification, and internet posting requirements described in 40 C.F.R. § 257.105 through 40 C.F.R. § 257.107.

Groundwater monitoring and analysis completed as part of the Part 845 monitoring under an approved monitoring program will be reported to IEPA within 60 days after completion of sampling and place the data in the facility's operating record as required by 35 I.A.C. § 845.610(b)(3)(D). Within 14 days of posting to the operating record, information will be posted to the publicly accessible internet site "Illinois CCR Rule Compliance Data and Information" as required by 35 I.A.C. § 845.810(d). Information will also be provided to IEPA annually, by January 31 for data collected the preceding year. The report will include the status of the groundwater monitoring and corrective action plan for the CPP AP2 in addition to other requirements detailed in 35 I.A.C. § 845.610(e).

4.9 Compliance with Applicable On-site Groundwater Quality Standards

In accordance with 35 I.A.C. § 845.600(a)(1), the groundwater protection standard at the waste boundary will be the higher of either the 35 I.A.C. § 845.600 standard or the concentration determined by background groundwater monitoring.

As provided in 35 I.A.C. § 845.780(c)(2), at the end of the 30-year post-closure care period, groundwater monitoring will continue to be conducted in post-closure care until the groundwater results show the concentrations are:

- Below the GWPS in 35 I.A.C. § 845.600; and
- Not increasing for those constituents over background, using the statistical procedures and performance standards in 35 I.A.C. § 845.640(f) and (g), provided that:
  - Concentrations have been reduced to the maximum extent feasible; and
  - Concentrations are protective of human health and the environment.

Following detection of an exceedance of the GWPS, an Alternate Source Demonstration (ASD) will be evaluated as described in **Section 4.10**.

4.10 Alternate Source Demonstrations

As allowed in 35 I.A.C. § 845.650(e), following detection of an exceedance of the GWPS, an ASD will be evaluated and, if completed, submitted to IEPA within 60 days. The ASD will provide lines of evidence that a source other than AP2 caused the contamination and AP2 did not contribute to the contamination, or that the exceedance of the GWPS resulted from error in sampling, analysis, statistical evaluation, natural variation in groundwater quality, or a change in the potentiometric surface and groundwater flow direction.

The ASD will include information and analysis that supports the conclusions and a certification of accuracy by a qualified professional engineer. Once the ASD is approved by IEPA, the Part 845 groundwater monitoring will continue as defined in **Section 4.1.3**.

If an ASD is not completed and submitted, or IEPA does not approve the ASD, a notification of the exceedance will be provided to IEPA and placed in the operating record. Additional actions will also be completed as required by 35 I.A.C § 845.650(d)(1) through (3), including initiation of an assessment of corrective measures under 35 I.A.C § 845.660. As allowed in 35 I.A.C § 845.650(e)(7), a petition for review of IEPA's non-concurrence under 35 I.A.C. § 105 may also be filed.

5. REFERENCES

AECOM, 2017. *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2 at Illinois Power Generating Company, Coffeen Power Station, 134 Cips Lane, Coffeen, IL 62107*, January 26, 2017.

Illinois Environmental Protection Agency, 2021. *Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845*, April 15, 2021.

Natural Resource Technology, Inc. (NRT), 2017a. *Groundwater Monitoring Plan, Ash Pond No. 2, Coffeen Power Station*, January 24, 2017.

Natural Resource Technology, Inc. (NRT), 2017b. *Sampling and Analysis Plan, Final, Coffeen Ash Pond No. 2, Coffeen Power Station, Coffeen, Illinois, Project No. 2285, Revision 0*. October 17, 2017

United States Environmental Protection Agency (USEPA), March 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance. Office of Resource Conservation and Recovery, Program Implementation and Information Division, United States Environmental Protection Agency, Washington D.C. EPA/530/R-09/007.

TABLES

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ıcted	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft BGS)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Scre Diam (inch
2021	597.61	--	Top of PVC	594.82	6.00	11.00	588.82	583.82	11.00	562.82	5	4
2008	--	625.86	Top of Disk	623.73	13.13	17.92	610.60	605.81	18.27	605.50	4.8	2
2008	625.35	625.35	Top of Riser	623.11	12.79	17.63	610.32	605.48	17.98	605.10	4.8	2
2015	--	626.36	Top of Disk	623.82	15.51	20.16	608.31	603.66	20.30	603.50	4.7	2
2015	--	625.57	Top of Disk	623.03	14.36	18.79	608.67	604.24	19.29	603.70	4.4	2
2010	--	613.37	Top of Disk	610.36	10.00	20.00	600.36	590.36	20.40	590.00	10	2
2015	--	626.47	Top of Disk	623.81	13.11	17.78	610.70	606.03	18.15	605.70	4.7	2
2007	--	615.67	Top of Disk	613.57	6.42	11.17	607.15	602.40	11.62	601.60	4.8	2
2007	--	623.63	Top of Disk	621.40	9.01	13.76	612.39	607.64	14.21	607.20	4.8	2
2016	625.36	625.36	Top of PVC	621.86	13.56	18.37	608.30	603.49	18.75	603.10	4.8	2
2016	621.32	621.32	Top of PVC	618.35	13.78	18.61	604.57	599.74	19.04	598.40	4.8	2
	--	605.87	Top of Prot Casing	605.87	--	--	--	--	--	--	--	--
	--	594.94	Top of Prot Casing	594.94	--	--	--	--	--	--	--	--
	--	599.52	Top of Prot Casing	599.52	--	--	--	--	--	--	--	--

ative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
the monitoring network: background (B), compliance (C), or water level measurements only (WLO)
mplementation of impoundment closure per an approved Construction Permit application

TABLE 3-1. BACKGROUND GROUNDWATER QUALITY AND STANDARDS
GROUNDWATER MONITORING PLAN
COFFEEN POWER PLANT
ASH POND NO. 2
COFFEEN, ILLINOIS

Parameter	Background Concentration	845 Limit	Groundwater Protection Standard	Unit
Antimony, total	0.003	0.006	0.006	mg/L
Arsenic, total	0.0066	0.010	0.010	mg/L
Barium, total	0.14	2.0	2.0	mg/L
Beryllium, total	0.001	0.004	0.004	mg/L
Boron, total	0.029	2	2	mg/L
Cadmium, total	0.001	0.005	0.005	mg/L
Chloride, total	75	200	200	mg/L
Chromium, total	0.019	0.1	0.1	mg/L
Cobalt, total	0.0059	0.006	0.006	mg/L
Fluoride, total	0.513	4.0	4.0	mg/L
Lead, total	0.012	0.0075	0.012	mg/L
Lithium, total	0.019	0.04	0.04	mg/L
Mercury, total	0.0002	0.002	0.002	mg/L
Molybdenum, total	0.0045	0.1	0.1	mg/L
pH (field)	7.5 / 6.6	9.0 / 6.5	9.0 / 6.5	SU
Radium 226 and 228 combined	1.89	5	5	pCi/L
Selenium, total	0.0048	0.05	0.05	mg/L
Sulfate, total	370	400	400	mg/L
Thallium, total	0.001	0.002	0.002	mg/L
Total Dissolved Solids	840	1200	1200	mg/L

Notes:
For pH, the values presented are the upper / lower limits
GWPS for calcium and turbidity do not apply per 35 I.A.C. § 845.600(b)
mg/L = milligrams per liter
SU = standard units
pCi/L = picocuries per liter

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Analytical Method [1]	Number of Samples	Field Duplicates [2]	Field Blanks [3]	Equipment Blanks [3]	MS/MSD [4]	Total	Container Type	Minimum Volume [5]	Preservation (Cool to 4 °C for all samples
6020, Li - EPA 200.7	11	2	0	0	1	14	plastic	600 mL	HNO_3 to pH<2
7470A or 6020	11	2	0	0	1	14	plastic	400 mL	HNO_3 to pH<2
9214 or EPA 300	11	2	0	0	1	14	plastic	300 mL	Cool to 4 °C
9251 or EPA 300	11	2	0	0	1	14	plastic	100 mL	Cool to 4 °C
9036 or EPA 300	11	2	0	0	1	14	plastic	50 mL	Cool to 4 °C
SM 2540 C	11	2	0	0	1	14	plastic	200 mL	Cool to 4 °C
9315 or EPA 903	11	0	0	0	0	11	plastic	1000 mL	HNO_3 to pH<2
9320 or EPA 904	11	0	0	0	0	11	plastic	1000 mL	HNO_3 to pH<2
SM 4500-H+ B	11	NA	NA	NA	NA	11	flow-through cell	NA	none
SM 4500-O/405.1	11	NA	NA	NA	NA	11	flow-through cell	NA	none
SM 2550	11	NA	NA	NA	NA	11	flow-through cell	NA	none
SM 2580 B	11	NA	NA	NA	NA	11	flow-through cell	NA	none
SM 2510 B	11	NA	NA	NA	NA	11	flow-through cell	NA	none
SM 2130 B	11	NA	NA	NA	NA	11	flow-through cell or hand-held turbidity meter	NA	none

[O: CJC 08/18/21; C: LDC 08/31/21][U:

W-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as appropriate.
equency of one per group of 10 or fewer investigative water samples. Field duplicates will not be collected for radium analysis.
retion of the project manager; Equipment blanks will be collected at a rate of 1 per sampling event if non-dedicated equipment is used.
S/MSD) samples will be collected at a frequency of one per group of 20 or fewer investigative water samples per CCR unit/multi-unit. Additional volume to be determined by laboratory.
e determined by the laboratory.
eryllium, boron, cadmium, calcium, chromium, cobalt, lead, lithium, molybdenum, selenium, thallium. Metals may be analyzed via ICP/ ICP-MS USEPA methods 6010 or 6020 depending on laboratory instrun
e sample filtered through a .45 micron filter may be collected for metals analysis in addition to the unfiltered sample. Both samples would be submitted for analysis.
ce and quality control for field sampling purposes only; not required to be collected or reported under Part 845; collection of parameter may be discontinued without notification.

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TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS

ADDENDUM TO THE GROUNDWATER MONITORING PLAN

COFFEEN POWER PLANT

ASH POND NO. 2

COFFEEN, ILLINOIS

Constituent	CAS	Unit	Analytical Methods [1]	USEPA MCL [2]	35 I.A.C. § 845.600	RL [4, 5]	MDL [5]
Metals							
Antimony	7440-36-0	mg/L	6020	0.006	0.006	0.003	0.00036
Arsenic	7440-38-2	mg/L	6020	0.01	0.01	0.001	0.00013
Barium	7440-39-3	mg/L	6020	2	2	0.001	0.00028
Beryllium	7440-41-7	mg/L	6020	0.004	0.004	0.001	0.000017
Boron	7440-42-8	mg/L	6020	NS	2	0.01	0.0023
Cadmium	7440-43-9	mg/L	6020	0.005	0.005	0.001	0.000042
Calcium	7440-70-2	mg/L	6020	NS	NS	0.15	0.15
Chromium	7440-47-3	mg/L	6020	0.1	0.1	0.004	0.00027
Cobalt	7440-48-4	mg/L	6020	0.006	0.006	0.002	0.000017
Lead	7439-92-1	mg/L	6020	0.015	0.0075	0.001	0.000025
Lithium	7439-93-2	mg/L	6020 or EPA 200.7	0.04	0.04	0.02	0.0001
Mercury	7439-97-6	mg/L	6020 or 7470A	0.002	0.002	0.0002	0.000078
Molybdenum	7439-98-7	mg/L	6020	0.1	0.1	0.001	0.000063
Selenium	7782-49-2	mg/L	6020	0.05	0.05	0.001	0.00032
Thallium	7440-28-0	mg/L	6020	0.002	0.002	0.001	0.000062
Inorganics							
Fluoride	7681	mg/L	9214 or EPA 300	4	4	0.25	0.065
Chloride	16887-00-6	mg/L	9251 or EPA 300	250 [3]	200	1	0.15
Sulfate	18785-72-3	mg/L	9036 or EPA 300	250 [3]	400	1	0.24
Total Dissolved Solids	10052	mg/L	SM 2540C	500 [3]	1200	17	--
Other							
Radium 226 and 226 combined	7440-14-4	pCi/L	9315/9320 or EPA 903/904	5	5	-- [6]	-- [7]
Field							
pH	NA	SU	SM 4500-H+ B	NS	6.5-9.0	NA	NA
Oxidation/Reduction Potential	NA	mV	SM 2580 B	NS	NS	NA	NA
Dissolved Oxygen	NA	mg/L	SM 4500-O/405.1	NS	NS	NA	NA
Temperature	NA	°C	SM 2550	NS	NS	NA	NA
Specific Conductivity	NA	µS/cm	SM 2510 B	NS	NS	NA	NA

RAMBOLL

TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS

ADDENDUM TO THE GROUNDWATER MONITORING PLAN

COFFEEN POWER PLANT

ASH POND NO. 2

COFFEEN, ILLINOIS

Constituent	CAS	Unit	Analytical Methods [1]	USEPA MCL [2]	35 I.A.C. § 845.600	RL [4, 5]	MDL [5]
Turbidity	NA	NTU	SM 2130 B	NS	NS	NA	NA

[O: CJC 08/18/21; C: LDC 08/31/21],[U:KLT 9/23/21; C: CJC 10/4/21]

Notes:

[1] Analytical method numbers are from SW-846 unless otherwise indicated. Metals will be analyzed via Method 6020 or 6010 depending on laboratory equipment availability. Selected method will ensure reporting limits (RL) are below Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.600 groundwater protection standards.

[2] USEPA MCL = United States Environmental Protection Agency Maximum Contaminant Level.

[3] USEPA SMCL = United States Environmental Protection Agency Secondary Maximum Contaminant Level.

[4] RLs will be less than the 35 I.A.C. § 845.600 groundwater protection standards.

[5] RLs and method detection limits (MDL) will vary depending on the laboratory performing the work.

[6] All radium results will be reported (values may be positive or negative) and will include uncertainty and the calculated MDC.

[7] Laboratories calculate a minimum detectable concentration (MDC) based on the sample.

°C = degrees Celsius

µS/cm = microSiemens per centimeter

CAS = Chemical Abstract Number

MDL = Method detection limit as established by the laboratory

mg/L = milligrams per liter

mV = millivolts

NA = Not applicable

NS = No standard

NTU = nephelometric turbidity unit

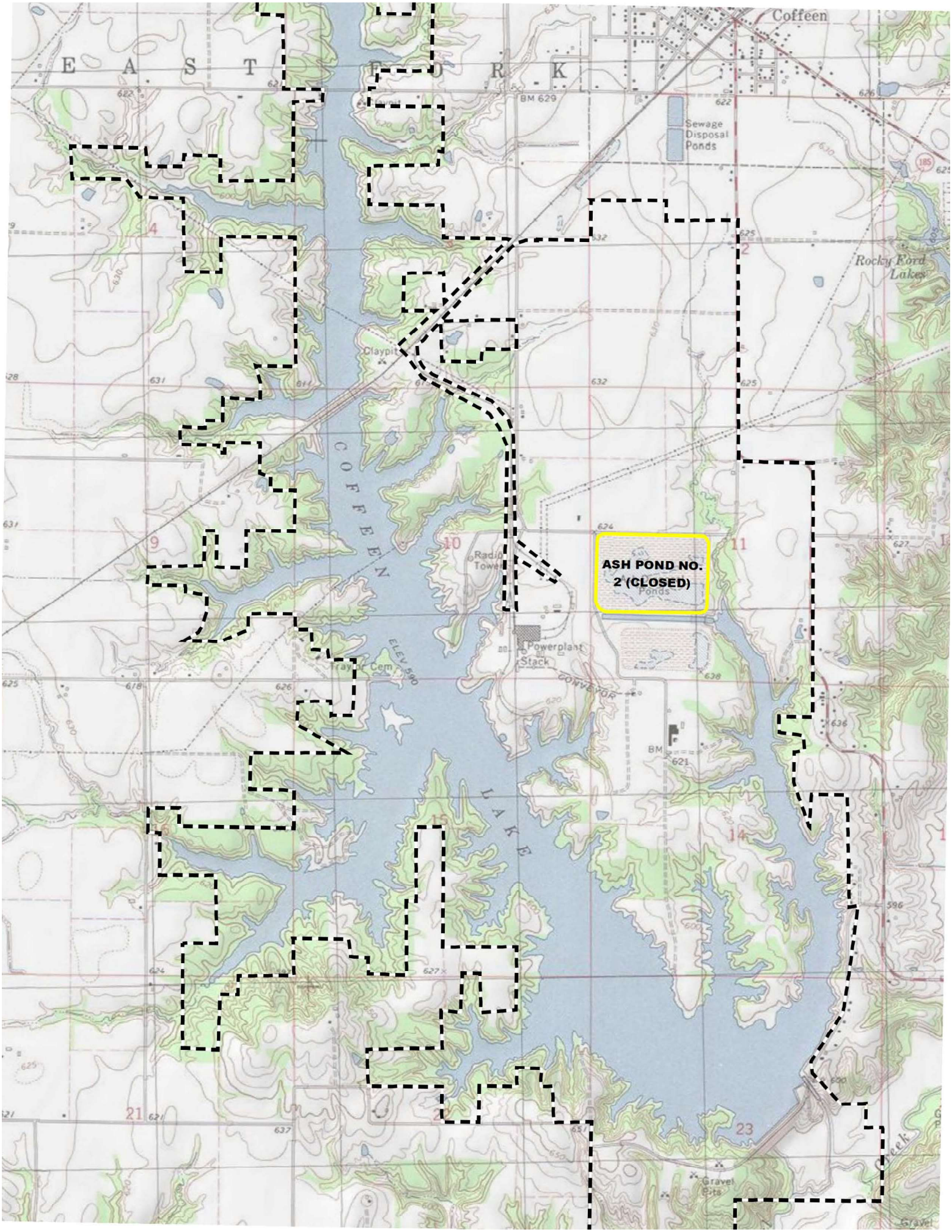
pCi/L = picoCuries per liter

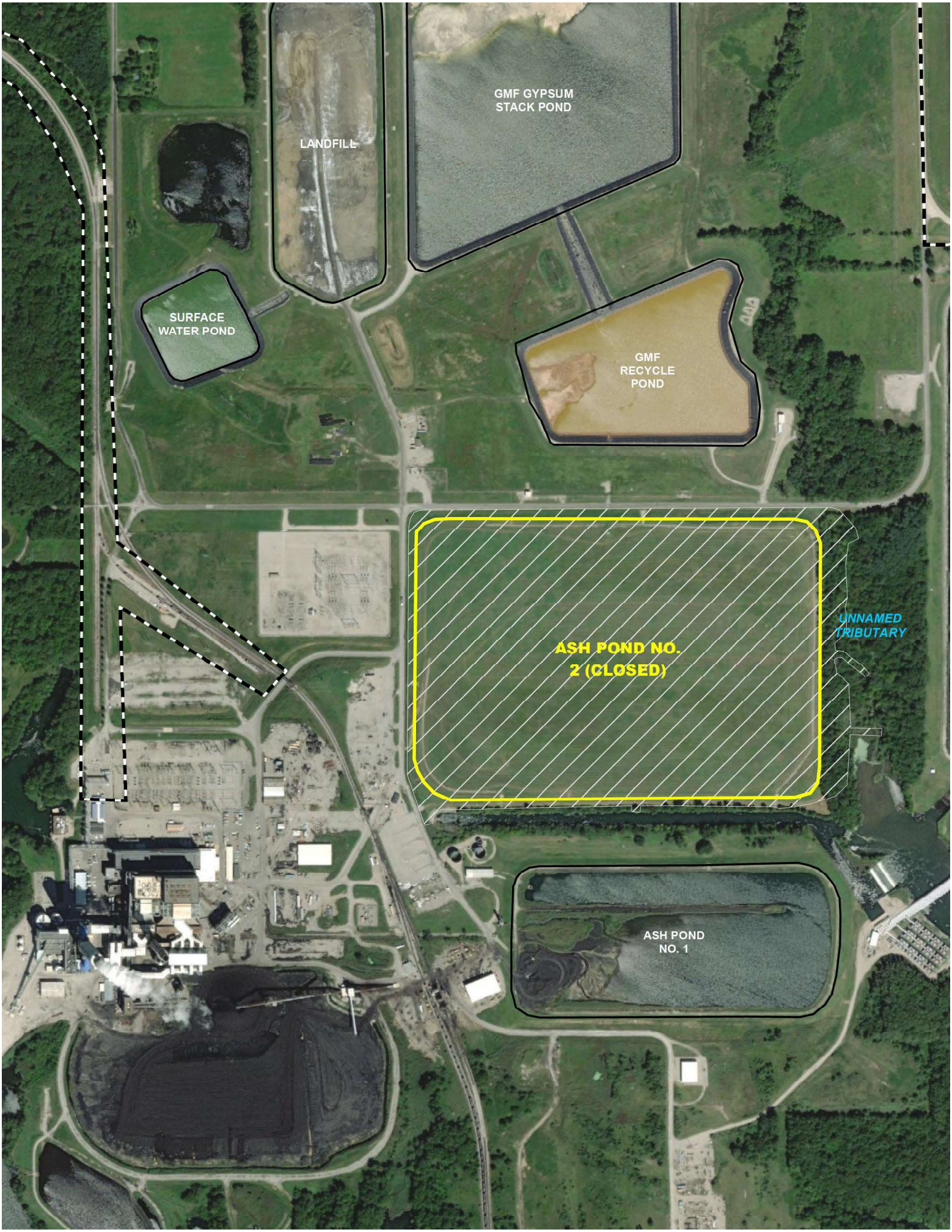
RL = Reporting limit as established by the laboratory

SM = Standard Methods for the Examination of Water and Wastewater

SU = standard units

FIGURES


Coffeen
EAST FORK
BM 629
Sewage Disposal Ponds
Rocky Ford Lakes
Claypit
COFFEEN
Radio Tower
ASH POND NO. 2 (CLOSED)
Ponds
Powerplant Stack
CONVEYOR
ELEV 590
Trayor Cem
BM 621
LAKE
Gravel Pits
Gravel


GMF GYPSUM
STACK POND
LANDFILL
SURFACE
WATER POND
GMF
RECYCLE
POND
ASH POND NO.
2 (CLOSED)
UNNAMED
TRIBUTARY
ASH POND
NO. 1



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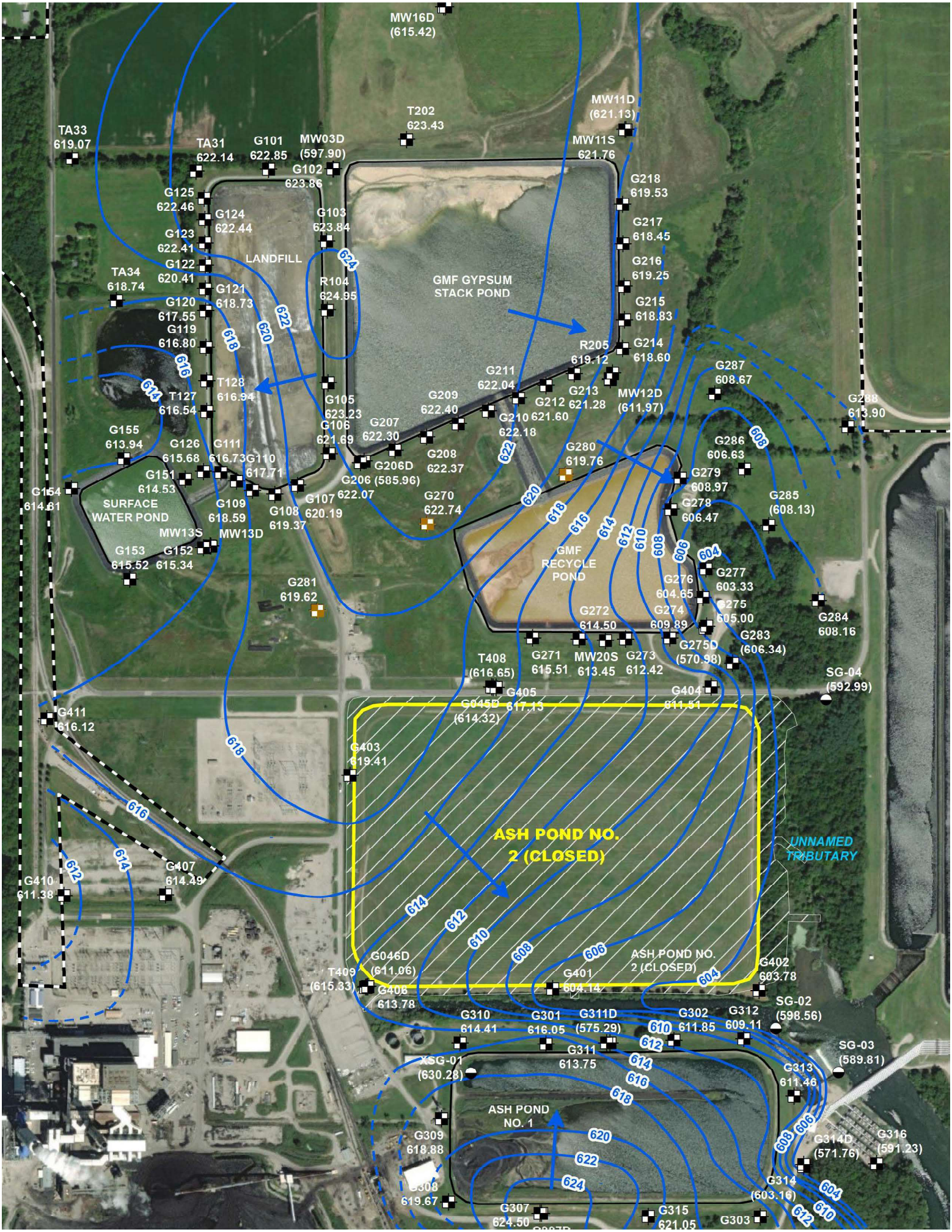
845 REGULATED UNIT (SUBJECT UNIT)

IEPA MONITORING WELL LOCATIONS AND


MW16D
(615.42)
T202
623.43
MW11D
(621.13)
MW11S
621.76
TA33
619.07
TA31
622.14
G101
622.85
MW03D
(597.90)
G102
623.86
G218
619.53
G125
622.46
G124
622.44
G103
623.84
G217
618.45
G123
622.41
LANDFILL
G216
619.25
G122
620.41
TA34
618.74
R104
624.95
GMF GYPSUM
STACK POND
G121
618.73
G215
618.83
G120
617.55
G119
616.80
R205
619.12
G214
618.60
G211
622.04
G287
608.67
T128
616.94
T127
616.54
G105
623.23
G209
622.40
G213
621.28
MW12D
(611.97)
G212
621.60
G210
622.18
G288
613.90
G106
621.69
G207
622.30
G155
613.94
G126
615.68
G111
616.73
G110
617.71
G208
622.37
G206D
G206 (585.96)
622.07
G280
619.76
G286
606.63
G279
608.97
G151
614.53
G164
614.81
SURFACE
WATER POND
G109
618.59
G107
620.19
G108
619.37
G270
622.74
G278
606.47
G285
(608.13)
MW13S
MW13D
G153
615.52
G152
615.34
GMF
RECYCLE
POND
G281
619.62
G277
603.33
G276
604.65
G275
605.00
G274
609.89
G284
608.16
G272
614.50
G283
(606.34)
G275D
(570.98)
T408
(616.65)
G271
615.51
MW20S
613.45
G273
612.42
SG-04
(592.99)
G405
617.15
G404
611.51
G045D
(614.32)
G411
616.12
G403
619.41
ASH POND NO.
2 (CLOSED)
UNNAMED
TRIBUTARY
G410
611.38
G407
614.49
G046D
(611.06)
T409
(615.33)
G406
613.78
ASH POND
NO. 2 (CLOSED)
G401
604.14
G402
603.78
SG-02
(598.56)
G310
614.41
G301
616.05
G311D
(575.29)
G302
611.85
G312
609.11
SG-03
(589.81)
G311
613.75
XSG-01
(630.28)
G313
611.46
ASH POND
NO. 1
G309
618.88
G316
(591.23)
G314D
(571.76)
G308
619.67
G314
(603.16)
G307
624.50
G315
621.05
G303
620
622
624
618
616
614
612
610
608
606
604



REGULATED UNIT (SUBJECT UNIT)

PROPOSED 845 GROUNDWATER MONITORING WELL NETWORK

R001719

APPENDICES

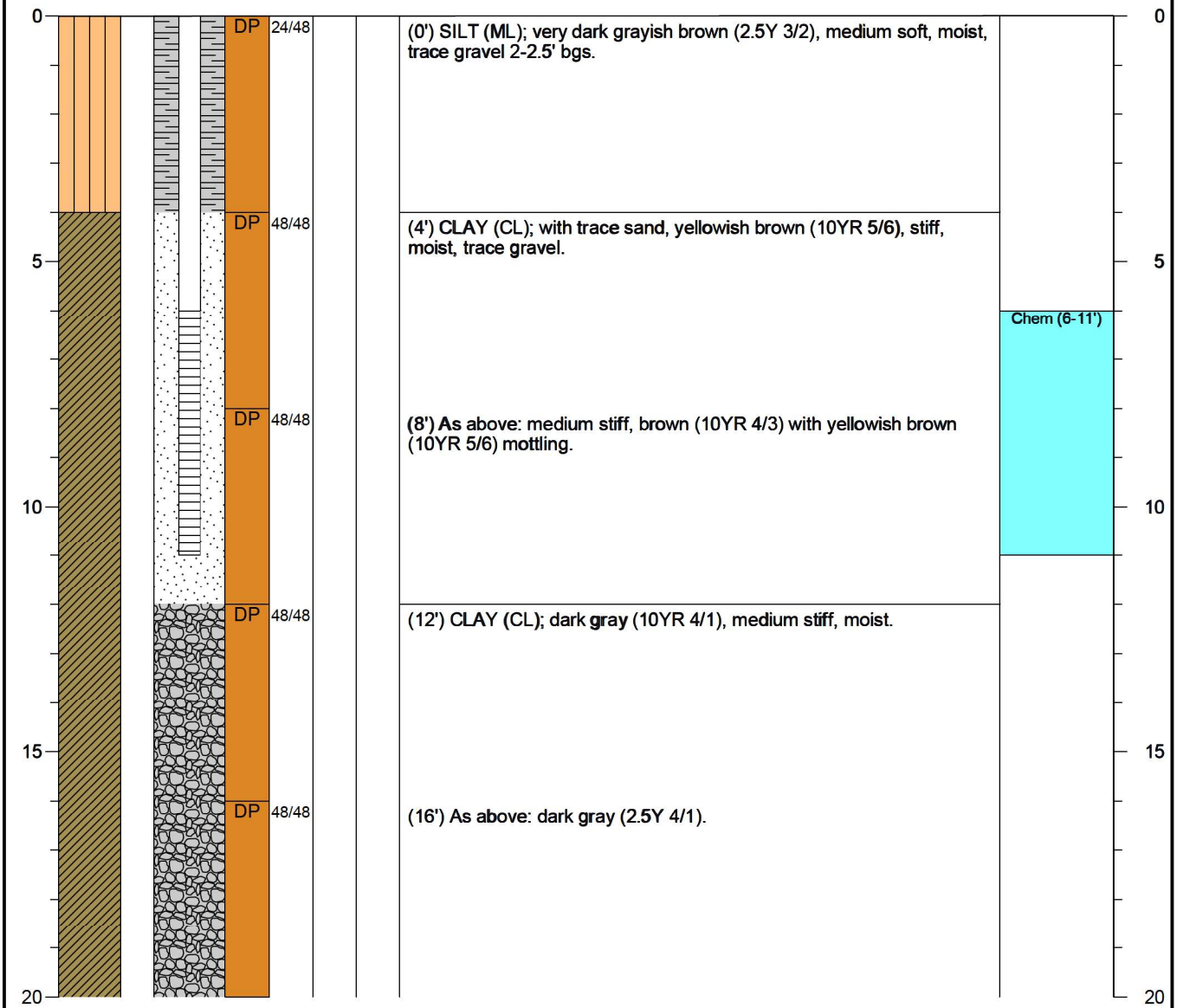
APPENDIX A
G1001 & G1003 BORING AND WELL CONSTRUCTION LOGS

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP8005, Coffeen Power Station
Address: Coffeen, IL 62017

WELL LOG
Well No. G1001
Page: 1 of 2

Drilling Start Date:	04/05/2021	Boring Depth (ft):	32	Well Depth (ft):	12
Drilling End Date:	04/05/2021	Boring Diameter (in):	6	Well Diameter (in):	1
Drilling Company:	Roberts Drilling	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Direct Push	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	Geoprobe	Top of Casing Elev. (ft)		Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):		Seal Material(s):	Bentonite Chips
Logged By:	A. Toye	Northing, Easting (NAD83):		Filter Pack:	Sand



NOTES: No groundwater encountered.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP8005, Coffeen Power Station
Address: Coffeen, IL 62017

WELL LOG
Well No. G1001
Page: 2 of 2

Drilling Start Date:	04/05/2021	Boring Depth (ft):	32	Well Depth (ft):	12
Drilling End Date:	04/05/2021	Boring Diameter (in):	6	Well Diameter (in):	1
Drilling Company:	Roberts Drilling	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Direct Push	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	Geoprobe	Top of Casing Elev. (ft)		Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):		Seal Material(s):	Bentonite Chips
Logged By:	A. Toye	Northing, Easting (NAD83):		Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	COLLECT: Recovery (in)	COLLECT: Blow Counts	COLLECT: N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				DP	48/48			(20') As above: gravel at 1 ft.		20
25				DP	48/48			(24') As above: dry pocket at 2.8 ft.		25
30				DP	18/48			(28') As above: trace gravel and silt at 2 ft.		30
35								(32') End of Boring.		35

NOTES: No groundwater encountered.

Geosyntec consultants

SOIL BORING LOG

BORING NUMBER: G1002-2

PROJECT: GLP8005	PROJECT NO.: Coffeen MWA	E —	N —
LOCATION: Coffeen, IL	PHASE NO.: 2	G. S. ELEVATION: ~
CLIENT: Vistra	TASK NO.: —	BORING DEPTH: 21.0'
DRILLING CO: Roberts Env	DRILLER:	DRILLING METHOD: DP
LOGGED BY: A Toye	STARTED: 5/25/21	COMPLETED: 5/25/21

Depth (ft)	Elevation (ft)	Sample No.	Recovery / Attempted	Strata Change	Soil/Rock Description	Notes Blow Count N	Unit Weight (pcf)	Q_p (tsf)	Q_u (tsf)	wc (%)
			16/36"		1.3' of SILTY CLAY, med grey, ~~soft~~, moist					
2										
3										
4		Chem Sample	36/36"		24" of CLAYEY SAND, orange brown to light grey, soft, moist	← Slugged to split spoon				
6										
8		Chem Sample			12" of CLAY w SOME SAND, orange brown w light grey mottling, low Plastic, dry		Scree n	8		
10		Chem Sample	36/36		0.6' of Sand, orange, fine grained, slightly moist					
					3.7' of SAND w SOME SILT, greyish brown, dry					
12		Chem Sample			0.7' of SAND, orange, slightly moist			12		
13										
14		Chem Sample	14/24		1.5' of SILTY SAND, orange w grey mottling, dry					
16			0/24"		NO RECOVERY					
18			20/24"		1.8' SILT w SAND & CLAY, ~~grey~~ grey, low Plastic, dry					
19										
20			24/24"		2' CLAY, grey, med Plastic, moist					
21					EOB 21'					
22										

R001725

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID	G1001	Site Location	Coffeen, IL
Project Name	Coffeen Power Station	Field Personnel	A Toye, C Luttrell
Project Number	GLP8005	Recorded By	A Toye

Permit Number
Installation Date(s) 4-05-2021
Drilling Method Direct Push
Borehole Diameter 6.00"
Drilling Contractor Roberts Environmental
Driller
Drilling Fluid N/A
Fluid Loss During Drilling N/A Gallons

Materials Used

Riser Pipe: Diameter 4 inches
Construction
☑ PVC schedule 40
☐ Stainless Steel
☐ Other

Slotted Area: Length 5.00 feet
Diameter 4.00 inches
Slot Size .010 inches
Construction
☑ PVC schedule 40
☐ Stainless Steel
☐ Other
Silt Trap Used ☐ Yes ☐ No

Bottom End Cap: ☐ Male ☐ Female ☐ Slip
☐ PVC
☐ Stainless Steel
☐ Other

Top Cap: ☐ Male ☐ Female ☐ Slip ☐ J Plug
☐ PVC
☐ Stainless Steel
☐ Other

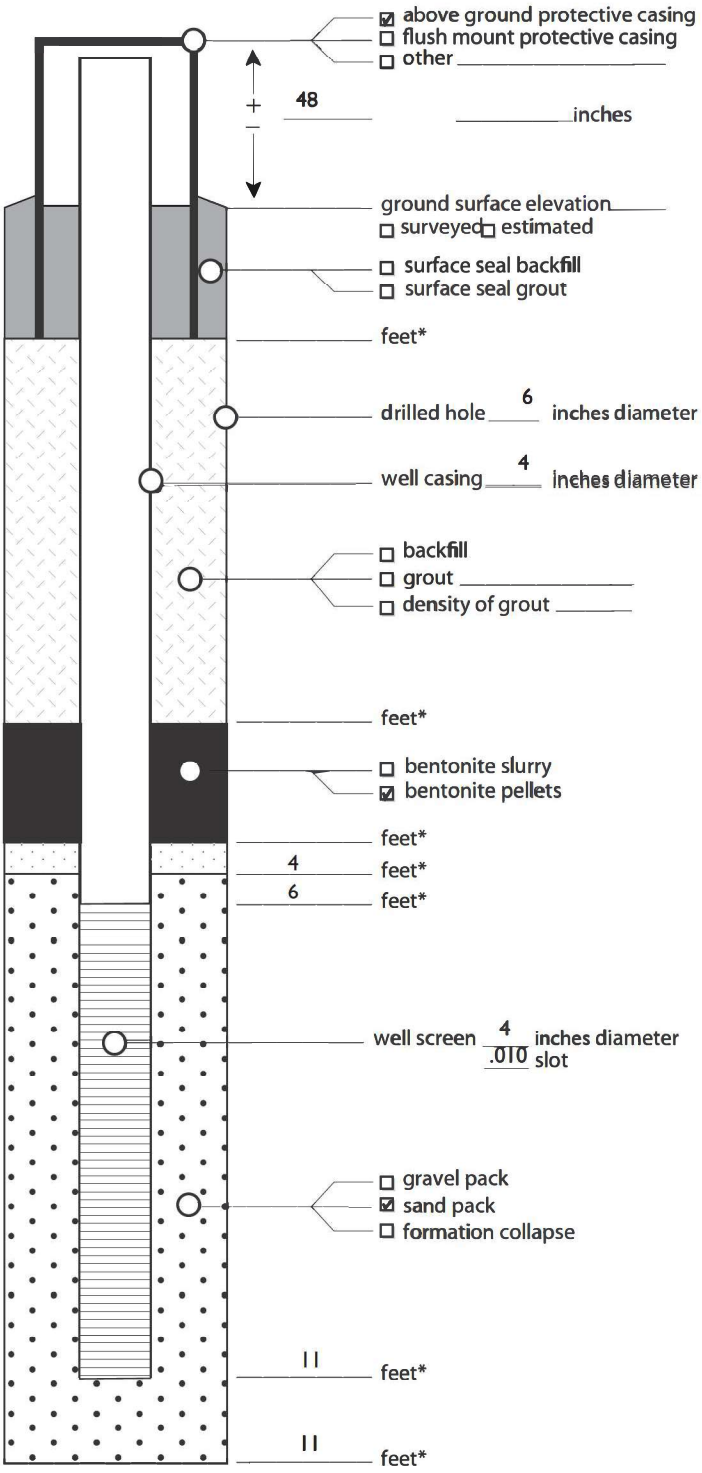
Protective Casing: Length 5 feet
Diameter 6 inches
Construction ☐ Cast Aluminum
☑ Cast Steel
☐ Other

Casing Installation: Length 11 feet
Diameter 4 inches
Material PVC

Sandpack: Filter Sil
Coarse Sand: bags of lb per bag Size
Fine Sand: 4 bags of 50 lb per bag Size

Seal:
Bentonite Pellets: 2 bags of 50 lb per bag Type Bentonite Plug
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: bags of lb per bag Type
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R001726

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SOIL BORING LOG

Page 1 of 1

BORING NUMBER: GI002-2

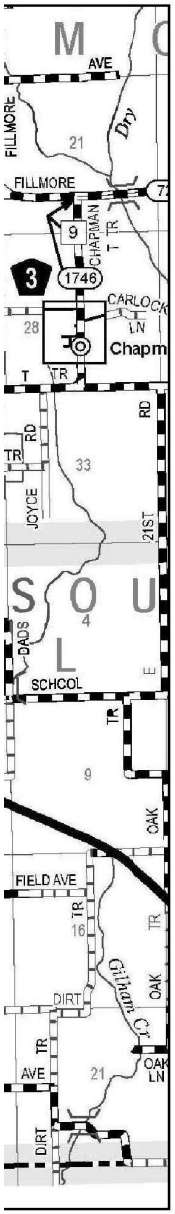
PROJECT: GLP8005	PROJECT NO.: Coffeen MW4	E —	N —
LOCATION: Coffeen, IL	PHASE NO.: 2	G. S. ELEVATION: ~
CLIENT: Vistra	TASK NO.: —	BORING DEPTH: 21.0'
DRILLING CO: Roberts Env	DRILLER:	DRILLING METHOD: DP
LOGGED BY: A Toye	STARTED: 5/25/21	COMPLETED: 5/25/21

Depth (ft)	Elevation (ft)	Sample No.	Recovery / Attempted	Strata Change	Soil/Rock Description	Notes Blow Count	Unit Weight (pcf)	Qp (tsf)	Qu (tsf)	wc (%)
			16/36"		1.3' of SILTY CLAY, med grey, soft, moist					
2										
3										
4		Chem Sample	36/36"		24" of CLAYEY SAND, orange brown to light grey, soft, moist	← Slugged to split spoon				
6										
8		Chem Sample			12" of CLAY w SOME SAND, orange brown w light grey mottling, low Plastic, dry		Screen	8		
10		Chem Sample	36/36		0.6' of SAND, orange, fine grained, slightly moist					
					3.7' of SAND w SOME SILT, greyish brown, dry					
12		Chem Sample			0.7' of SAND, orange, slightly moist			12		
13										
14		Chem Sample	14/24		1.5' of SILTY SAND, orange w grey mottling, dry					
16			0/24"		NO RECOVERY					
18			20/24"		1.8' SILT w SAND & CLAY, grey, low Plastic, dry					
19										
20			24/24"		2' CLAY, grey, med Plastic, moist					
21					EOB 21'					
22										

R001727

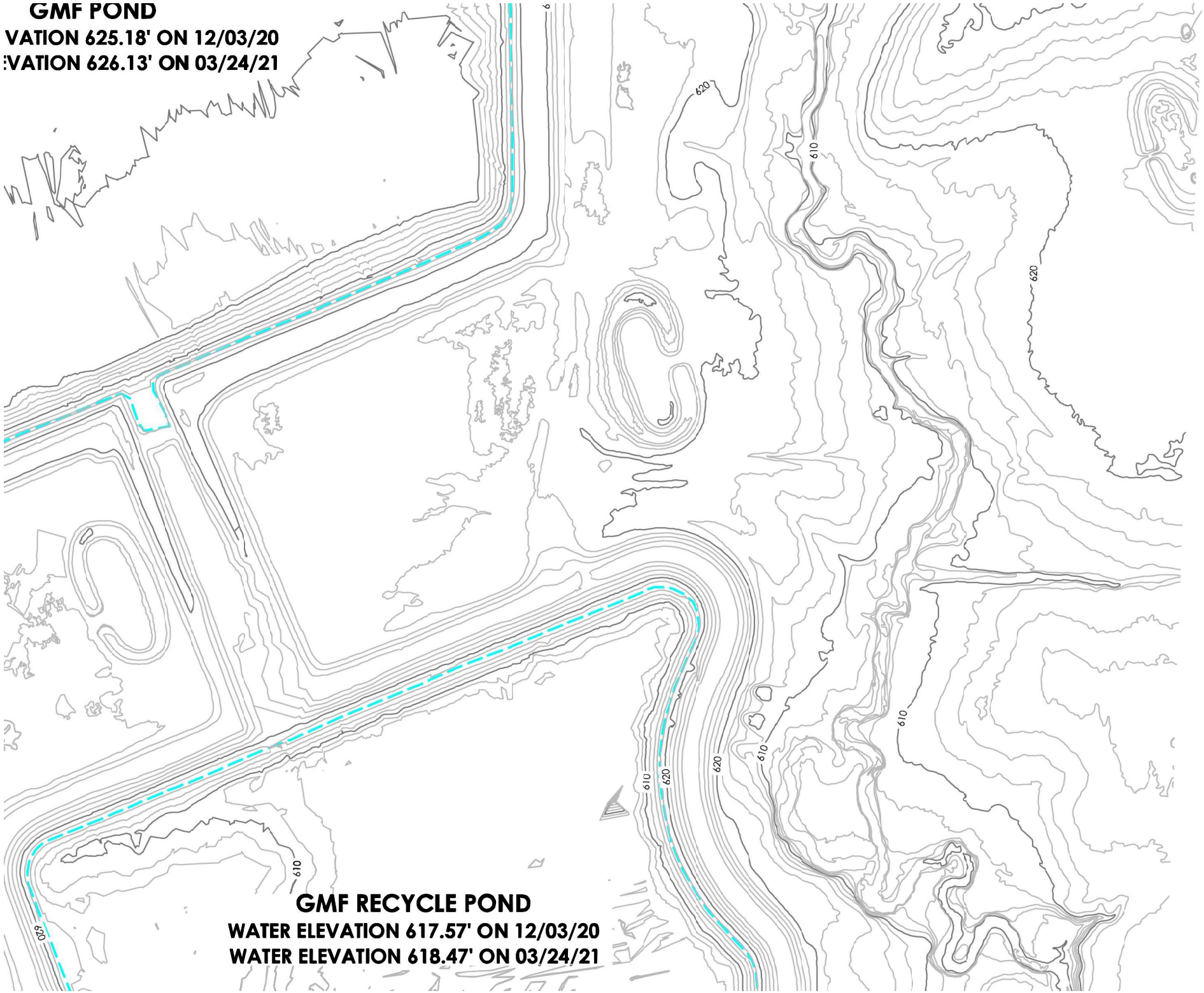
BER 2020 TOPOG

COFFEEN, ILLINOIS



ADDRESS
134 CIPS LANE
COFFEEN, ILLINOIS 62017

VISTRA
ENERGY


GMF POND
VATION 625.18' ON 12/03/20
EVATION 626.13' ON 03/24/21
R001728
620
610
620
610
620
610
610
620
610
620
GMF RECYCLE POND
WATER ELEVATION 617.57' ON 12/03/20
WATER ELEVATION 618.47' ON 03/24/21


GMF POND
VATION 625.18' ON 12/03/20
VATION 626.13' ON 03/24/21
R001729
G-287
G-286
G-285
OA
GMF RECYCLE POND
WATER ELEVATION 617.57' ON 12/03/20
WATER ELEVATION 618.47' ON 03/24/21

D 2

R001730


APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL END
APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL PIPE
640
630
620
610
600
590
580

R001731


G-1002
APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL END
SG-02
G-312
G-311
G-311D
G-302
APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL PIPE
APPROXIMATE AREA OUTFALL PIPE
SG-03

APPENDIX B
STATISTICAL ANALYSIS PLAN

Prepared for
Illinois Power Generating Company

Date
October 25, 2021

Project No.
1940100806-002

STATISTICAL ANALYSIS PLAN

ASH POND NO. 2
COFFEEN POWER PLANT
COFFEEN, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

STATISTICAL ANALYSIS PLAN
COFFEEN POWER PLANT ASH POND NO. 2

Project Name	**Coffeen Power Plant Ash Pond No. 2**
Project No.	**1940100806-005**
Recipient	**Illinois Power Generating Company**
Document type	**Statistical Analysis Plan**
Version	**FINAL**
Date	**October 25, 2021**

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Brian G. Hennings, PG
Senior Managing Hydrogeologist



Eric J. Tlachac, PE
Senior Managing Engineer



Rachel A. Banoff, EIT
Project Statistician

LICENSED PROFESSIONAL CERTIFICATIONS

This certification is based on the description of the statistical methods selected to evaluate groundwater as presented in the following Statistical Analysis Plan; Coffeen Power Plant Ash Pond No. 2. The procedures described in the plan will be used to establish background conditions and implement compliance monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. The Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in the United States Environmental Protection Agency (USEPA)'s *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance,* March 2009), and is intended to provide a logical process and framework for conducting the statistical analysis of the data obtained during groundwater monitoring. In accordance with 35 I.A.C. § 845.640(f)(1), the statistical method chosen for analysis of background groundwater quality will be either the tolerance interval or the prediction interval procedure for each constituent listed in 35 I.A.C. § 845.600(a)(1) at this CCR unit per 35 I.A.C. § 845.640(f)(1)(C). Groundwater Protection Standards (GWPS) will be established in accordance with 35 I.A.C. § 845.600(a) (greater of the background concentration or numerical limit specified in 35 I.A.C. § 845.600(a)(1)). The GWPS will be compared to the lower confidence limit for the observed concentrations for each constituent in each compliance well. Consistent with the *Unified Guidance*, the same general statistical method of confidence interval testing against a fixed GWPS is recommended in compliance and corrective action programs. Confidence intervals provide a flexible and statistically accurate method to test how a parameter estimated from a single sample compares to a fixed numerical limit. Confidence intervals explicitly account for variation and uncertainty in the sample data used to construct them.

Description of the statistical methods chosen for analysis of groundwater monitoring data and application of these methods for determining exceedances of the GWPS identified in 35 I.A.C. § 845.600(a) is provided in this Statistical Analysis Plan.

35 I.A.C. § 845.640 Statistical Analysis (PE)

I, Eric J. Tlachac, a qualified professional engineer in good standing in the State of Illinois, certify that the statistical methods summarized above and described in this document (Statistical Analysis Plan; Coffeen Power Plant Ash Pond No. 2) are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.

Eric J. Tlachac
Qualified Professional Engineer
062-063091
Illinois
Date: October 25, 2021



35 I.A.C. § 845.640 Statistical Analysis (PG)

I, Brian G. Hennings, a qualified professional geologist in good standing in the State of Illinois, certify that the statistical methods described in this document (Statistical Analysis Plan; Coffeen Power Plant Ash Pond No. 2) are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.

Brian G. Hennings
Professional Geologist
196.001482
Illinois
Date: October 25, 2021



35 I.A.C. § 845.640 Statistical Analysis

I, Rachel A. Banoff, a qualified professional, certify that the statistical methods described in this document (Statistical Analysis Plan; Coffeen Power Plant Ash Pond No. 2), are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.

Rachel A. Banoff, EIT
Project Statistician
Date: October 25, 2021

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Table A Statistical Calculations Used in Compliance Monitoring Procedures

ACRONYMS AND ABBREVIATIONS

§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
ANOVA	analysis of variance
CCR	coal combustion residuals
COC	constituents of concern
GWPS	groundwater protection standard
IEPA	Illinois Environmental Protection Agency
LCL	lower confidence limit
LTL	lower tolerance limit
MSE	mean squared error
P	probability
Part 845	Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
RCRA	Resource Conservation and Recovery Act
RL	reporting limit
ROS	regression on order statistics
SI	surface impoundment
SSI	statistically significant increase
SWFPR	site-wide false positive rate
Unified Guidance	*Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (USEPA, 2009)
UPL	upper prediction limit
USEPA	United States Environmental Protection Agency
UTL	upper tolerance limit

1. INTRODUCTION

In April 2021, the Illinois Environmental Protection Agency (IEPA) issued a final rule for the regulation and management of Coal Combustion Residuals (CCR) in surface impoundments (SIs) under the Standards for the Disposal of CCR in Surface Impoundments: Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845 (Part 845). Facilities regulated under Part 845 are required to develop and sample a groundwater monitoring well network to evaluate whether impounded CCR materials are impacting downgradient groundwater quality. The groundwater quality evaluation must include selection and certification by a qualified professional engineer of the statistical procedures to be used. The procedures described in the evaluation will be used to establish background conditions and implement compliance and corrective action monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. This Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in United States Environmental Protection Agency's (USEPA's) *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance*) (March 2009).

This Statistical Analysis Plan does not include procedures for groundwater sample collection and analysis, as these activities are conducted in accordance with the Sampling and Analysis Plan prepared for each CCR unit in accordance with 35 I.A.C. § 845.640. This Statistical Analysis Plan will be used as the primary reference for evaluating groundwater quality during operation and post-closure care.

1.1 Statistical Analysis Objectives

This Statistical Analysis Plan is intended to provide a logical process and framework for conducting the statistical analyses of data obtained during groundwater monitoring conducted in accordance with the Sampling and Analysis Plan for each CCR unit. The Statistical Analysis Plan will enable a qualified professional engineer to certify that the selected statistical methods are appropriate for evaluating the groundwater monitoring data for the applicable CCR unit(s).

1.2 Statistical Analysis Plan Approach

The main sections of this Statistical Analysis Plan should be viewed as a "generic" outline of statistical methods utilized for each CCR unit and constituent required to be monitored. The statistical analysis of the groundwater monitoring data, however, will be conducted on an individual-constituent or well basis, and may involve the use of appropriate statistical procedures depending on multiple factors such as detection frequency and normality distributions.

The CCR Rule outlines two phases of groundwater monitoring:

- Background Monitoring in accordance with 35 I.A.C. § 845.650(b)(1)
- Compliance Monitoring in accordance with 35 I.A.C. § 845.650

Each phase of the groundwater monitoring program requires specific statistical procedures to accomplish the intended purpose. During the background monitoring phase, background groundwater quality will be established utilizing upgradient and background wells and downgradient groundwater quality data will be collected to facilitate statistics in subsequent phases. Compliance Monitoring is then initiated through the evaluation of the downgradient

groundwater monitoring data for exceedances of the groundwater protection standard (GWPS) established by Part 845 (concentration specified in 35 I.A.C. § 845.600 or an IEPA-approved background concentration). The developed statistical analysis plan will be implemented for each monitoring phase and in accordance with the statistical procedures.

2. BACKGROUND MONITORING AND DATA PREPARATION

The background and compliance monitoring wells were sampled and analyzed for constituents, as listed in Part 845 (antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chloride, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, pH, radium 226 and 228 combined, selenium, sulfate, thallium, total dissolved solids, and turbidity), during the baseline phase of the groundwater monitoring program.

The background monitoring well(s) were placed upgradient of the CCR unit, or at an alternative background location, where they are not affected by potential leakage from the CCR unit. Compliance monitoring wells were placed at the waste boundary of the CCR unit, along the same groundwater flow path. As 35 I.A.C. § 845.630(a) specifies, the location of these wells ensures that background accurately represents the quality of unaffected groundwater, while compliance wells accurately represent groundwater quality at the waste boundary and monitor all potential contaminant pathways.

As required by 35 I.A.C. § 845.650(a)(1), eight sampling events were completed within 180 days of April 21, 2021. As outlined, groundwater sampling procedures included sampling of the background and compliance wells using low-flow sampling methods, collection of one field quality control sample per event, and groundwater samples were not field filtered before laboratory analysis of total recoverable metals.

Following completion of the eight sampling events, background groundwater quality was established for Part 845 constituents. Groundwater monitoring will be conducted quarterly for at least the first five years. In accordance with 35 I.A.C. § 845.650(b)(4), after the first five years, a request to reduce the monitoring frequency to semiannual may be submitted to IEPA if all of the following can be demonstrated:

- Groundwater monitoring effectiveness will not be compromised by the reduced frequency
- Sufficient data has been collected to characterize groundwater
- Monitoring to date does not show any statistically significant increasing trends
- The concentrations of monitored constituents at the compliance monitoring wells are below the applicable GWPSs established in 35 I.A.C. § 845.600

The following subsections outline the statistical tests and procedures (methods) that will be utilized to evaluate data collected for each constituent in both background and compliance wells for Background and Compliance Monitoring. When necessary and contingent upon equivalent statistical power, an alternative test not included in this Statistical Analysis Plan may be chosen due to site-specific data requirements.

2.1 Sample Independence

Independence of sample results is a major assumption for most statistical analyses. To ensure physical independence of groundwater sampling results, the minimum time between sampling events must be longer than the time required for groundwater to move through the monitoring well. The sampling schedules for both the baseline and compliance monitoring periods are specified in 35 I.A.C. § 845.650(b) and may conflict with the statistical assumption of independence of sample results.

2.2 Non-Detect Data Processing

The reporting limit (RL) will be used as the lower level for the reporting of non-detected groundwater quality data. For all summary statistics (box plots, timeseries, etc.), the RL will be substituted for concentrations reported below the RL, including non-detects. With professional judgement, analytical results between the RL and the method detection limit, *i.e.,* estimated values, typically identified with a "J" flag, may be utilized if provided by the laboratory.

For all statistical test procedures:

- If the frequency of non-detect data are less than or equal to 15 percent, half of the RL will be substituted for these data
- If the non-detect frequency is between 15 percent and 50 percent, either the Kaplan-Meier or robust regression on order statistics (ROS) will be used to estimate the mean and standard deviation adjusted for the presence of left-censored values
- If the non-detect frequency is greater than 50 percent, a non-parametric test will be used
- If only one background result is detected that value will be used as the non-parametric upper prediction limit (UPL)

2.3 Testing for Normality

Many statistical analyses assume that sample data are normally distributed (parametric). However, environmental data are frequently not normally distributed (nonparametric). 35 I.A.C. § 845.640(g) requires the knowledge of the background data distribution for comparison to compliance results. The *Unified Guidance* document recommends the Shapiro-Wilk normality test for sample sizes of 50 or less, and the Shapiro-Francia normality test for sample sizes greater than 50.

When possible, transformation of datasets to achieve normal distributions is preferred.

2.4 Testing for Outliers

Part 845 constituents will be screened for the existence of outliers using a method described by the *Unified Guidance.* Outliers are extreme data points that may represent an anomaly or erroneous data point. To test for outliers, one or more of the following outlier tests will be utilized:

- Dixon's test, for well-constituent pairs with less than 25 samples, assumes normally distributed data.
- Rosner's test, for well-constituent pairs with more than 20 samples, assumes normally distributed data.
- Grubb's test for well-constituent pairs with seven or more samples, assumes normally distributed data.
- Time series, box-whisker plots, and probability plots provide visual tools to identify potential outliers, and evaluation of seasonal, spatial, or temporal variability for both normally and non-normally distributed data.

Data quality control, groundwater geochemistry, and sampling procedures will be evaluated as potential sources of error leading to an outlier result. The outlier tests cannot be used alone to determine whether a value is a true outlier that should be excluded from future statistical

analysis. Corroborating evidence needed to exclude values includes a discrete data reporting or analytical error, or potential laboratory bias. Absent corroborating evidence, the flagged values are considered true, but extreme, values in the data set. Professional judgement will be used to exclude extreme outliers from further statistical analyses. Outliers will be retained in the database.

With professional judgement, a confirmatory sample may be collected to allow for the distinction between an outlier and a true representation of groundwater quality at the monitoring point. If re-sampling is conducted, this sample will be collected within 90 days following outlier identification. If the confirmatory sample indicates the original result as an outlier, it will be reported as such.

2.5 Trend Analysis

Statistical analyses supporting the lack of trend are a fundamental step to confirm the assumption that groundwater quality values are stationary or constant over time at a CCR unit. These analyses allow for evaluation of variation in the background and compliance data for each constituent over time. A statistically significant increasing trend in background data could indicate an existing release from the CCR unit or alternate source, requiring further investigation. In addition, statistically significant trending background data can result in increased standard deviation and, therefore, greater prediction or control limits. Consequently, the increased prediction or control limit will have less power or ability to identify a release from the CCR unit.

A linear regression, coupled with a t-test for slope significance at a 95 percent confidence level (0.05 significance level), may be used on datasets for each constituent with few non-detects and a normally distributed variance of the mean to evaluate time trends. The Theil-Sen trend line, coupled with the Mann-Kendall test for slope significance at a 95 percent confidence level (0.05 significance level), will be used for datasets with frequent non-detects or non-normal variance. Similarly, trend analyses could also be used on compliance data to evaluate a possible release from the CCR unit.

2.6 Spatial Variation

Spatial trends and/or variation between background wells could indicate an existing release from a CCR unit. If the spatial variability is not due to an existing release, intrawell comparisons in compliance wells may be used to account for spatial variability and monitor for a future release. However, the CCR unit being monitored was placed into service prior to the start of groundwater monitoring and it is unknown whether a previous release has occurred. Accordingly, intrawell comparisons in compliance wells cannot be used to determine the occurrence of a future release. Interwell comparisons between compliance wells and background wells will be used.

2.7 Temporal Variation

Time series plots can be used to identify temporal dependence. Potentially significant temporal components of variability can be identified by graphing single constituent data from multiple wells together on a time series plot. With temporal dependence, the time series plot as a pattern of parallel traces, in which the individual wells will tend to rise and fall together across the sequence of sampling dates. Time series plots can be helpful by plotting multiple constituents over time for the same well, or averaging values for each constituent across wells on each sampling event and then plotting the averages over time. In either case, the plots can signify whether the general concentration pattern over time is simultaneously observed for different

constituents. If so, it may indicate that a group of constituents is highly correlated in groundwater or that the same artifacts of sampling and/or lab analysis impacted the results of several monitoring parameters.

Hydrologic factors such as drought, recharge patterns or regular (*e.g.,* seasonal) water table fluctuations may be responsible for the temporal variation. In these cases, it may be useful to test for the presence of a significant temporal effect by first constructing a parallel time series plot and then running a formal one-way analysis of variance (ANOVA) ($\alpha = 0.05$) for temporal effects. A one-way ANOVA for temporal effects considers multiple well data sets for individual sampling events or seasons as the relevant statistical factor. If event-specific analytical differences or seasonality appear to be an important temporal factor, the one-way ANOVA for temporal effects can be used to formally identify seasonality, parallel trends, or changes in lab performance that affect other temporal effects. The one-way ANOVA for temporal effects assumes that the data groups are normally distributed with constant variance. It is also assumed that for each of a series of background wells, measurements are collected at each well on sampling events or dates common to all the wells. Results of the ANOVA can also be used to create temporally stationary residuals, where the temporal effect has been 'subtracted from' the original measurements. These stationary residuals may be used to replace the original data in subsequent statistical testing.

If the data cannot be normalized, a similar test for a temporal or seasonal effect can be performed using the Kruskal-Wallis test ($\alpha = 0.05$). Each sampling event should be treated as a separate 'well,' while each well is treated as a separate 'sampling event.' In this case, no residuals can be computed since the Kruskal-Wallis test employs ranks of the data rather than the measurements themselves.

Where both spatial and temporal variation occur, two-way ANOVA can be considered where both well location and sampling event/season are treated as statistical factors. This procedure is described in Davis (1994).

2.8 Updating Background

Updating the background dataset periodically by adding recent results to an existing background dataset can improve the statistical power and accuracy of the statistical analysis, especially for non-parametric prediction intervals. The *Unified Guidance* recommends updating statistical limits (background) when at least four to eight new measurements (every 1 to 2 years under a quarterly monitoring program), are available for comparison to historical data. Professional judgement will be used to evaluate whether any background data appear to be affected by a release and need to be excluded from a background update. A t-test for equal means (if normal data distribution) or appropriate non-parametric test (if non-normal data distribution) such as a Mann-Whitney (or Wilcoxon) rank-sum or box-whisker plots, will be conducted to evaluate whether the two groups of background sample populations are statistically different prior to updating any background datasets. A 0.05 significance level will be utilized when evaluating the two populations, with the null hypothesis that they are equivalent. In addition, time series graphs or other trend evaluation statistics will be conducted on the new background dataset to verify the absence of a release or changing groundwater quality. If the tests indicate that there are no statistical differences between the two background populations, the new data will be combined with the existing dataset. If the two populations are found to be different, the data will be reviewed to evaluate the cause of the difference. If the differences appear to be caused by a

release (if the new data are significantly higher, or lower for pH), then the previous background dataset may continue to be used. Furthermore, verified outliers will not be added to an existing background dataset. In accordance with the *Unified Guidance*, continual background updates will not be conducted due to the lack of sufficient samples for a statistical comparison.

3. COMPLIANCE MONITORING

Compliance monitoring is designed to monitor groundwater for evidence of a release by comparing Part 845 constituents in compliance wells to both background concentrations and the GWPS. Compliance Monitoring will begin the quarter following approval of this groundwater monitoring plan and issuance of the Operating Permit. The selected Compliance Monitoring statistical method used to compare compliance groundwater quality data for each constituent to the GWPS will provide for adequate statistical power, error levels and individual test false positive rates, and be appropriate for the distribution and detection frequency of the background dataset. Statistical power is the ability of a statistical test to detect a true exceedance.

In accordance with 35 I.A.C. § 845.610(b)(3)(D), compliance monitoring statistical analyses will be completed and submitted to IEPA within 60 days after completion of sampling.

3.1 GWPS Establishment and Exceedance Determination

In accordance with 35 I.A.C. § 845.600(a), the GWPS will be the constituent concentrations specified in 35 I.A.C. § 845.600(a)(1) except for when the background concentration is greater, or no concentration is specified (*i.e.,* for calcium and turbidity), in which case the GWPS will be the background concentration. The GWPS based on background concentration will be calculated using a parametric upper tolerance limit (UTL), a parametric UPL for a future mean, or a non-parametric UPL for a future median.

Statistical calculations that will be utilized in Compliance Monitoring procedures are summarized in **Table A** below and listed in **Sections 3.1.1** through **3.1.7**. Depending on the distribution of the data and the percentage of non-detects, it may be more appropriate to use a parametric model over a non-parametric model. As necessary, other techniques as mentioned in the *Unified Guidance* and/or new methods will be implemented.

Table A. Statistical Calculations Used in Compliance Monitoring Procedures

Compliance Monitoring						
Significant Trend?	Background Data			Compliance Data		
	Percent Non-Detects	Distribution	GWPS Determination	Percent Non-Detects	Distribution	Method to Determine Exceedance
No	0 ≤ 50	Normal	35 I.A.C § 845.600(a)(1) constituent concentration or The Upper Tolerance Limit	≤75	Normal	Parametric Lower Confidence Limit around a Normal Mean
				≤75	Log-Normal	Parametric Lower Confidence Limit around a Lognormal Geometric Mean
				NA	Non-Normal	Non-Parametric Lower Confidence Limit around a Median
				>75	Unknown/ Cannot be determined	
	50 ≤ 70	Normal	The Upper Prediction Limit for a Future Mean	NA	NA	Future mean
	>70	Non-Normal	Upper Prediction Limit for a Future Median	NA	NA	Future median
	100	Non-Normal	Double Quantification Rule	NA	NA	Individual Retesting Values
Yes	0 ≤ 50	Normal	UCL of Confidence Band around Linear Regression	≤75	Residuals after subtracting trend are normal, equal variance	Lower Limit from Confidence Band around Linear Regression
	50 ≤ 100	Non-Normal	UCL of Confidence Band around Thiel-Sen trend line	≤75	Residuals not normal	Lower Limit from Confidence Band around Thiel-Sen

3.1.1 The Upper Tolerance Limit

The UTL will be used to calculate the GWPS when pooled background data are normally distributed, with a non-detect frequency of 50 percent or less. When non-detect frequency is 15 percent or less, half the RL will be substituted for non-detects. The *Unified Guidance* recommends 95 percent confidence level and 95 percent coverage (95/95 tolerance interval).

- When non-detect frequency is 15 percent or less, half the RL will be substituted for non-detects (simple substitution), and the normal mean and standard deviation will be calculated.

- The Kaplan-Meier or the ROS method will be used when the detection frequency is between 15 percent and 50 percent. The Kaplan-Meier method assesses the linearity of a censored probability plot to determine whether the background sample can be approximately normalized. If so, then the Kaplan-Meier method will be used to compute estimates of the mean and standard deviation adjusted for the presence of left-censored values. The Kaplan-Meier or ROS estimate of the mean and standard deviation will be substituted for the sample mean and standard deviation.
- If background normality cannot be achieved, non-parametric UTLs will not be calculated until a minimum of 60 background samples have been collected (to achieve 95 percent coverage).

The parametric UTL on a future mean will be calculated from the background dataset as follows:

$$UTL = \overline{x} + \kappa\,(n, \gamma, \alpha - 1) \cdot s$$

$\overline{x}$ = background sample mean

s = background sample standard deviation

$\kappa\,(n, \gamma, \alpha - 1)$ = one-sided normal tolerance factor based on the chosen coverage (γ) and confidence level (α -1) and the size of the background dataset (n). Values are tabulated in Table 17-3 in Appendix D of the *Unified Guidance*. If exact values are not provided, then κ values can be estimated by linear interpolation.

If the UTL is constructed on the logarithms of original observations to achieve normality, where $\overline{y}$ and s_y are the log-mean and log-standard deviation, the limit will be exponentiated for back-transformation to the concentration scale as follows:

$$UTL \equiv \exp\left[\overline{y} + \kappa\,(n, \gamma, \alpha - 1) \cdot s_y\right]$$

$\overline{y}$ = background sample log-mean

s_y = background sample log-standard deviation

When the GWPS is based on the 35 I.A.C. § 845.600(a)(1) constituent concentrations or a UTL derived from the background dataset, an exceedance in compliance wells relative to the GWPS will be evaluated using confidence intervals. A confidence interval defines the upper and lower bound of the true mean of a constituent concentration in groundwater within a specified confidence range.

- Non-detects in compliance data will be handled similarly to upgradient analyses, with half the RL substituted for non-detects when the frequency is 15 percent or less.
- The Kaplan-Meier, or the ROS method, will be used when the detection frequency is between 15 percent and 50 percent to compute estimates of the mean and standard deviation adjusted for the presence of left-censored values. These estimates will then be substituted for the sample mean and standard deviation.

Once the GWPS is established for background data using the UTL, either parametric or non-parametric confidence intervals will be computed for each constituent in compliance wells to identify GWPS exceedances.

3.1.2 Parametric Confidence Intervals around a Mean

If compliance data are approximately normal, one-sided parametric confidence intervals around a sample mean will be constructed for each constituent and well pair. The lower confidence limit (LCL) will be calculated as:

$$LCL_{1-\alpha} = \overline{x} - t_{1-\alpha,n-1} \cdot \frac{s}{\sqrt{n}}$$

$\overline{x}$ = compliance sample mean

s = compliance sample standard deviation

n = compliance sample size

$t_{1-\alpha,n-1}$ = obtained from a Student's t-table with (n−1) degrees of freedom (Table 16-1 in Appendix D of the *Unified Guidance*)

The chosen t value will aim to achieve both a low false-positive rate, and high statistical power. Minimum α values are tabulated in Table 22-2 of Appendix D of the *Unified Guidance*. The selected minimum α value, from which the t value will be derived, will have at least 80 percent power (1-β = 0.8) when the underlying mean concentration is twice the GWPS.

If compliance data are distributed lognormally, the LCL will be computed around the lognormal geometric mean as:

$$LCL_{1-\alpha} = \exp\left(\overline{y} - t_{1-\alpha,n-1} \cdot \frac{s_y}{\sqrt{n}}\right)$$

$\overline{y}$ = compliance sample log-mean

s_y = compliance sample log-standard deviation

3.1.3 Non-Parametric Confidence Intervals around a Median

Non-parametric confidence intervals around the median will be computed if the compliance data contain greater than 50 percent non-detects or are not normally distributed. The mathematical algorithm used to construct non-parametric confidence intervals is based on the probability (*P*) that any randomly selected measurement in a sample of n concentration measurements will be less than an unknown *P* x 100th percentile of interest (where *P* is between 0 and 1). Then the probability that the measurement will exceed the *P* x 100th percentile is (1−*P*). The number of sample values falling below the *P* x 100th percentile out of a set of n should follow a binomial distribution with parameters n and success probability *P*, where 'success' is defined as the event that a sample measurement is below the *P* x 100th percentile. The probability that the interval formed by a given pair of order statistics will contain the percentile of interest will then be determined by a cumulative binomial distribution *Bin(x;n,p)*, representing the probability of *x* or fewer successes occurring in *n* trials with success probability p. *P* will be set to 0.50 for an interval around the median.

The sample size n will be ordered from least to greatest. Given *P* = 0.50, candidate interval endpoints will be chosen by ordered data values with ranks close to the product of (n+1) x 0.50. If the result of (n+1) x 0.50 is a fraction (for even-numbered sample sizes), the rank values immediately above and below will be selected as possible candidate endpoints. If the result of (n+1) x 0.50 is an integer (for odd-numbered sample sizes), one will be added to and subtracted

from the result to get the upper and lower candidate endpoints. The ranks of the endpoints will be denoted L* and U*. For a one-sided LCL, the confidence level associated with endpoint L* will be computed as:

$$1 - \alpha = Bin(L^* - 1; n, 0.50) = \sum_{x=L^*}^{n} \binom{n}{x} \left(\frac{1}{2}\right)^n$$

If the candidate endpoint(s) do not achieve the desired confidence level, new candidate endpoints (L*–1) and (U*+1) and achieved confidence levels will be calculated. If one candidate endpoint equals the data minimum or maximum, only the rank of the other endpoint will be changed. Achievable confidence levels are tabulated using these equations in Table 21-11 in Appendix D of the *Unified Guidance*.

Both parametric and non-parametric confidence limits will then be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance monitoring wells. A GWPS exceedance is determined if the LCL exceeds the GWPS.

3.1.4 The Upper Prediction Limit for a Future Mean

The parametric UPL for a future mean will be used to calculate the GWPS if the pooled background data contain 50 to 70 percent non-detects and normality can be achieved. The Kaplan-Meier or ROS methods will be used to estimate the mean and standard deviation. The non-parametric UPL for a future median will be calculated as the GWPS if background samples cannot be normalized or contain greater than 70 percent non-detects. The parametric UPL for a future mean will be calculated from the background dataset at follows:

$$UPL_{1-\alpha} = \overline{x} + \kappa s$$

$\overline{x}$ = background sample mean

s = background standard deviation

κ = multiplier based on the order (p) of the future mean to be predicted, the number of compliance wells to be tested (w), the background sample size (n) the number (c) of constituents of concern (COCs), the "1-of-m" retesting scheme, and the evaluation schedule (annual, semi-annual, quarterly). Values are tabulated in 19-5 to 19-9 in Appendix D of the *Unified Guidance*.

The mean of order p will be computed for each well and compared against the UPL. For any compliance point mean that exceeds the limit, p additional resamples may be collected at that well for a 1-of-2 retesting scheme. Resample means will then be compared to the UPL. A GWPS exceedance has been deemed to occur at a compliance well when the initial mean and all resample means exceed the UPL.

3.1.5 The Non-Parametric Upper Prediction Limit for a Future Median

The non-parametric UPL for a future median will be used to calculate the GWPS if the pooled background data contain greater than 70 percent non-detects and normality cannot be achieved. Non-parametric methods assume that the data does not have an underlying distribution. To calculate the non-parametric UPL on a future value, the target per-constituent false positive rate (α_{const}) will be determined as follows:

$$\alpha_{const} = 1 - (1 - \alpha)^{1/c}$$

α = the site-wide false positive rate (SWFPR) of 0.10 recommended by the *Unified Guidance*

c = the number of monitoring constituents

The number of yearly statistical evaluation (nE) will be multiplied by the number of compliance wells (w) to determine the look-up table entry, w*. The background sample size (n) and w* will be used to select an achievable per-constituent false positive rate value in Table 19-24 of Appendix D in the *Unified Guidance*. The chosen achievable per-constituent false positive rate value will determine the type of non-parametric prediction limit (maximum or 2nd highest value in background) and a retesting scheme for a future median. The background data will be sorted in ascending order, and the upper prediction limit will be set to the appropriate order statistic previously determined by the achievable per-constituent false positive rate value in Table 19-24. If all constituent measurements in a background sample are non-detect, the Double Quantification rule will be used. The use of the Double Quantification rule in Compliance Monitoring will only be applicable if the RL is above the 35 I.A.C. § 845.600(a)(1) constituent concentration or a constituent concentration is not specified in § 845.600(a)(1). This scenario is highly unlikely. The constituent will also be removed from calculations identifying the target false positive rate.

Two initial measurements per compliance well will be collected. If both do not exceed the upper prediction limit, a third initial measurement will not be collected since the median of order 3 will also not exceed the limit. If both exceed the prediction limit, a third initial measurement will not be collected since the median will also exceed the limit. If one initial measurement is above and one below the limit, a third initial observation may be collected to determine the position of the median relative to the UPL. Up to three resamples will be collected in order to assess the resample median. In all cases, if two or more of the compliance point observations are non-detect, the median will be set equal to the RL. The median value for each compliance well will be compared to the UPL. For the 1-of-2 retesting scheme, if any compliance point median exceeds the limit, up to three additional resamples will may be collected from that well. The resample median will be computed and compared to the UPL. A GWPS exceedance has been deemed to occur at a compliance well when either the initial median, or both the initial median and resample median exceed the UPL.

If the concentrations of detected constituents are below the established GWPS, Compliance Monitoring will continue.

3.1.6 Parametric Linear Regression and Confidence Band

If the t-test detects a significant trend in the parametric linear regression line using either background or compliance data for a particular constituent, confidence bands accounting for trends will be constructed to account for the trend-induced variation. If this is not accounted for, a wider confidence interval will inevitably be calculated for a given confidence level and sample size (n). A wider confidence interval will result in less statistical power, or ability to demonstrate an exceedance or return to compliance. When a linear trend line has been estimated, a series of confidence intervals is estimated at each point along the trend. This creates a simultaneous confidence band that follows the trend line. As the underlying population mean increases or decreases, the confidence band does also to reflect this change at that point in time.

Linear regression will be used when background or compliance data are approximately normally distributed, with a constant sample variance around the mean, and the frequency of non-detects is low. The linear regression of concentration against sampling date (time) will be computed as follows:

$$\hat{b} = \sum_{i=1}^{n} (t_i - \bar{t}) \cdot x_i / (n-1) \cdot s_t^2$$

x_i = i^{th} concentration value and

t_i = i^{th} sampling date

$\bar{t}$ = sampling mean date

s_t^2 = variance of the sampling dates

This estimate leads to the following regression equation:

$$\hat{x} = \bar{x} + \hat{b} \cdot (t - \bar{t})$$

$\bar{x}$ = mean concentration level

$\hat{x}$ = estimated mean concentration at time t

The regression residuals will also be computed at each sampling event to ensure uniformity and lack of significant skewness. Regression residuals will be computed at each sampling event as follows:

$$r_i = x_i - \hat{x}_i$$

The estimated variance around the regression line, or mean squared error (MSE) will be computed as follows:

$$s_e^2 = \frac{1}{n-2} \sum_{i=1}^{n} r_i^2$$

The confidence intervals around a linear regression trend line given confidence level (1-α) and a point in time (t_0), will be computed as follows:

$$LCL_{1-\alpha} = \hat{x}_0 - \sqrt{2s_e^2 \cdot F_{1-2\alpha,2,n-1} \cdot \left[\frac{1}{n} + \frac{(t_0 - \bar{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$$UCL_{1-\alpha} = \hat{x}_0 - \sqrt{2s_e^2 \cdot F_{1-2\alpha,2,n-2} \cdot \left[\frac{1}{n} + \frac{(t_0 - \bar{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$\hat{x}_0$ = estimated mean concentration from the regression equation at time t_0

$F_{1-2\alpha,2,n-2}$ = upper $(1-2\alpha)^{th}$ percentage point from an F-distribution with 2 and (n-2) degrees of freedom

For background data, the UCL around the linear regression line will be used as the GWPS for the trending constituent. For compliance data, confidence bands around the linear regression line will be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance wells. A GWPS exceedance is determined when the LCL based on the trend line first exceeds the GWPS.

3.1.7 Non-Parametric Thiel-Sen Trend Line and Confidence Band

If the Mann-Kendall test detects a significant trend in the non-parametric Thiel-Sen line using either background or compliance data for a particular constituent, confidence bands accounting for trends will be constructed to account for the trend-induced variation. The Thiel-Sen trend line will be used as a non-parametric alternative to linear regression when trend residuals cannot be normalized or if there are a higher percentage of non-detects in either background or compliance data. The Thiel-Sen trend line estimates the median concentration over time by combining the median pairwise slope with the median concentration value and the median sample date. To compute the Thiel-Sen line, the data will first be ordered by sampling event x1, x2, xn. All possible distinct pairs of measurements (x_i, x_j) for j > i will be considered and the simple pairwise slope estimate will be computed for each pair as follows:

$$m_{ij} = (x_j - x_i)/(j - i)$$

With a sample size of n, there will be a total of N = n(n-1)/2 pairwise estimates (m_{ij}). If a given observation is a non-detect, half the RL will be substituted. The N pairwise slope estimates (m_{ij}) will be ordered from least to greatest (renamed m(1), m(2),..m(N)). The Thiel-Sen estimate of slope (Q) will be calculated as the median value of the list depending on whether N is even or odd as follows:

$$Q = \begin{cases} m_{([N+1]/2)} \; if \; N \; is \; odd \\ (m_{(N/2)} + m_{([N+2]/2)})/2 \; if \; N \; is \; even \end{cases}$$

The sample concentration magnitude will be ordered from least to greatest, x(1), x(2), to x(n) and the median concentration will be calculated as follows:

$$\tilde{x} = \begin{cases} x_{([n+1]/2)} \; if \; n \; is \; odd \\ (x_{(n/2)} + x_{([n+2]/2)})/2 \; if \; n \; is \; even \end{cases}$$

The median sampling date ($\tilde{t}$) with ordered times (t(1), t(2), to t(n)) will also be determined in this way. The Thiel-Sen trend line will then be computed for an estimate at any time (t) of the expected median concentration (x) as follows:

$$x = \tilde{x} + Q \cdot (\mathrm{t} - \tilde{t}) = (\tilde{x} - Q \cdot \tilde{t}) + Q \cdot \mathrm{t}$$

To construct a confidence band around the Thiel-Sen line, sample pairs (ti, xi) will be formed with a sample date (ti) and the concentration measurement from that date (xi). Bootstrap samples (B) will be formed by repeatedly sampling n pairs at random with replacement from the original sample pairs. This will be repeated 500 times. For each bootstrap sample, a Thiel-Sen trend line will be constructed using the equation above. A series of equally spaced time points (tj) will be identified along the range of sampling dates represented in the original sample, j =1 to m. The Thiel-Sen trend line associated with each bootstrap replicate will be used to compute an estimated concentration ($\hat{x}_j^B$). An LCL will be constructed for the lower α^{th} percentile $\hat{x}_j^{[\alpha]}$ from the distribution of estimated concentrations at each time point (tj). For a UCL, compute the upper (1-α)th percentile, $\hat{x}_j^{[1-\alpha]}$ at each time point (tj).

For background data, the UCL around the Thiel-Sen trend line will be used as the GWPS for the trending constituent. For compliance data, confidence bands around the Thiel-Sen trend line will be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance wells. A GWPS exceedance is confirmed when the LCL based on the trend line first exceeds the GWPS.

3.2 Determination of Statistically Significant Increases over Background

In accordance with 35 I.A.C. §§ 845.610(b)(3)(B) and 845.640(h), individual monitoring event concentrations for each constituent detected in the compliance monitoring wells during compliance monitoring sampling events will be compared to the background concentration as determined by the methods described above. An exceedance of the background concentration for any constituent measured at any compliance monitoring well, or constituent detection if not detected in the background samples, constitutes a Statistically Significant Increase (SSI). An exception to this method is pH, where two-sided (upper and lower) tolerance limits are established from the distribution of the background groundwater quality data. An exceedance of either the UTL or lower tolerance limit (LTL) would constitute an SSI for pH.

4. REFERENCES

Davis, C.B., 1994. *Environmental Regulatory Statistics.* In GP Patil & CR Rao (Eds.) *Handbook of Statistics, Volume 12: Environmental Statistics*, Chapter 26. New York: Elsevier Science B.V.

United States Environmental Protection Agency (USEPA), 2009. *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance*. EPA 530-R-09-007. March 2009.

ATTACHMENT 2
GROUNDWATER MONITORING PLAN DATED JANUARY 24, 2017; AND RESPONSE TO COMMENT LETTER DATED NOVEMBER 27, 2017

DYNEGY

ILLINOIS POWER GENERATING COMPANY
Coffeen Power Station
134 CIPS Lane
Coffeen, IL 62017
Montgomery County

By UPS

November 27, 2017

William E. Buscher, P.G.
Manager, Hydrogeology and Compliance Unit
Groundwater Section, Division of Public Water Supplies, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276

Re: Coffeen Power Station
Inactive Ash Pond No. 2
Responses to IEPA's October 27, 2017 Comments on IPGC's February 1, 2017 Closure and Post-Closure Care Plans

Dear Mr. Buscher:

The enclosed document has been prepared to respond to the eight comments in your October 27, 2017 letter regarding our February 1, 2017 Closure and Post-Closure Care plans for inactive ash pond no. 2. The comments are based in part upon the telephone conference call discussion with you and your staff and Natural Resources Technology staff on November 7, 2017.

Please let us know if you would like to meet with us, or have another telephone conference call to discuss these responses. My telephone no. is 618-343-7761.

Sincerely,

Rick Diericx
Managing Director – Environmental Compliance Group

Enclosures

bcc: M. Ballance / J. Frierdich / V. Modeer – Collinsville
T. Davis – Collinsville
Stu Cravens – NRT (Bloomington, IL)
Rick Diericx Reading File - Collinsville

Natural Resource Technology
AN OBG COMPANY

OBG | There's a Way

November 21, 2017

Mr. Rick Diericx
Managing Director – Environmental Compliance Group
Dynegy Operating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234-6135

Subject: Response to IEPA Comments – Coffeen Station Inactive Ash Pond No. 2
Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2
NRT Project No. 2380

Dear Mr. Diericx:

Natural Resource Technology, Inc., an OBG Company (NRT) is providing this letter to Dynegy Operating Company (Dynegy) in response to comments received from the Illinois Environmental Protection Agency (IEPA) dated October 27, 2017 regarding the *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2* (Closure Plan; AECOM, January, 2017) at Illinois Power Generating Company Coffeen Power Station, in Coffeen, IL.

This Response to Comments will serve as Addendum 1 to the Closure Plan dated January 2017. For ease of review, IEPA comments are presented below in italics, followed by responses. Supplemental information to support the responses, when required, is included as Attachments 1-3. This document provides responses to all IEPA comments numbered 1 - 8.

Comment 1

It is mentioned multiple times in the closure and post-closure care plans that there are coal mines in the vicinity at depth. Please provide additional information on the locations and depths of the coal mines in the vicinity of Ash Pond No. 2.

Response: The Truax-Traer Coal Company and the Consolidation Coal Company extracted coal underlying Ash Pond No. 2 from 1964 to 1983 (Attachment 1 – Mine Index 871). The mine was originally known as the "Hillsboro" Mine and after Consolidation Coal Company took over the mining operation it was renamed "Consolidation No. 63, Hillsboro". Herrin No. 6 Coal was mined from depths of 500-510 feet below ground surface. The coal seam was 5.8-7.1 feet thick and an estimated 26,800,000 tons of coal were removed from the mine during the operational period (see Reference 1) with an extraction ratio of approximately 25% based on an estimate of volume removed from the recorded mine maps. A Mine Workings Map dated 1969 is overlaid on an aerial of Ash Pond No. 2 and included in Attachment 1 (Figure 1 – Overlay of Historic Mine). Comparison of the mine extents from 1969 with the extent of the mine included in Reference 1and shown on the Coal Mines in Illinois, Coffeen Quadrangle map included in Attachment 1 indicates there was no additional mining below Ash Pond No. 2 between 1969 and 1983 when the mine closed. As stated in Mine Index 871 (Attachment 1) the Coal Section of the Illinois State Geologic Survey (ISGS) has been assured that the extents included in Reference and Attachment 1 are final and complete.

Comment 2

The Agency requests the addition of a groundwater monitoring well on the east side of Inactive Ash Pond No. 2.

Response: NRT has evaluated the site conditions in the area east of Ash Pond No. 2 and has determined that there is no feasible access to install a monitoring well outside of the embankment because of steep slopes, heavy vegetation, and the presence of wetlands. In addition, several borings along the east side of Ash Pond No. 2 (B403A, P010, and G402) did not encounter the uppermost aquifer during drilling. Given significant access concerns and the limited nature of the aquifer NRT does not recommend installation of a monitoring well.

However, if required or deemed necessary in the future by the IEPA, a boring could be advanced through the berm following completion of closure construction activities to determine if the uppermost aquifer (Hagarstown) is present. Assuming the uppermost aquifer is present, a well could be installed through the berm if requested.

Comment 3

The two new groundwater monitoring wells to the west of the Inactive Ash Pond No. 2 are approved.

Response: A schedule for installation of the wells will be developed following approval of this Closure Plan. Appropriate documentation will be submitted to the IEPA upon completion of installation.

Comment 4

Will changes need to be made to the NPDES permit as part of the implementation of the closure plan?

Response: Yes, an application to modify the Coffeen NPDES permit (IL0000108) is being prepared to authorize the discharge of "dewatering" wastewaters from Ash Pond No. 2 to Coffeen Lake. The application will include an Antidegradation Assessment for Coffeen Lake in support of that modification request.

Comment 5

Calibration of the MODFLOW model was completed using only November 2016 groundwater elevations. Further calibration using more groundwater elevation data over a larger span of time should be completed.

Response: November 2016 groundwater elevations were used to calibrate the MODFLOW model because this was the first and only complete data set available for model development that included groundwater elevations from monitoring wells set in the uppermost aquifer, including wells G406 and G407 installed in August 2016. In order to address IEPA concerns about the efficacy of the groundwater elevation data range used for the model calibration, a comparison of observed versus predicted groundwater elevation values and groundwater flow directions will be provided in post-closure annual reports to assess model performance. If the predictive model does not adequately represent groundwater elevation and flow directions, the model will be recalibrated using available groundwater elevation data collected after November 2016. Similarly, post-closure groundwater quality data will be compared to transport model predictions to assess model performance in post-closure annual reports.

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Comment 6

In the Application for a GMZ, it is noted that the problem with groundwater was identified via sampling in 2015. The Agency notes that the Coffeen Power Station received a Violation Notice in 2012 for groundwater standards violations in groundwater around Inactive Ash Pond No. 2.

Response: The GMZ application was revised to include reference to Violation Notice W-2012-00064 (Attachment 2).

Comment 7

Also in the GMZ application, no other remedies to groundwater violations are considered other than to state they are not deemed practical or cost effective. Please discuss other remedies considered and why they are not practical for mitigation relative to the nature of the subsurface or cost-effective.

Response: The GMZ Application was revised to include the following text (Attachment 2):

> "Previous experience at similar sites developing and evaluating alternative remedial options and determining costs indicates capping is often the most cost-effective and cost-efficient remedy. Therefore, dewatering and capping were initially evaluated. Based on the results of the evaluation and predictive modeling, the selected remedy successfully mitigates groundwater impacts. Groundwater monitoring will continue to be performed to evaluate the effectiveness of the remedy. If the selected remedy is not demonstrated as successful through collection of data and comparison to predictive values and applicable groundwater quality standards, then other remedial options will be evaluated."

Comment 8

All monitoring wells must be sampled for the parameters listed in 35 IAC 620.410 (a) and (d), with the exception of perchlorate. Statistical analysis for each well's parameters using approved methods listed in 40 CFR 257 should be included.

Response: Tables 2 - 5 of the Groundwater Monitoring Plan, which was included as Appendix B of the Closure Plan, have been revised to include all parameters of 35 IAC 620.410 (a) and (d) with the exception of perchlorate. Revised tables are included in Attachment 3. Note these tables also include aluminum and proposed changes to groundwater standards which are included in IEPA's Proposed Changes to 35 IAC Part 620.

Please don't hesitate to contact us if you have any questions regarding these responses to comments and associated attachments provided herein.

Sincerely,
NRT | An OBG Company

Nathaniel R. Keller, PG
Hydrogeologist

Stu J. Cravens, PG
Principal Hydrogeologist

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Attachments:

Attachment 1: Comment 1 – Historic Mine Documentation
Attachment 2: Comment 2 – Revised GMZ Application
Attachment 3: Comment 8 – Revised Tables 2,3,4, and 5 from Appendix B: Groundwater Monitoring Plan

cc: Ms. Amy Zimmer – IEPA, Hydrogeology and Compliance Unit
Mr. Tom Davis, PE - Dynegy, Inc.
Mr. Jason Frierdich, PE – Dynegy, Inc.
Mr. Matt Ballance, PE – Dynegy, Inc.
Mr. Vic Modeer, PE – Dynegy, Inc.
Mr. John Romang, - Illinois Power Generating Company

References:

1 Obrad, Jennifer M., 2011. Directory of Coal Mines in 7.5-Minute Quadrangle Series, Coffeen Quadrangle Montgomery and Bond Counties. The Board of Trustees of the University of Illinois.

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Attachment 1

Comment 1-
Historic Mine Documentation

Mine Index 871
Consolidation Coal Company, Hillsboro Mine (Consolidation No. 63 Mine)

Type: Underground Total mined-out acreage shown: 4,841

SHAFT, SLOPE, DRIFT or TIPPLE LOCATIONS

Type	County	Township-Range	Section	Quarters-Footage
Man shaft	Montgomery	7N 3W	14	SW NE NW
Air shaft	Montgomery	7N 2W	18	SE NE NE
Hoist & air shaft	Montgomery	7N 3W	14	NE NW NW

GEOLOGY

Seam(s) Mined	Depth (ft)	Thickness (ft) Min	Max	Ave	Mining Method
Herrin	500-510			5.83-7.17	RPP

Geologic Problems Reported: Roof problems were widespread, the sites characterized by slickensided fault planes that cut irregularly through the roof shales and claystones. Small clay dikes were also associated with this small-scale faulting. Floor heaving was slight, but had been a larger problem in the past.

PRODUCTION HISTORY

Company	Mine Name	Years	Production (tons)
Truax-Traer Coal Company	Hillsboro	1964-1970	5,605,812
Consolidation Coal Company	Consolidation No. 63, Hillsboro	1971-1983	21,173,542
			26,779,354

Last reported production: July 1983

SOURCES OF DATA

Source Map	Date	Original Scale	Digitized Scale	Map Type
Company, Coal Section files	2-1-1983	1:12000	1:2170	Final *

* The map date is before mine closure, but the Coal Section has been assured that the workings shown on the map are indeed final. The mined area shown on the accompanying map is the approximate size expected for the reported production. This suggests that the mine outline is complete.

Annotated Bibliography (data source, brief description of information)

Coal Reports - Production, ownership, years of operation, mine type, depth, thickness.
Directory of Illinois Coal Mines (Montgomery County) - Mine names, mine index, ownership, years of operation.
Mine notes (Montgomery County) - Shaft location, seam, depth, thickness, geologic problems.
Company map, Coal Section files, 1983 Line Project - Shaft locations, mine outline, mining method.

Y:\Mapping\Projects\2380\MXD\Figure 1_New Location Map.mxd Author: sbrtsd Date/Time: 11/10/2017 2:08:22 PM



Natural Resource Technology
AN ODC COMPANY

PROJECT NO: 2380

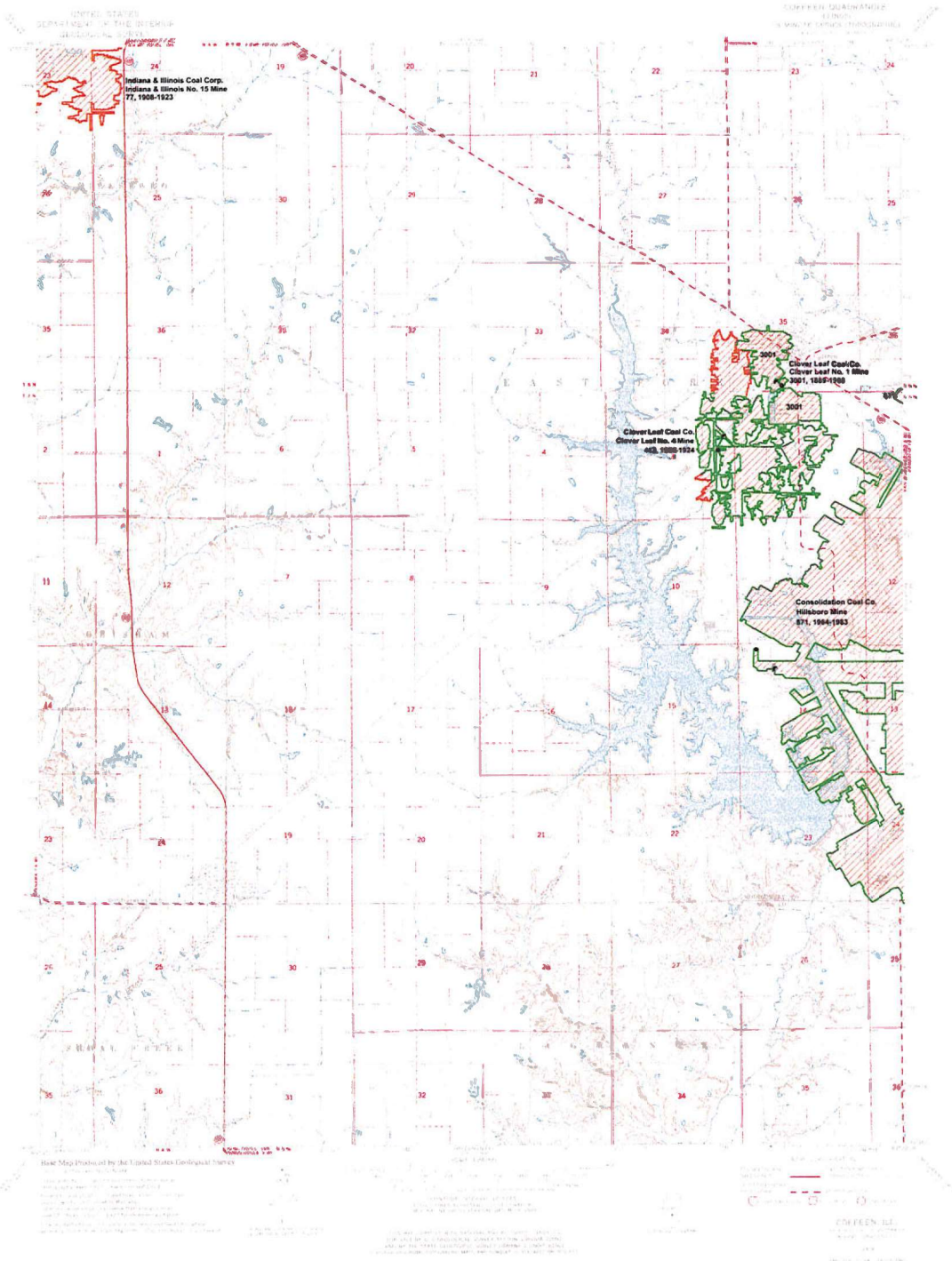
FIGURE NO: 1

OVERLAY OF HISTORIC MINE

RESPONSE TO IEPA COMMENTS - CLOSURE AND POST-CLOSURE CARE PLAN FOR THE COFFEEN ASH POND NO. 2
COFFEEN POWER STATION
COFFEEN, ILLINOIS

DRAWN BY/DATE:
SDS 11/8/17
REVIEWED BY/DATE:
NRK 11/8/17
APPROVED BY/DATE:
SJC 11/10/17

R001766



Coal Mines in Illinois
Coffeen Quadrangle
Montgomery & Bond Counties, Illinois

This map accompanies the Coal Mines Directory for the Coffeen Quadrangle. Consult the directory for a complete explanation of the information shown on this map.

Mining Method
- Room & Pillar (RP)
- Room & Pillar Basic (RPB)
- Modified Room & Pillar (MRP)
- Room & Pillar Panel (RPP)
- Blind Room & Pillar (BRP)
- Checkerboard Room & Pillar (CRP)
- High Extraction Retreat (HER)
- Longwall (LW)
- Underground, Method Unknown
- Strip Mine
- Auger Mine
- General Area of Mining

Source of Mine Outline
- Final Mine Map
- Not Final Mine Map
- Undated Mine Map
- Incomplete Mine Map
- Secondary Source Map

Tipple, Shaft, Slope, Drift Locations
- Strip Mine Tipple - Active
- Strip Mine Tipple - Abandoned
- Mine Shaft - Active
- Mine Shaft - Abandoned
- Mine Slope - Active
- Mine Slope - Abandoned
- Mine Drift - Active
- Mine Drift - Abandoned
- Air Shaft
- Uncertain Location
- Uncertain Type of Opening

Location



Mine Annotation
(space permiting)
Company
Mine Name
ISGS Index No., Years of Operation

Disclaimer
Please check the Coal Section at the Illinois State Geological Survey's web site at http://www.isgs.illinois.edu for the most up-to-date version of these products.

Note that each quadrangle scale mined-out area map requires the use of the associated text directory for full explanation of map features and mine attributes. Also note that some quadrangles have multiple seams of mining and therefore more than one map may be available for a particular quadrangle. Please take care to check for multiple maps, as extensive mining may exist in the other seams.

The maps and digital files used for these studies were compiled from data obtained from a variety of public and private sources and have varying degrees of completeness and accuracy. This compilation map presents reasonable interpretation of the geology of the area and is based on available data. Locations of some mine features maybe offset by 500 feet or more due to errors in the original source maps, the compilation process, digitizing, or a combination of these factors. These data are not intended for use in site-specific screening or decision-making. Use of these documents does not eliminate the need for detailed studies to fully understand the geology of a specific site. The Illinois State Geological Survey, Institute of Natural Resource Sustainability, or the University of Illinois make no guarantee, expressed or implied, regarding the correctness of the interpretations presented in the data set and accept no liability for the consequences of decisions made by others on the basis of the information presented here.

These maps were designed for use at 1:24,000. Enlarging the map may reduce accuracy, as the original scale of the source maps used to compile the outlines shown varies from 1:48,000 to 1:190,080, and some mine locations are inaccurately hand-digitized. See the accompanying mine directory or the original scale of the source map used for a specific mine to check accuracy at a given portion of the map. Areas with no mines shown may still be undermined; see the undocumented mines list at the back of each mine directory.

The image of the U.S.G.S. topographic base map was projected from the original UTM to Lambert Conformal Conic

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Institute of Natural Resource Sustainability
Illinois State Geological Survey
615 E. Peabody Dr.
Champaign, IL 61820

Mine Outlines Compiled by
Jennifer M. Obrad

November 21, 2011

Attachment 2

Comment 2 – Revised GMZ Application

Title 35, Illinois Admin. Code, Part 620 – APPENDIX D
Confirmation of an Adequate Corrective Action Pursuant to 35 Ill. Adm. Code 620.250(a)(2)

Pursuant to 35 Ill. Adm. Code 620.250(a) if an owner or operator provides a written confirmation to the Agency that an adequate corrective action, equivalent to a corrective action process approved by the Agency, is being undertaken in a timely and appropriate manner, then a groundwater management zone may be established as a three-dimensional region containing groundwater being managed to mitigate impairment caused by the release of contaminants from a site. This document provides the form in which the written confirmation is to be submitted to the Agency.

Note 1. Parts I and II are to be submitted to IEPA at the time that the facility claims the alternative groundwater standards. Part III is to be submitted at the completion of the site investigation. At the completion of the corrective process, a final report is to be filed which includes the confirmation statement included in Part IV.

Note 2. The issuance of a permit by IEPA's Division of Air Pollution Control or Water Pollution Control for a treatment system does not imply that the Agency has approved the corrective action process.

Note 3. If the facility is conducting a cleanup of a unit which is subject to the requirements of the Resource Conservation and Recovery Act (RCRA) or the 35 Ill. Adm. Code 731 regulations for Underground Storage Tanks, this confirmation process is not applicable and cannot be used.

Note 4. If the answers to any of these questions require explanation or clarification, provide such in an attachment to this document.

Information provided in the following technical documents is referenced within this form:

- AECOM, 2016c. Revised 30% Closure Design Package for Coffeen Power Station Ash Pond No. 2. April 16, 2016.
- Natural Resource Technology, Inc., 2016a. Hydrogeologic Characterization Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016b. Groundwater Monitoring Plan. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016c. Groundwater Model Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.
- Natural Resource Technology, Inc., 2016d. Hydrostatic Modeling Report. Coffeen Ash Pond No. 2, Illinois Power Generating Company Coffeen Power Station, Coffeen, IL.

A legal description and map of the proposed GMZ is provided in Appendix A of this GMZ Application. The GMZ will extend vertically through all water-bearing strata through the Hagarstown Member and upper weathered portions of the Vandalia Till Member at an estimated elevation ranging from approximately 604 to 608 ft MSL.

Part I. Facility Information

Facility Name Coffeen Power Station

Facility Address 134 CIPS Lane, Coffeen, IL 62017

County Montgomery

Standard Industrial Code (SIC) 4911

1. Provide a general description of the type of industry, products manufactured, raw materials used, location and size of the facility. ***Electric power generation and coal combustion residual (CCR) disposal. Ash Pond 2 is located within the Coffeen Power Station which encompasses approximately 4,000 acres including a 1,100-acre lake.***

2. What specific units (operating or closed) are present at the facility which are or were used to manage waste, hazardous waste, hazardous substances or petroleum?

	YES	NO
Landfill	X	
Surface Impoundment	X	
Land Treatment		X
Spray Irrigation		X
Waste Pile		X
Incinerator		X
Storage Tank (above ground)	X	
Storage Tank (underground)	X	
Container Storage Area	X	
Injection Well	X	
Water Treatment Units	X	
Septic Tanks	X	
French Drains	X	
Transfer Station		X
Other Units (please describe)		

3. Provide an extract from a USGS topographic or county map showing the location of the site and a more detailed scaled map of the facility with each waste management unit identified in Question 2 or known/suspected source clearly identified. Map scale must be specified and the location of the facility must be provided with respect to Township, Range and Section. ***Facility is located in Sections 10 and 11, Tier 7 N, Range 3 W, of the 3rd PM. Figure 1 has the facility located on a USGS topographic map (7½ minute).***

4. Has the facility ever conducted operations which involved the generation, manufacture, processing, transportation, treatment, storage or handling of "hazardous substances" as defined by the Illinois Environmental Protection Act? Yes ☒ No ☐
If the answer to this question is "yes" generally describe these operations. ***Storage and handling of anhydrous ammonia, sulfuric acid, 50% sodium hydroxide, and chlorine gas.***

5. Has the facility generated, stored or treated hazardous waste as defined by the Resource Conservation and Recovery Act? Yes ☒ No ☐
If the answer to this question is "yes" generally describe these operations. ***Small quantity TSD.***

6. Has the facility conducted operations which involved the processing, storage or handling of petroleum? Yes ☒ No ☐ If the answer to this question is "yes" generally describe these operations. ***Store, load, and unload diesel fuel and kerosene.***

7. Has the facility ever held any of the following permits?

   a. Permits for any waste storage, waste treatment or waste disposal operation. Yes ☒ No ☐
   If the answer to this question is "yes", identify the IEPA permit numbers. ***IL0000108 and 1998-289- UIC.***

   b. Interim Status under the Resources Conservation and Recovery Act (filing of a RCRA Part A application). Yes ☐ No ☒
   If the answer to this question is "yes", attach a copy of the last approved Part A application.

   c. RCRA Part B Permits. Yes ☐ No ☒
   If the answer to this question is "yes", identify the permit log number.

8. Has the facility ever conducted the closure of a RCRA hazardous waste management unit? Yes ☐ No ☒

9. Have any of the following State or federal government actions taken place for a release at the facility?

   a. Written notification regarding known, suspected or alleged contamination on or emanating from the property (e.g., a Notice pursuant to Section 4(q) of the Environment Protection Act)? Yes ☒ No ☐
   If the to this question is "yes", identify the caption and date of issuance. ***Violation Notice No. W-2012-00064 was issued on June 27, 2012 for boron, manganese, sulfate, and total dissolved solids concentrations which exceeded Class I GW Standards at APW-2/G402.***

   b. Consent Decree or Order under RCRA, CERCLA, EPAct Section 22.2 (State Superfund), or EPAct Section 21(f) (State RCRA). Yes ☐ No ☒

   c. If either of Items a. or b. were answered by checking "yes", is the notice, order or decree still in effect? Yes ☒ No ☐ ***Concentrations remain above Class I GW Standards which is why this GMZ is being requested.***

10. What groundwater classification will the facility be subject to at the completion of the remediation?

    Class I ☒ Class II ☐ Class III ☐ Class IV ☐

    If more than one Class applies, please explain.

11. Describe the circumstances which the release to groundwater was identified. ***Groundwater sampling at Ash Pond 2 was initiated in 2015. Exceedances of Class I groundwater quality standards in monitoring wells associated with Ash Pond 2 include the parameters arsenic, boron, lead, manganese, sulfate, and total dissolved solids.***

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true and accurate.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

PART II: Release Information

1. Identify the chemical constituents release to the groundwater. Attach additional documents as necessary.

Chemical Description	Chemical Abstract No.
Arsenic	*7440-38-2*
Boron	*7440-42-8*
Lead	*7439-92-1*
Manganese	*7439-96-5*
Sulfate	*14808-79-8*
Total Dissolved Solids	*10052*

2. Describe how the site will be investigated to determine the source or sources of the release. ***Ash Pond 2 has been investigated as described in the Hydrogeologic Characterization Report (Natural Resource Technology, Inc. [NRT], 2016a).***

3. Describe how groundwater will be monitored to determine the rate and extent of the release. ***The monitoring network to monitor the rate and extent of the release is described in the Groundwater Monitoring Plan (NRT, 2016b).***

4. Has the release been contained on-site at the facility? ***The release is contained within the facility boundary. Migration of CCR constituents is limited by Coffeen Lake, which acts as a groundwater discharge area and hydraulic barrier.***

5. Describe the groundwater monitoring network and groundwater and soil sampling protocols in place at the facility. ***The groundwater monitoring network and sampling protocols are described in the Groundwater Monitoring Plan (NRT, 2016b).***

6. Provide the schedule for investigation and monitoring. ***The site investigation is complete and groundwater monitoring will continue for the required/permitted frequency and monitoring period as described in the Groundwater Monitoring Plan Section 4.2: Sampling Schedule (NRT, 2016b).***

7. Describe the laboratory quality assurance program utilized for the investigation. ***Laboratory quality assurance is described in the Groundwater Monitoring Plan Sections 4.4: Laboratory Analysis and 4.5: Quality Assurance (NRT, 2016b). The quality assurance/quality control procedures described in the Groundwater Monitoring Plan will be supplemented by the selected Illinois EPA-approved laboratory's QA Manual.***

8. Provide a summary of the results of available soil testing and groundwater monitoring associated with the release at the facility. The summary or results should provide the following information: dates of sampling; types of samples taken (soil or water); locations and depths of samples; sampling and analytical methods; analytical laboratories used; chemical constituents for which analyses were performed; analytical detection limits; and concentrations of chemical constituents in ppm (levels below detection should be identified as "ND"). ***A narrative summary of the results of groundwater monitoring is discussed in the Hydrogeologic Characterization Report Section 3: Groundwater Quality (NRT, 2016a). Analytical data summary tables and graphs are available in the Hydrogeologic Characterization Report Appendix F: Groundwater Quality Data and Appendix G: Water Quality Trend Graphs (NRT, 2016a). Lab reports for all monitoring events have previously been submitted to the Agency.***

PART II: Release Information (Continued)

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of knowledge and belief, true and accurate and confirm that the actions identified herein will be undertaken in accordance with the schedule set forth herein.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

Part III: Remedy Selection Information

1. Describe the selected remedy. ***The remedy includes ash dewatering, relocating/reshaping the CCR within Ash Pond 2 to achieve acceptable grades, construction of a geomembrane cover system and establishing a vegetative cover to minimize long-term erosion (AECOM, 2016).***

2. Describe other remedies which were considered and why they were rejected. ***Previous experience at similar sites developing and evaluating remedial alternatives and costs indicate capping is often the most cost effective and cost-efficient. Therefore, dewatering and capping were initially evaluated. Based on the results of the evaluation and modeling, the selected remedy successfully mitigates groundwater impacts. If the selected remedy is not shown successful through collection of data and comparison to predictive values, then other remedial options will be evaluated.***

3. Will waste, contaminated soil or contaminated groundwater be removed from the site in the course of this remediation? Yes ☐ No ☒
   If the answer to this question is "yes", where will the contaminated material be taken?

4. Describe how the selected remedy will accomplish the maximum practical restoration of beneficial use of groundwater. ***The dewatering and installation of a geomembrane cover system will control the potential for water infiltration into the closed CCR unit and will allow drainage of surface water off of the cover system. These actions will reduce leachate generation and migration and groundwater quality will improve over time, as described in the Groundwater Model Report (NRT, 2016c).***

5. Describe how the selected remedy will minimize any threat to public health or the environment. ***The currently defined extent of the release does not threaten public health. As discussed in the Hydrogeologic Characterization Report Section 2.5 (NRT, 2016a), there are currently no impairments to groundwater usage on the Coffeen Power Station property or surrounding properties associated with Ash Pond 2. No impairments to groundwater usage resulting from establishment of the proposed GMZ are anticipated. CCR dewatering and the geomembrane cover system will reduce leachate generation and migration from Ash Pond 2 and minimize CCR constituents entering the environment, as described in the Groundwater Model Report (NRT, 2016c).***

6. Describe how the selected remedy will result in compliance with the applicable groundwater standards. ***The in place closure of Ash Pond 2, as proposed, will result in a reduction of leachate production, decreasing CCR constituent concentrations and contraction of the groundwater plume. A Groundwater Model Report (NRT, 2016c), included in Appendix D of AECOM 2016, suggests that the geosynthetic cover system will control recharge and subsequent leachate generation within the limits of the Site and reduce concentrations of boron below Class I standards. Concentration reductions are expected to begin approximately one year after completion of the cover system.***

7. Provide a schedule for design, construction and operation of the remedy, including dates for the start and completion. ***A schedule for implementing the remedies is included in Section 1.3 in AECOM, 2016.***

8. Describe how the remedy will be operated and maintained. ***The operation and maintenance of the remedy is described in Section 3: Post-Closure Care Plan (AECOM, 2016).***

9. Have any of the following permits been issued for the remediation?

   a. Construction or Operating permit from the Division of Water Pollution Control. Yes ☐ No ☒

   b. Land treatment permit from the Division of Water Pollution Control. Yes ☐ No ☒
      If the answer to this question is "yes", identify the permit number.

   c. Construction or Operating permit from the Division of Air Pollution Control. Yes ☐ No ☒

If the answer to this question is "yes", identify the permit number.

10. How will groundwater at the facility be monitored following completion of the remedy to ensure that the groundwater standards have been attained? ***Groundwater monitoring procedures are described in Section 4 of the Groundwater Monitoring Plan (NRT, 2016b).***

Based on my inquiry of those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true and accurate and confirm that the actions identified herein will be undertaken in accordance with the schedule set forth herein.

Coffeen Power Station	
Facility Name	Signature of Owner/Operator
134 CIPS Lane, Coffeen, IL 62017	**Illinois Power Generating Company**
Location of Facility	Name of Owner/Operator
1358030005	
Illinois EPA Identification Number	Date

Attachment 3

Comment 8 – Revised Tables 2,3,4, and 5 from Appendix B: Groundwater Monitoring Plan

R001777

Table 2. Proposed Monitoring Well Network and Analyses
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Boring/ Well ID	Ground Surface at Time of Install	Measuring Point Elevation (2015)	Top of Screen Elevation	Bottom of Screen Elevation	Screen length	Screen Top	Screen Bottom	Proposed Analyses for IEPA Monitoring	Additional Monitoring Programs Performed at Well	Other Analyses (USEPA CCR Rule or IEPA)
G270	622.92	625.92	609.79	605	5	16.1	20.9	IEPA 620.410 (a), and (d), no perchlorate[3]	Ash Pond 2 & GRP - CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G281	623.82	626.36	608.31	603.66	5	18.1	22.7		Ash Pond 2 CCR	
G401	623.03	625.57	608.67	604.24	4	16.9	21.3			
G402	610.56	613.37	600.60	590.6	10	12.8	22.8			
G403	623.81	626.47	610.70	606.03	5	15.8	20.4			
G404	613.10	615.67	606.68	601.93	5	9.0	13.7			
G405	620.90	623.63	611.89	607.14	5	11.7	16.5			
G406	621.86	621.86	608.30	603.49	5	13.6	18.4		None	None
G407	618.35	621.32	604.57	599.74	5	16.8	21.6			
G410[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G411[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G154	623.52	626.35	609.26	604.76	5	17.1	21.6		SW Pond - IEPA	IEPA Approved Parameters
G279	629.19	632.04	606.79	602.40	4	25.3	29.6		GRP - IEPA and CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G280	622.95	625.85	610.16	605.32	5	15.7	20.5			

Notes:

[1] Proposed wells to be installed upon approval of Closure Plan and GMZ application

[2] Field parameters include: pH, oxidation -reduction potential, specific conductance, temperature, and dissolved oxygen

[3] Groundwater samples collected for metals analyses will be field filtered.

Groundwater quality analyses including methods and sampling details are included in Table 4.

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Table 3. Background Groundwater Quality and Applicable Groundwater Quality Standards
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Parameters (totals)[6]	Sampling Program	IL Class I Std[1] (mg/L)	Background Concentration[2] for IEPA (mg/L)	Applicable Groundwater Standard[3] for IEPA (mg/L)	Maximum[5] (mg/L)	Minimum[5] (mg/L)
Aluminum (d)[4]	IEPA	3.5	tbd	tbd	0.1	<0.005
Antimony	CCR, IEPA	0.006	tbd	tbd	<0.003	<0.003
Arsenic	CCR, IEPA	0.01	tbd	tbd	0.25	<0.001
Barium	CCR, IEPA	2.0	tbd	tbd	0.24	0.014
Beryllium	CCR, IEPA	0.004	tbd	tbd	0.0018	<0.001
Boron	CCR, IEPA	2.0	tbd	tbd	17	<0.01
Calcium	CCR	NS	tbd	tbd	450	<0.1
Cadmium	CCR, IEPA	0.005	tbd	tbd	0.008	<0.001
Chloride	CCR, IEPA	200	tbd	tbd	160	1.5
Chromium	CCR, IEPA	0.1	tbd	tbd	0.034	<0.004
Cobalt	CCR, IEPA	1, 0.002[4]	tbd	tbd	0.28	<0.001
Copper (d)	IEPA	0.65, 0.2[4]	tbd	tbd	0.021	<0.001
Cyanide	IEPA	0.2	tbd	tbd	<0.005	<0.003
Fluoride	CCR, IEPA	4	tbd	tbd	1.06	0.031
Iron (d)	IEPA	5	tbd	tbd	13	<0.005
Lead	CCR, IEPA	0.0075	tbd	tbd	0.220	<0.001
Lithium	CCR	NS	tbd	tbd	0.057	<0.01
Manganese(d)	IEPA	0.15	tbd	tbd	1.02	<0.018
Mercury	CCR, IEPA	0.002	tbd	tbd	0.00093	<0.0002
Molybdenum	CCR, IEPA	NS	tbd	tbd	0.043	<0.001
Nickel (d)	IEPA	0.1	tbd	tbd	0.035	<0.003
Nitrate-N	IEPA	10	tbd	tbd	8.8	<0.01
Selenium	CCR, IEPA	0.05	tbd	tbd	0.027	<0.001
Silver (d)	IEPA	0.05	tbd	tbd	<0.005	<0.003
Sulfate	CCR, IEPA	400	tbd	tbd	2,500	2.3
Thallium	CCR, IEPA	0.002	tbd	tbd	0.0013	<0.001
TDS (d)	CCR, IEPA	1,200	tbd	tbd	3,900	320
Vanadium (d)	IEPA	0.049, 0.00049[4]	tbd	tbd	0.025	<0.003
Zinc (d)	IEPA	5	tbd	tbd	0.59	<0.002
Field pH	CCR, IEPA	6.5 - 9.0	tbd	tbd	8.03	5.80
Radium 226/228	CCR, IEPA	20/20, 5[4]	tbd	tbd	4.46	0.185

Notes:
All parameters are totals unless noted. Standards apply to dissolved or total concentrations
(d) Dissolved
tbd = To Be Determined for Illinois EPA monitoring program; CCR Appendix III and IV parameters based on future monitoring , started in November 2015
Bold = Background Concentration exceeds Class I Groundwater Standard
Red = Exceeds Applicable Groundwater Standard
NS = No Class II Groundwater Standard
USEPA (t) = background concentration for parameter [total] required under USEPA program (40 CFR Part 257)
[1] IPCB 620 Class I: Potable Resource Groundwater Standard
[2] Background Concentration to be calculated following 8 sampling events at all wells in accordance with 40 CFR 257
[3] Applicable Groundwater Standard is the higher of the Background Concentration and the Class I Groundwater Standard (or the lower if compared to the pH lower limit)
[4] Standards listed are proposed changes to 35 Ill. Adm. Code Part 620 by Illinois EPA
[5] Groundwater concentrations based on historical results for wells in the proposed sampling program
[6] Groundwater samples collected for metals analysis as required by IL620.410 will be field filtered

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Table 4. Sampling and Analysis Summary
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Parameter	Analytical Method[5]	Number of Samples	Field Duplicates[1]	Field Blanks[2]	Equipment Blanks[2]	MS/MSD[3]	Total	Container Type	Minimum Volume[4]	Preservation (Cool to 4 °C for all samples)	Sample Hold Time from Collection Date
Metals - Appendix III [(1)]											
Boron (total and dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO_3 to pH<2	6 months
Calcium	6020	7	1	0	0	1	9	plastic	600 mL	HNO_3 to pH<3	6 months
Metals - Appendix IV [(2)] and Additional Metals											
Other Metals [(3)] (total and dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Manganese (d)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Lithium	6020	7	1	0	0	1	9	plastic	600 mL	HNO3 to pH<2	6 months
Mercury	7470A or 6020	14	2	0	0	1	17	plastic	400 mL	HNO_3 to pH<2	28 days
Inorganic Parameters - Appendix III [(1)] and Other Inorganic Parameters											
Cyanide	SM 4500-CN or C – EPA 335.4	14	2	0	0	1	17	amber	50 mL	NaOH, Cool to 4 °C	14 days
Fluoride	9214	14	2	0	0	1	17	plastic	300 mL	Cool to 4 °C	28 days
Chloride	9251	14	2	0	0	1	17	plastic	100 mL	Cool to 4 °C	28 days
Nitrate-N	EPA 300.0	14	2	0	0	1	17	plastic	10 mL	Cool to 4 °C	48 hours
Sulfate	9036	14	2	0	0	1	17	plastic	50 mL	Cool to 4 °C	28 days
Total Dissolved Solids	SM 2540 C	14	2	0	0	1	17	plastic	200 mL	Cool to 4 °C	7 days
Radium - Appendix IV [(2)]											
Radium 226	9315 or EPA 903	14	0	0	0	1	15	plastic	1000 mL	HNO3 to pH<2	6 months
Radium 228	9320 or EPA 904	14	0	0	0	1	15	plastic	1000 mL	HNO_3 to pH<2	6 months
Field Parameters											
pH [(1)]	SM 4500-H+ B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Dissolved Oxygen	SM 4500-O/405.1	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Temperature	SM 2550	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Oxidation/Reduction Potential	SM 258O B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Specific Conductivity	SM 2510 B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Turbidity [(4)]	SM 2130 B	14	NA	NA	NA	NA	14	flow-through cell or hand-held turbidity meter	NA	none	immediately

Notes:

[(1)] USEPA Appendix III Parameters (boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids (TDS))

[(2)] USEPA Appendix IV Parameters
(antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, radium 226 and 228 combined)

[(3)] Other Metals = aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, molybdenum, nickel, silver, selenium, thallium, vanadium, zinc

[(4)] If turbidity exceeds 10 NTUs, a duplicate sample filtered through a .45 micron filter may be collected for metals analysis in addition to the unfiltered sample. Both samples would be submitted for analysis.

NA = not applicable

HNO_3 = nitric acid

°C = degrees Celsius

mL = milliliter

1. Field duplicates will be collected at a frequency of one per group of 10 or fewer investigative water sample. Field duplicates will not be collected for radium analysis.
2. Field blanks will be collected at the discretion of the project manager; Equipment blanks will be collected at a rate of 1 per sampling event if non-dedicated equipment is used.
3. Matrix Spike/Matrix Spike Duplicate (MS/MSD) samples will be collected at a frequency of one per group of 20 or fewer investigative water samples per CCR unit/multi-unit. Additional volume to be determined by laboratory.
4. Sample volume is estimated and will be determined by the laboratory.
5. Analytical method numbers are from SW-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as apropriate.

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Table 5. Summary of Detection Limits for Proposed Monitoring Program Class I Groundwater Standards
Groundwater Monitoring Plan
Coffeen Power Station - Ash Pond 2

Constituent	Unit	Analytical Methods [1]	USEPA MCL [2] (ug/L)	IL Class I Std [7] (ug/L)	RL [4] (ug/L)	MDL [4] (ug/L)
Metals[8]						
Aluminum (d)	µg/L	6020	200 [3]	3500	10	0.85
Antimony	µg/L	6020	6	6	1	0.25
Arsenic	µg/L	6020	10	10	1	0.25
Barium	µg/L	6020	2000	2000	1	0.4
Beryllium	µg/L	6020	4	4	1	0.5
Boron	µg/L	6020	NS	2000	25	10
Boron(d)	µg/L	6020	NS	2000	2.3	10
Cadmium	µg/L	6020	5	5	1	0.25
Calcium	µg/L	6020	NS	NS	125	100
Chromium	µg/L	6020	100	100	1	0.3
Cobalt	µg/L	6020	NS	1000, 2	1	0.25
Copper (d)	µg/L	6020	NS	650, 200	3	0.025
Cyanide	µg/L	4500	200	200	5	0.85
Iron (d)	µg/L	6010	300 [3]	5,000	10	0.88
Lead	µg/L	6020	NS	7.5	1	0.25
Lithium	µg/L	6020	NS	NS	1	0.5
Manganese (d)	µg/L	6020	50 [3]	150	1	0.055
Mercury	µg/L	6020 or 7470A	2	2	0.2	0.051
Molybdenum	µg/L	6020	NS	NS	1	0.25
Nickel (d)	µg/L	6020	NS	100	5	0.075
Nitrate- N	µg/L	300	10000	10000	30	8
Selenium	µg/L	6020	50	50	1	0.9
Silver (d)	µg/L	6020	100 [3]	50	55	0.028
Thallium	µg/L	6020	2	2	1	0.25
Vanadium (d)	µg/L	6020	NS	49, 0.49	5	0.27
Zinc (d)	µg/L	6020	5000 [3]	5	6	0.495
Inorganics						
Fluoride	mg/L	9214	4	4	0.1	0.05
Chloride	mg/L	9251	250 [3]	200	5	1
Sulfate	mg/L	9036	250 [3]	400	10	5
Total Dissolved Solids	mg/L	SM 2540 C	500 [3]	1200	20	10
Other						
Combined Radium 226/228	pCi/L	9315/9320 or EPA 903/904	5	20/20, 5	-- [5]	-- [6]
Field						
pH	SU	SM 4500-H+ B	NS	6.5-9.0	NA	NA
Oxidation/Reduction Potential	mV	SM 2580 B	NS	NS	NA	NA
Dissolved Oxygen	mg/L	SM 4500-O/405.1	NS	NS	NA	NA
Temperature	°C	SM 2550	NS	NS	NA	NA
Specific Conductivity	µS/cm	SM 2510 B	NS	NS	NA	NA
Turbidity	NTU	SM 2130 B	NS	NS	NA	NA

Notes:

NS = No standard
ug/L = micrograms per liter
mg/L = milligrams per liter
pCi/L = picoCuries per liter
µS/cm = microSiemens per centimeter
NTU = nephelometric turbidity unit
(d) = dissolved analysis

RL = Reporting limit as established by the laboratory
MDL = Method detection limit as established by the laboratory
SM = Standard Methods for the Examination of Water and Wastewater

1. Analytical method numbers are from SW-846 unless otherwise indicated.
2. USEPA MCL = United States Environmental Protection Agency Maximum Contaminant Level.
3. USEPA SMCL = United States Environmental Protection Agency Secondary Maximum Contaminant Level.
4. Reporting limits and method detection limits will vary depending on the laboratory performing the work.
5. All radium results will be reported (values may be positive or negative) and will include uncertainty and the calculated MDC.
6. Laboratories calculate a minimum detectable concentration (MDC) based on the sample.
7. 35 IAC 620.410 standards are listed including proposed changes submitted to the IL Pollution Control Board

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GROUNDWATER MONITORING PLAN

Ash Pond 2
Coffeen Power Station
Coffeen, Illinois

January 24, 2017

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GROUNDWATER MONITORING PLAN

ASH POND 2
COFFEEN POWER STATION
COFFEEN, ILLINOIS

Project No. 2380

Prepared For:

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Coffeen Power Station
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1 INTRODUCTION

1.1 Overview

This Groundwater Monitoring Plan was prepared by Natural Resource Technology, Inc. (NRT) in support of a Closure Plan for Ash Pond 2 located at the Coffeen Power Station (CPS) which is owned by Illinois Power Generating Company (IPGC).. This plan and the Closure Plan will apply specifically Ash Pond 2, one of the five Coal Combustion Residuals (CCR) units associated with the CPS.

This plan describes the groundwater monitoring and reporting to be completed in support of the Closure Plan for the Ash Pond 2. In addition to this groundwater monitoring plan, a Groundwater Management Zone Application is being submitted under separate cover.

1.2 Site Location and Background

Ash Pond 2 is located approximately 2 miles south of the City of Coffeen in Montgomery County, Illinois (Figure 1). The power plant and the CCR Units are situated on a peninsula between two lobes of Coffeen Lake which was created in 1963 by damming a portion of the East Fork of Shoal Creek (IDNR, 2014). The lake covers approximately 1,100 acres and provides cooling water for the CPS.

Ash Pond 2 is located within Section 11 Township 7 North and Range 7 East. The city of Coffeen is approximately 2 miles north of the CPS and the city of Hillsboro, IL is about 8 miles to the northwest. The CPS is located in an agricultural area. Historically, however, several coal mines were operated at depth in the vicinity of the site as well as a US Minerals processing facility located to the north. The CPS property is bordered by Coffeen Lake on the west, east, and south, and by agricultural land to the north.

Ash Pond 2 was first investigated in 2010, as requested by the Illinois Environmental Protection Agency (IEPA). Results of the investigation (NRT, 2013) indicated impacts to groundwater in the vicinity of Ash Pond 1 and 2, including exceedances of Class I Groundwater Standards for boron, sulfate, manganese, sulfate and total dissolved solids. Additional wells were installed in 2015 to comply with the Federal CCR Rule (40 CFR Part 257), and define the extent of exceedances associated with Ash Pond 2. Based on the groundwater results of wells installed in 2015, Hanson submitted a Corrective Action Plan (CAP, Hanson, 2016) to define the proposed remedy. Ash Pond 2 will be closed by leaving CCR in place using an alternative geomembrane cover system, following partial dewatering of the pond. This design will control the potential for slope failure and water infiltration into the closed CCR unit and will allow for drainage of surface water off of the cover system (AECOM, 2016).

IEPA responded to Dynegy regarding the CAP with a draft letter including comments. Dynegy and IEPA met on July 20, 2016 to discuss the CAP and proposed remedy. Following the discussion, IEPA in a letter dated August 9, 2016 provided the following comments (summarized):

1. Investigation may be required to define the source and extent of exceedances from Ash Pond 2.
2. A vertical component is required for the GMZ.
3. The GMZ contains portions of CCR units not proposed to close; GMZ must be revised to include only areas where CAP for Ash Pond 2 will mitigate impacts.
4. Hydraulic conductivity of foundation layer needs to be evaluated, to determine if CAP is appropriate.
5. A groundwater monitoring plan, specific to Ash Pond 2 must be submitted with CAP.
6. Modeling is required to demonstrate corrective action will be successful, and at what point in the future.
7. Evaluate the impacts of the corrective action on Coffeen Lake, with respect to applicable surface water standards.

This GW monitoring plan is provided as requested in Comment #5. The Closure Plan, to which this Groundwater Monitoring Plan, as well as the Hydrogeologic Characterization Report, Groundwater Model Report, and Hydrostatic Model Report are attached, provides the additional information necessary to address these comments and justify the selected corrective action.

1.3 Conceptual Site Model

The geology and hydrogeology described above is summarized and grouped into the following hydrostratigraphic units for the remaining discussion in this report:

- Ash Unit – Saturated CCR within the various CCR Units
- Upper Confining Unit – Low permeability clays and silts, including the Loess Unit and the upper clayey till portion of the Hagarstown Member
- Uppermost Aquifer (Groundwater Monitoring Zone) – Thin (generally less than 3 feet), moderate permeability sand, silty sand, and sandy silt/clay units which include the Hagarstown Member and the upper Vandalia Member (where weathered)
- Lower Confining Unit – Thick (generally greater that 15 feet), very low permeability sandy silt till or clay till that includes the unweathered lower Vandalia Member, Mulberry Grove Member (discontinous), and Smithboro Member
- Bedrock – Pennsylvanian-age Bond Formation characterized by limestone and calcareous clays and shales. Bedrock was not encountered in any borings advanced onsite

Mounding of water within saturated ash in the impoundment creates a component of radial flow. The extent of this groundwater movement appears to be limited, as the elevated heads overlying the Upper

Confining Unit dissipate across the Ash Pond 2 berms. Potentially impacted water from the seeps observed along the berms may partially infiltrate through the Upper Confining Unit and/or run off toward the Lake or Unnamed Creek.

The Uppermost Aquifer underlying Ash Pond 2 consists of the Hagarstown Member and the weathered (upper) portions of the Vandalia Member, which is being monitored to define the extent of CCR constituents derived from Ash Pond 2. The Uppermost Aquifer is confined except where the Hagarstown Member is exposed along the eastern side of the impoundment within the former ravine (Figure 4). Based on hydraulic conductivity values (10^{-3} to 10^{-4} cm/sec) measured in the monitoring wells screened in the Hagarstown Member, groundwater at CPS has previously been classified as Class I in accordance with 35 IAC 620 (Hanson, 2009).

CCR within Ash Pond 2 is underlain by the Upper Confining Unit beneath the majority of the impoundment footprint. However, in former drainage features present prior to construction the saturated ash is in contact with the Hagarstown Beds and underlain by the Vandalia Member. Given the relatively high permeability of the Hagarstown Beds, leachate from Ash Pond 2 infiltrates into this unit, migrates through/under the eastern berm (where the Hagarstown Member is continuous below the berm) and discharges along the slope, as evidenced by the observation of seeps (Figure 4).

Groundwater within the Hagarstown Beds beyond the boundary of Ash Pond 2 flows predominantly to the east and south. Both the southern discharge flume and the Unnamed Creek intersect and cutoff the Hagarstown unit, eliminating further migration of potentially impacted groundwater. Impacted groundwater may also migrate to the north and northwest in the Hagarstown, potentially under the influence of the passive (gravity drain) underdrain system associated with the Recycle Pond and active underdrain system associated with the Landfill.

2 GROUNDWATER MONITORING

A groundwater investigation around Ash Pond 2 was initially completed in 2010-2012, A monitoring program was initiated in November 2015 to comply with the requirements of 40 CFR Part 257 (CCR Rule). Upon approval of the Closure Plan in which this document is included, the monitoring network will consist of the current CCR monitoring program and additional wells associated with other CPS units to comply with both IEPA and CCR Rule requirements. The proposed groundwater monitoring well network consists of a sufficient number of wells, installed at appropriate locations and depths, to monitor post-closure compliance with groundwater quality standards for Class I: Potable Resource Groundwater.

The proposed groundwater monitoring program included in this document is consistent with the requirements of 35 IAC Part 620 with Illinois EPA-approved modifications as well as 40 CFR Part 257. The wells will monitor the Hagarstown unit in the vicinity of Ash Pond 2 which has been designated the uppermost aquifer and has been monitored for the IEPA approved programs associated with the Landfill, Gypsum Stack Pond and Gypsum Recycle Pond.

The monitoring wells are designed and constructed in accordance with applicable standards, including the following:

- All monitoring wells are cased in a manner that maintains the integrity of the boreholes
- Wells are screened to allow sampling only at the specified interval
- All wells are covered with vented caps, unless located in flood-prone areas, and equipped with devices to protect against tampering and damage

The monitoring well network described below fulfills the following goals:

- Enable the collection of groundwater samples that represent the quality of background water that has not been affected by the Ash Pond 2
- Enable the collection of groundwater samples that represent the quality of downgradient groundwater
- Include wells that are located within the stratigraphic unit that may serve as potential contaminant migration pathways

2.1 Existing Well Network and Monitoring Programs

The existing monitoring wells present around the five units is summarized in Table 1 and shown on Figure 2. This subsection discusses the monitoring wells associated with Ash Pond 2, and Subsections 2.1.1 and 2.1.2 describe the monitoring performed around Ash Pond 2. Monitoring wells specifically associated with Ash Pond 2 include five leachate head wells (OW1 – OW-5), 7 monitoring wells

(G401 - G407), 8 piezometers (B-1(d), B-2(s), G45D, G46D, P009, P010, P012, and P014), and 2 temporary piezometers (T408 and T409). Monitoring wells around Ash Pond 2 were installed beginning in 2010 (G402), and the remaining wells and piezometers were installed in 2015 and 2016. The recent addition of wells and the piezometers, one of which is located within the ash impoundment, was completed in 2015 and 2016 to comply with the CCR Rule and define the vertical extent of CCR impacts. Monitoring wells around other CCR units were installed between 2008 and 2011 to monitor groundwater around the Landfill, Gypsum Stack Pond, and Recycle Pond as required by the IEPA.

2.1.1 IEPA Monitoring

Currently, no IEPA required groundwater monitoring is performed around Ash Pond 2. Following closure of Ash Pond 2 groundwater monitoring will be initiated to meet requirements of 35 IAC Part 620.410.

2.1.2 40 CFR Part 257 Monitoring

CCR Rule monitoring commenced in November 2015 and currently consists of quarterly groundwater elevation measurements and water quality samples collected at background monitoring wells G270 and G281, and downgradient wells G401, G402, G403, G404, and G405. The groundwater will be analyzed for Appendix III and Appendix IV parameters (see below) for eight quarterly sampling events. Piezometers (P009, P010, P012, and P014) are measured monthly for groundwater elevation only.

Appendix III Parameters (total, except TDS)			
Boron	Chloride	pH	Total Dissolved Solids (TDS)
Calcium	Fluoride	Sulfate	
Appendix IV Parameters (total)			
Antimony	Cadmium	Lead	Selenium
Arsenic	Chromium	Lithium	Thallium
Barium	Cobalt	Mercury	Radium 226/228
Beryllium	Fluoride	Molybdenum	
Field Parameters			
Dissolved Oxygen	Specific Conductivity	Temperature	Turbidity
Oxidation/Reduction Potential			

Following the completion of eight quarterly sampling events, the monitoring program will be modified so that the analytical parameters and sampling frequency are appropriate to the objectives and requirements of the CCR Rule.

2.2 Proposed Monitoring Network

This Closure Plan proposes a groundwater monitoring program to meet the requirements of 35 IAC Part 620.410. Wells to be sampled are summarized in Table 2 and below, and the proposed monitoring network is shown on Figure 5.

Boring logs and monitoring well construction reports for the groundwater monitoring system are provided in Appendix A. The well depths well screen intervals, depth to groundwater, and position relative to Ash Pond 2 are summarized below:

Well Number	Well Screen Interval (ft bgs)	Depth To Groundwater[1] (ft bgs)	Well Position in Hagarstown Unit	Additional Units Monitored
G154	14.3-18.8	11.67	Upgradient / Background	SW Pond
G270	13.1-17.9	7.61	Upgradient / Background	Gypsum Recycle Pond
G279	22.4-26.8	25.11		
G280	12.8-17.6	7.39		
G281	15.5-20.2	6.35		
G401	14.4-18.8	17.73	Downgradient / Side gradient	None
G402	10-20	9.13	Downgradient	
G403	13.1-17.8	4.67	Downgradient	
G404	6.4-11.2	5.09	Downgradient / Side gradient	
G405	9.0-13.8	5.15		
G406	13.6-18.4	9.35	Downgradient	
G407	13.8-18.6	8.05	Background / Downgradient	
G410[2]	TBD	TBD		
G411[2]	TBD	TBD		

[1] Groundwater depth elevations shown are from November 2016
[2] Proposed wells, to be installed upon approval of Closure Plan

Additional sampling is completed, as required by IEPA, at monitoring wells surrounding the Landfill, Gypsum Stack Pond, and Gypsum Recycling Pond. These sampling programs are not included or discussed in this Plan. However, groundwater elevations from these monitoring wells will be used for data analysis when they are collected in conjunction with the Ash Pond 2 monitoring.

Wells G410 and G411 are proposed to be installed, upon approval of the Closure Plan, to define the extent of sulfate exceedances above Class I standards in the Hagarstown Unit to the west of G407. The sulfate exceedances at well G407 have not been attiributed to Ash Pond 2 and will be further evaluated following completion of proposed wells G410 and G411 to the west.

2.3 Abandoned Wells

Monitoring wells and piezometers not included in the proposed network will be abandoned upon approval of this Groundwater Monitoring Plan. Piezometers G45D, north of Ash Pond 2, and G46D located on the southwest corner are no longer required because no CCR constituents were detected at concentrations of concern at these locations. Temporary wells T408 (nested with G45D), and T409 (nested with G46D), will also be abandoned because they were installed only to obtain horizontal hydraulic conductivities in the Vandalia Till Unit.

The leachate wells OW-1 through OW-5 and piezometers (B-1(d), B-2(s), P009, P010, P012, and P014) will be abandoned prior to capping of Ash Pond 2. The locations of the leachate well, monitoring wells, and piezometers that will be abandoned are shown on Figure 5.

3 APPLICABLE GROUNDWATER QUALITY STANDARDS

3.1 Groundwater Classification

Based on the detailed geologic information provided for the Hagarstown Unit at the Site, groundwater can be classified as Class I - Potable Resource Groundwater. Although the thickness of the sand and gravel is generally less than 5 feet, the field hydraulic conductivity tests performed on the Hagarstown had geometric mean hydraulic conductivities of approximately 2.9×10^{-4} cm/s, and in some locations it was measured as high as 10^{-3} cm/sec. Sands and gravels with a hydraulic conductivity of greater than 1×10^{-4} cm/s meet the provisions of Section 620.210 for Class I Potable Resource Groundwater.

3.2 Applicable Groundwater Quality Standards

The groundwater quality standards for the proposed monitoring well network screened in the Hagarstown Unit are Class I Potable Resource Groundwater [35 IAC 620.410] standards or background concentrations, based on statistical analyses (Section 3.3). For determination of background concentrations, only parameters included in the proposed analyte list (Table 2) and from wells within the proposed network were used in the evaluation. Background concentrations were calculated for arsenic, boron, manganese, pH, sulfate and TDS from background wells G270, G280, and G281.

Based on the statistical evaluation of the background groundwater data (Table 3), background concentrations exceed groundwater quality standards for Class I Potable Resource Groundwater for manganese. Therefore, the background groundwater concentration for manganese will apply to the proposed monitoring well network. Since background concentrations are lower than the Class I Potable Resource Groundwater standard for arsenic, boron, pH, sulfate and TDS, the Class I Potable Resource Groundwater will be applied.

Background groundwater quality for additional parameters subject to the USEPA CCR Rule (i.e., Appendix III and IV) will be established through statistical evaluation following completion of 8 quarters of groundwater sampling of background wells that commenced in November 2015. The groundwater quality standard for these parameters at the proposed monitoring well network for Ash Pond 2 will be the greater of either the background concentration or the groundwater quality standard for Class I Potable Resource Groundwater. Parameters with no Class I standard will not be evaluated for the IEPA monitoring program but will be evaluated separately for the USEPA CCR Rule with the methods outlined in 40 CFR Part 257. The current list of applicable groundwater quality standards for the monitoring well network is shown on Table 3.

3.3 Statistical Evaluation of Background Groundwater Data

A statistical evaluation was performed to determine the maximum background concentrations likely to occur upgradient of Ash Pond 2 at the CPS. The groundwater quality data collected from upgradient monitoring wells G270, G280, and G281 was evaluated using the Electric Power Research Institute (EPRI, March 2014) computer database and analysis program, MANAGES™ (Version 3.4.49). The statistical analysis procedures used here are consistent with procedures described in the document: 2009 Unified Guidance. "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities—Unified Guidance," March 2009, EPA 530/R-09-2007 (USEPA, 2009).

The statistical methodology is provided in Appendix B. Establishing the tolerance interval(s) for the groundwater constituents was accomplished by using either a parametric or non-parametric procedure, based on the percentage of non-detects in the data sets and the distribution of the sample population. If the statistical data for a constituent had less than 50 percent non-detects and was normally or log-normally distributed, a parametric procedure was used. If the data was not normally or log-normally distributed or had more than 50 percent non-detects, a non-parametric procedure was used. Appendix B, Figure B-1 is a flow chart which illustrates the processes followed to determine the appropriate statistical procedure used for each constituent, based on its statistical characteristics.

3.4 Statistical Analysis Results

The results of the statistical analyses for the groundwater in Hagarstown Unit are located in Appendix B. Appendix B includes a statistical summary of the background water quality data from Wells G270, G280, and G281 and the statistical analysis procedure inputs and results.

Calculated background values (upper and lower limits) for the tested inorganic constituents and pH are listed in Appendix B, Table B-1 along with the percent non-detects, normal or lognormal distribution, test method, and confidence level. The calculated background values are also shown on Table 3 and are compared to the groundwater quality standards for Class I: Potable Resource Groundwater. The higher of the two values is shown as the Applicable Groundwater Standard on Table 3 (see additional discussion provided in Section 3.2).

3.5 Proposed Exceptions to the Groundwater Monitoring Parameters

Based on the results of groundwater monitoring performed at CPS to date, the following exceptions to the above applicable Class I: Potable Resource Groundwater standards are proposed:

- Analytical results (Appendix C) indicate iron has historically exceeded the groundwater quality standards of Class I Potable Resource Groundwater inorganic constituents listed in 35 IAC 620.410(a)(1). However, elevated iron concentrations are attributed to reducing

conditions and aquifer composition and are not prevalent in groundwater associated with Ash Pond 2.

- Nitrate is included in the inorganic parameters for Class I Potable Resource Groundwater. Historical monitoring has not exhibited nitrate exceedances and nitrate is not prevalent in groundwater associated with Ash Pond 2.

- Class I Potable Resource Groundwater requires monitoring the inorganic constituents copper, cyanide, nickel, silver, vanadium, and zinc listed in 35 IAC 620.410(a)(1). These constituents will not be monitored because they may be sensitive to the aquifer reducing conditions and are not associated with the chemical characteristics of CCR at Ash Pond 2.

- Perchlorate is commonly used as an oxidizer in solid propellants, munitions, fireworks, airbag initiators for vehicles, matches and signal flares. It is also used in some electroplating operations and found in some disinfectants and herbicides (USEPA, 2014). Perchlorate is an inorganic constituent listed in 35 IAC 620.410(a)(1) but has not been previously analyzed. Perchlorate will not be monitored because it is not associated with the chemical characteristics of CCR at Ash Pond 2.

The proposed groundwater monitoring parameters for the proposed monitoring well network are discussed further in Section 4.1.

4 GROUNDWATER MONITORING PLAN

The groundwater monitoring plan will monitor and evaluate groundwater quality to demonstrate compliance with the groundwater quality standards for Class I: Potable Resource Groundwater as well as USEPA MCLs or background exceedances, as appropriate. As discussed in Section 3, the proposed post-closure groundwater sampling network consists of three background monitoring wells and 11 compliance monitoring wells as shown on Figure 5.

4.1 Groundwater Monitoring

The proposed IEPA (35 IAC Part 620.410) well network for Ash Pond 2 consists of 11 monitoring wells (Table 2) installed in the Hagarstown Beds adjacent to Ash Pond 2, the Gypsum Recycle Pond and the SW Pond and 3 background monitoring wells (G270, G280, and G281). The wells included in the IEPA Closure Monitoring will be analyzed for the following laboratory and field parameters:

Laboratory Parameters		
Metals (dissolved)		
Arsenic	Lead	Manganese
Boron		
Inorganics (totals)		
Sulfate	Total Dissolved Solids	
Field Parameters		
pH	Temperature	
Oxidation/Reduction Potential	Specific Conductivity	
Dissolved Oxygen	Turbidity	

In addition to the IEPA Closure Monitoring, wells G270, G279, G280, G281, and G401 – G405 will be sampled and analyzed for additional parameters to comply with the CCR Rule. These wells will be monitored for the following laboratory and field parameters shown below:

Laboratory Parameters		
Metals (totals)		
Antimony	Cadmium	Lithium
Arsenic	Calcium	Mercury
Barium	Chromium	Molybdenum
Beryllium	Cobalt	Selenium
Boron	Lead	Thallium

Inorganics (totals)	
Fluoride	Sulfate
Chloride	Total Dissolved Solids
Other (total)	
Radium 226 and 228 combined	
Field Parameters	
pH	Temperature
Oxidation/Reduction Potential	Specific Conductivity
Dissolved Oxygen	Turbidity

As discussed in Section 3.5, other constituents listed under 35 IAC 620 will not be monitored at the proposed monitoring well network because the groundwater monitoring results to date indicate that the inorganic constituents copper, cyanide, nitrate, nickel, silver, and zinc either meet the Class I: Potable Resource Groundwater standards or are not associated with the chemical characteristics of CCR at Ash Pond 2. Iron will not be sampled because it is indicative of reducing conditions in the aquifer and is not prevalent in groundwater associated with Ash Pond 2. Following the initial eight rounds of sampling at the CCR Rule monitoring wells, the parameters to be monitored will be in accordance with the requirements of 40 CFR Part 257.94 and 257.95 and this plan.

4.2 Sampling Schedule

Groundwater sampling for the proposed monitoring well network will initially be performed quarterly according to the following schedule:

Frequency	Duration
Quarterly	Begins: upon approval of this plan, for wells and parameters within the IEPA Closure Monitoring Program only. Wells within the CCR monitoring program will be monitored in accordance with 40 CFR 257.
	Ends: 5 years after completion of cap and upon demonstration that monitoring effectiveness is not compromised and that there are no increasing trends attributable to Ash Pond 2
Semiannual	Begins: after IEPA approves that quarterly monitoring requirements have been satisfied.
	Ends: 5 years after initiation of semiannual monitoring and upon demonstration that monitoring effectiveness is not compromised and that there are no increasing trends attributable to Ash Pond 2.
Annual	Begins: after IEPA approves that semiannual monitoring requirements have been satisfied.
	Ends: upon IEPA approval of a certified post-closure care report, but no less than 30 years from the date of closure as specified in 40 CFR 257

Five years after approval of the Closure Plan, a request may be made to modify the post-closure care plan to reduce the frequency of groundwater monitoring to semi-annual sampling by demonstrating all of the following:

- Monitoring effectiveness will not be compromised by the reduced frequency of monitoring
- Sufficient data has been collected to characterize groundwater
- Concentrations of constituents monitored at the downgradient boundaries show no statistically significant increasing trends that can be attributed to the former ash ponds

If concentrations of parameters of concern at the downgradient wells of the site show no statistically significant increasing trends that can be attributed to Ash Pond 2 for the five years after reducing the monitoring frequency to semi-annual, a request may be made to modify the post-closure care plan to reduce monitoring frequency to annual sampling by demonstrating the same items above as for the reduction to semi-annual monitoring.

Groundwater monitoring may be discontinued upon Illinois EPA's approval of a certified post-closure care report after a minimum 30 years of post-closure groundwater monitoring has been completed. Specifically, when no statistically significant increase is detected in the concentration of any constituent above that measured and recorded during the immediately preceding scheduled sampling for four consecutive years after changing to an annual monitoring frequency.

Groundwater monitoring for the 40 CFR Part 257 well network will follow a schedule in accordance with the requirements of 40 CFR Part 257.94 and 257.95. Post-closure care groundwater monitoring will continue for a minimum of 30 years in accordance with 40 CFR Part 257.104

4.3 Groundwater Sample Collection

Groundwater samples will be collected consistent with the requirements of 35 IAC Part 620 and 40 CFR 257.93 as described in Appendix D. In addition to groundwater well samples, quality assurance samples will be collected as described in Section 4.5 (Table 4).

4.4 Laboratory Analysis

Laboratory analysis will be performed consistent with the requirements of 35 IAC Part 620 and 40 CFR 257.93 by a state-certified laboratory using methods approved by Illinois EPA and USEPA (Table 4). The practical quantitation limit (PQL) for all parameters analyzed will be lower than the applicable groundwater quality standard. Concentrations lower than the PQL will be reported as less than the PQL. A list of these parameters and the required PQLs are summarized in Table 5.

4.5 Quality Assurance Program

Consistent with the requirements of 35 IAC Part 620 and 40 CFR 257.93, the sampling and analysis program includes procedures and techniques for quality assurance and quality control (Table 4). Additional quality assurance samples to be collected will include the following:

- Two blind duplicate groundwater samples from randomly selected monitoring wells
- One equipment blank sample will be collected and analyzed for each day of sampling. If dedicated sampling equipment is used, than equipment blank samples will not be collected.

The duplicate and equipment blank quality assurance samples will be supplemented by the laboratory QA/QC program, which typically includes:

- Regular generation of instrument calibration curves to assure instrument reliability
- Laboratory control samples and/or quality control check standards that have been spiked, and analyses to monitor the performance of the analytical method
- Matrix spike/matrix spike duplicate analyses to determine percent recoveries and relative percent differences for each of the parameters detected
- Analysis of replicate samples to check the precision of the instrumentation and/or methodology employed for all analytical methods
- Analysis of method blanks to assure that the system is free of contamination

4.6 Groundwater Monitoring System Maintenance Plan

Consistent with the requirements of 35 IAC Part 620 and 40 CFR 257.91, maintenance will be performed as needed to assure that the monitoring wells provide representative groundwater samples. Monitoring wells will be inspected during each groundwater sampling event. Monitoring well inspections will consist of the following:

- Visual inspection, clearing of vegetation, replacement of markers, and painting of protective casings as needed to assure that monitoring wells are clearly marked and accessible
- Visual inspection and repair or replacement of well aprons as needed to assure that they are intact, drain water away from the well, and have not heaved
- Visual inspection and repair or replacement of protective casings as needed to assure that they are undamaged, and that locks are present and functional
- Checks to assure that well caps are intact and vented, unless in flood-prone areas in which case caps will not be vented

- Annual measurement of monitoring well depths to determine the degree of siltation within the wells. Wells will be redeveloped as needed to remove siltation from the screened interval if it impedes flow of water into the well

- Checks that wells are clear of internal obstructions, and flow freely

If maintenance of a monitoring well cannot address an identified deficiency, a replacement well will be installed.

4.7 Annual Statistical Analysis

Trend analysis will be performed annually for each of the monitored parameters. Sen's Estimate of Slope will be applied to a minimum of four consecutive quarterly monitoring results. If there are increasing trends during closure and post-closure care periods, they will be further investigated as described below.

- If the results of sampling and analysis show an increasing trend at any compliance monitoring well, a Mann-Kendall analysis will be performed at 95 percent confidence to determine whether or not the increasing trend is statistically significant.

- If a statistically significant increasing trend occurs during post-closure care, further investigation of monitored concentrations will be performed as well as more frequent inspections of the surface of the cover system.

- If the investigation attributes a statistically significant increasing trend to a source other than Ash Pond 2, then the Illinois EPA will be notified in writing, stating the cause of the increasing trend and providing the rationale used in such a determination.

- If there is not an alternative source causing the statistically significant increasing concentration and the sampling frequency had been reduced to semi-annual or annual sampling, a quarterly sampling schedule will be reestablished. The frequency of sampling will return to either semi-annual or annual, once four consecutive quarterly samples show no statistically significant increasing trend.

Notifications concerning statistically significant increasing trends and revisions of the sampling frequency will be reported to Illinois EPA in writing within 30 days after making the determinations.

In addition as required in 40 CFR Part 257.93, statistical analysis will be performed to determine whether or not a statistically significant increase over a background value has occurred for each constituent and at each well. Appropriate statistical methods will be chosen from the list of methods provided and the test chosen will be conducted separately for each constituent in each monitoring well. In addition, each statistical method chosen will comply with the performance standards, as appropriate, based on the test method used. If a statistically significant increase over background values is determined, procedures from 40 CFR Part 257 will be followed including 1) establishing an assessment monitoring program or 2) demonstrating that a source other than Ash Pond 2 caused the increase or demonstrating another plausible reason for the increase (error in sampling, etc.).

4.8 Data Reporting

Sampling and analysis data from quarterly, semi-annual and/or annual groundwater monitoring for the monitoring well network will be reported to Illinois EPA within 60 days after completion of sampling. Statistical analysis of the laboratory analytical data will be reported to Illinois EPA with the annual report for the facility, as described in the closure plan.

Data reporting for the 40 CFR Part 257 monitoring well network will be consistent with recordkeeping, notification, and internet posting requirements described in 40 CFR 257.105 through 257.107.

4.9 Compliance with Applicable On-Site Groundwater Quality Standards

In accordance with IAC 620 Section 620.240, the compliance boundary is a lateral distance of 25 feet outward from the outermost edge of Ash Pond 2 berms. Following completion of the corrective action, the groundwater standard at the compliance boundary will be in accordance with IAC 620 Section 450(a)(4) for groundwater quality restoration such that the standard for each released chemical constituent will be the higher of either the Class I groundwater standard or the concentration determined by groundwater monitoring at the compliance boundary.

Compliance with on-site groundwater quality standards, as measured at the proposed monitoring well network, will be achieved when there are no statistically significant increasing trends that are attributed to Ash Pond 2 for parameters detected at the compliance boundary after a minimum 30 years of post-closure groundwater monitoring has been completed. Evaluation of groundwater quality data under USEPA (2015) will be consistent with 40 CFR Part 257.93 and 257.94.

4.10 Corrective Action

If a statistically significant increasing trend is observed to continue over a period of two or more years in groundwater sampled at the well network, and a subsequent hydrogeologic site investigation demonstrates that such exceedances are due to a release from Ash Pond 2 and corrective actions are appropriate to mitigate such releases, a corrective action plan will be proposed as a modification to the post-closure care plan. A corrective action plan will be submitted to Illinois EPA within 180 days after completion of the investigation activities. The plan will propose corrective actions to be undertaken to mitigate the impacts associated with the constituents of concern which exceed applicable groundwater standards.

5 REFERENCES

AECOM, 2016. Revised 30% Closure Design Package for Coffeen Power Station Ash Pond No. 2. April 16, 2016.

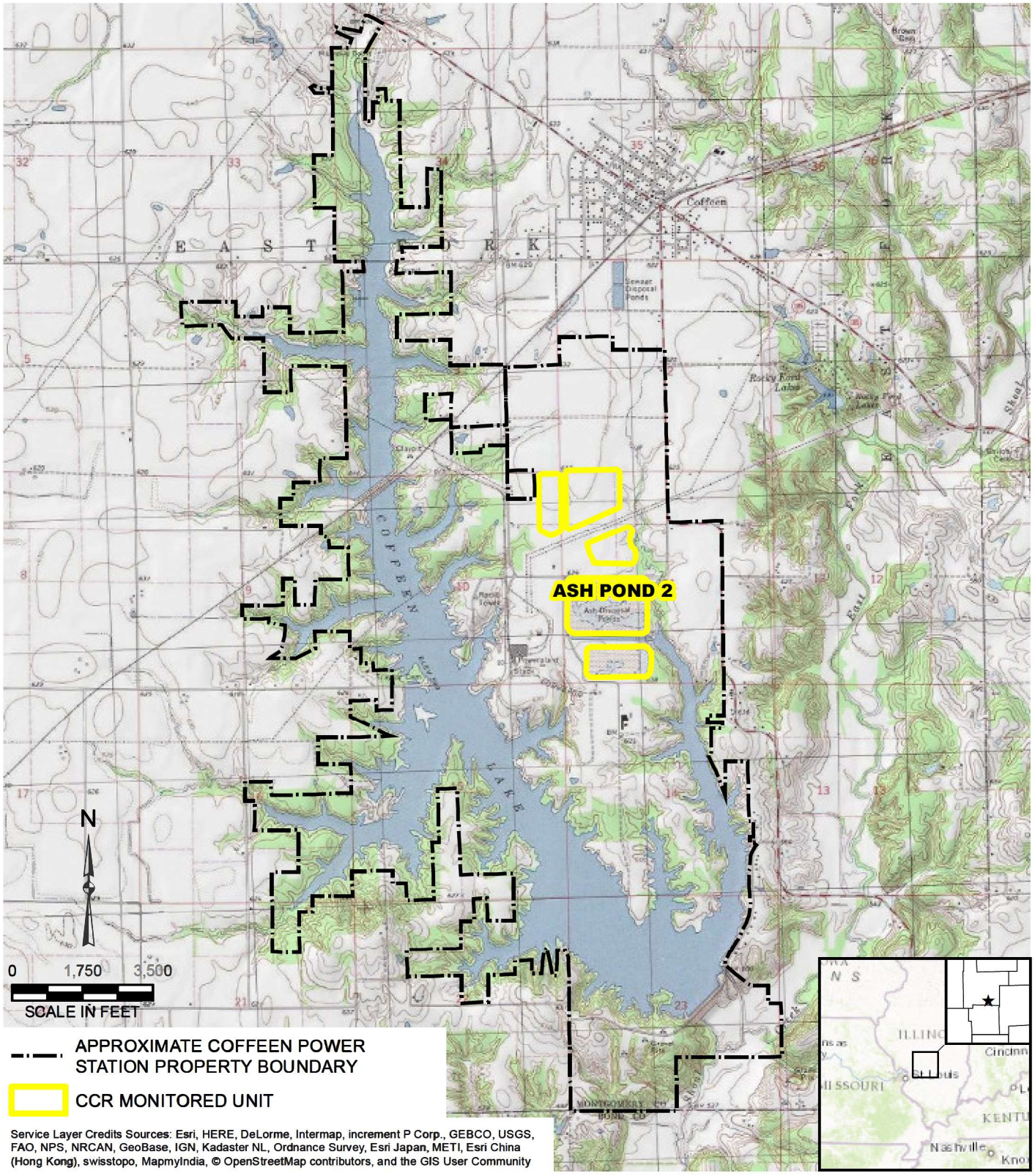
Natural Resource Technology, Inc. 2016. Hydrogeologic Site Characterization Report

USEPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance. EPA 530/R-09/007, U.S. Environmental Protection Agency, Office of Resource Conservation and Recovery, Washington, D.C., 554 p. + 4 app.

USEPA, January 2014. Technical Fact Sheet – Perchlorate

USEPA, April 17, 2015. 40 CFR Parts 257 and 261. Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule

FIGURES



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SDS 12/21/16
REVIEWED BY/DATE:
NRK 12/21/16
APPROVED BY/DATE:
SJC 12/21/16

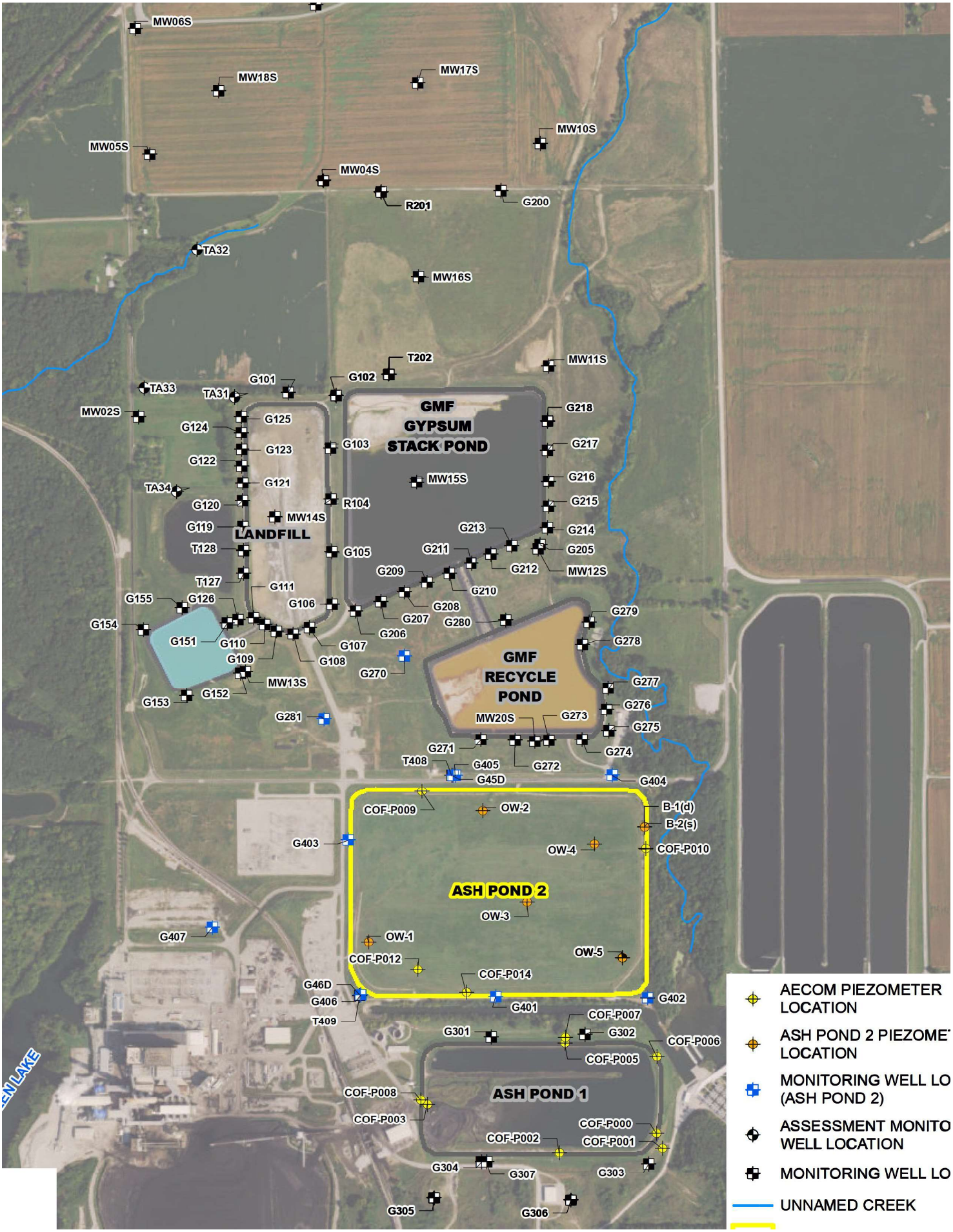
SITE LOCATION MAP

GROUNDWATER MONITORING PLAN
ASH POND 2
COFFEEN POWER STATION
COFFEEN, IL

PROJECT NO: 2380

FIGURE NO: 1

Natural Resource Technology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MW17S
MW10S
MW05S
MW04S
R201
G200
TA32
MW16S
T202
MW11S
TA33
G101
G102
TA31
GMF
GYPSUM
STACK POND
G218
MW02S
G125
G124
G123
G103
G217
G122
G121
MW15S
G216
TA34
G120
R104
G215
MW14S
G119
LANDFILL
G213
G214
T128
G105
G211
G205
G212
MW12S
G209
T127
G111
G210
G155
G126
G106
G208
G279
G154
G207
G280
G151
G110
G206
G278
G107
G109
G108
GMF
RECYCLE
POND
G270
G277
MW13S
G153
G152
G276
G281
MW20S
G273
G275
G271
G274
T408
G405
G272
G45D
G404
COF-P009
OW-2
B-1(d)
B-2(s)
G403
OW-4
COF-P010
ASH POND 2
OW-3
G407
OW-1
OW-5
COF-P012
COF-P014
G46D
G406
G401
G402
T409
COF-P007
G301
G302
COF-P006
COF-P005
COF-P008
ASH POND 1
COF-P003
COF-P000
COF-P002
COF-P001
G304
G307
G303
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G306
AECOM PIEZOMETER LOCATION
ASH POND 2 PIEZOME LOCATION
MONITORING WELL LO (ASH POND 2)
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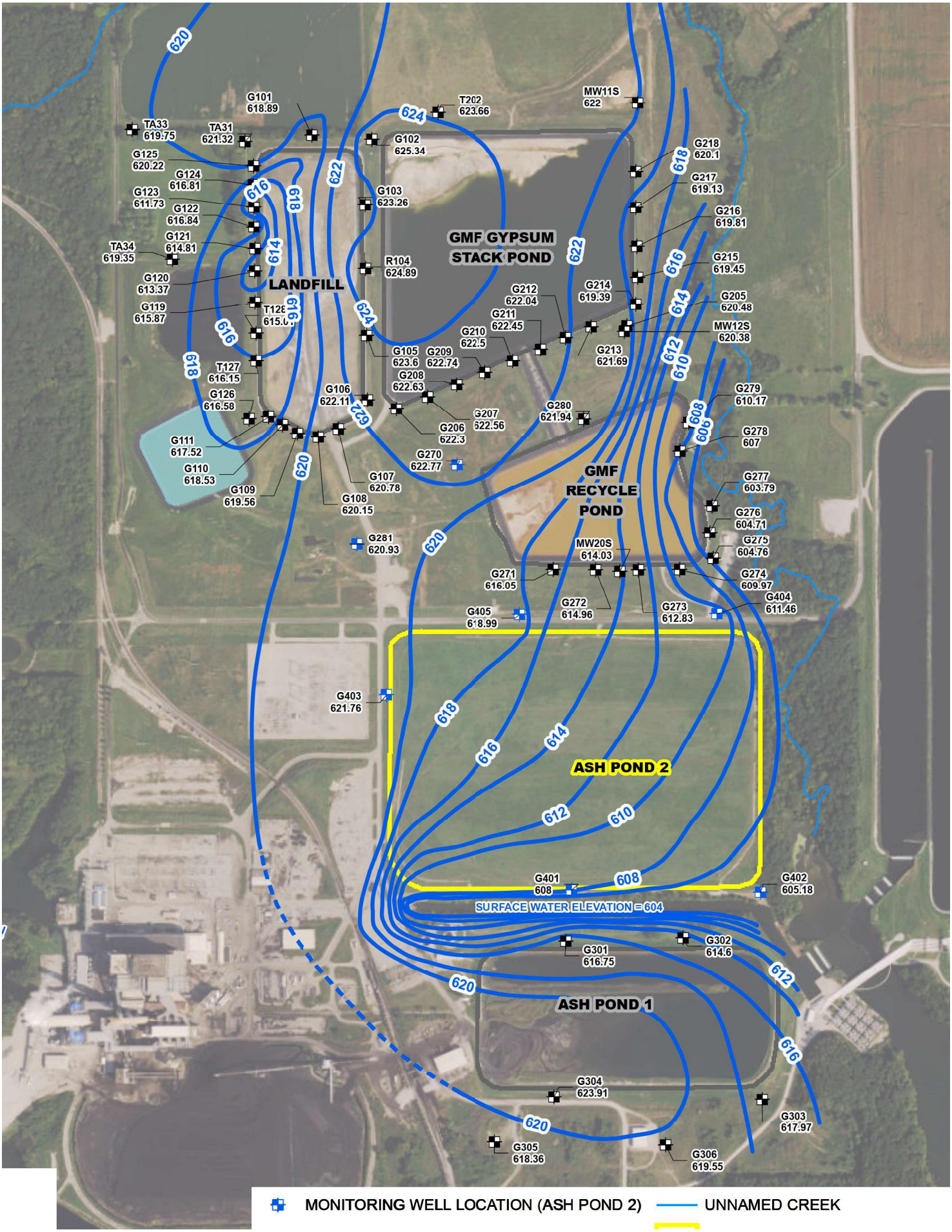
MONITORING WELL LO
UNNAMED CREEK


GMF GYPSUM STACK POND
LANDFILL
GMF RECYCLE POND
ASH POND 2
ASH POND 1
SURFACE WATER ELEVATION = 604
MONITORING WELL LOCATION (ASH POND 2)
UNNAMED CREEK
G101 618.89
T202 623.66
MW11S 622
TA33 619.75
TA31 621.32
G102 625.34
G125 620.22
G124 616.81
G123 611.73
G122 616.84
G103 623.26
G121 614.81
TA34 619.35
R104 624.89
G120 613.37
G119 615.87
T128 615.0
G212 622.04
G211 622.45
G210 622.5
G214 619.39
G218 620.1
G217 619.13
G216 619.81
G215 619.45
G205 620.48
MW12S 620.38
G213 621.69
G105 623.6
G209 622.74
G208 622.63
T127 616.15
G126 616.58
G106 622.11
G207 622.56
G206 622.3
G280 621.94
G279 610.17
G278 607
G111 617.52
G110 618.53
G109 619.56
G270 622.77
G107 620.78
G108 620.15
G277 603.79
G276 604.71
G275 604.76
G281 620.93
MW20S 614.03
G271 616.05
G272 614.96
G273 612.83
G274 609.97
G404 611.46
G405 618.99
G403 621.76
G401 608
G402 605.18
G301 616.75
G302 614.6
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G306 619.55
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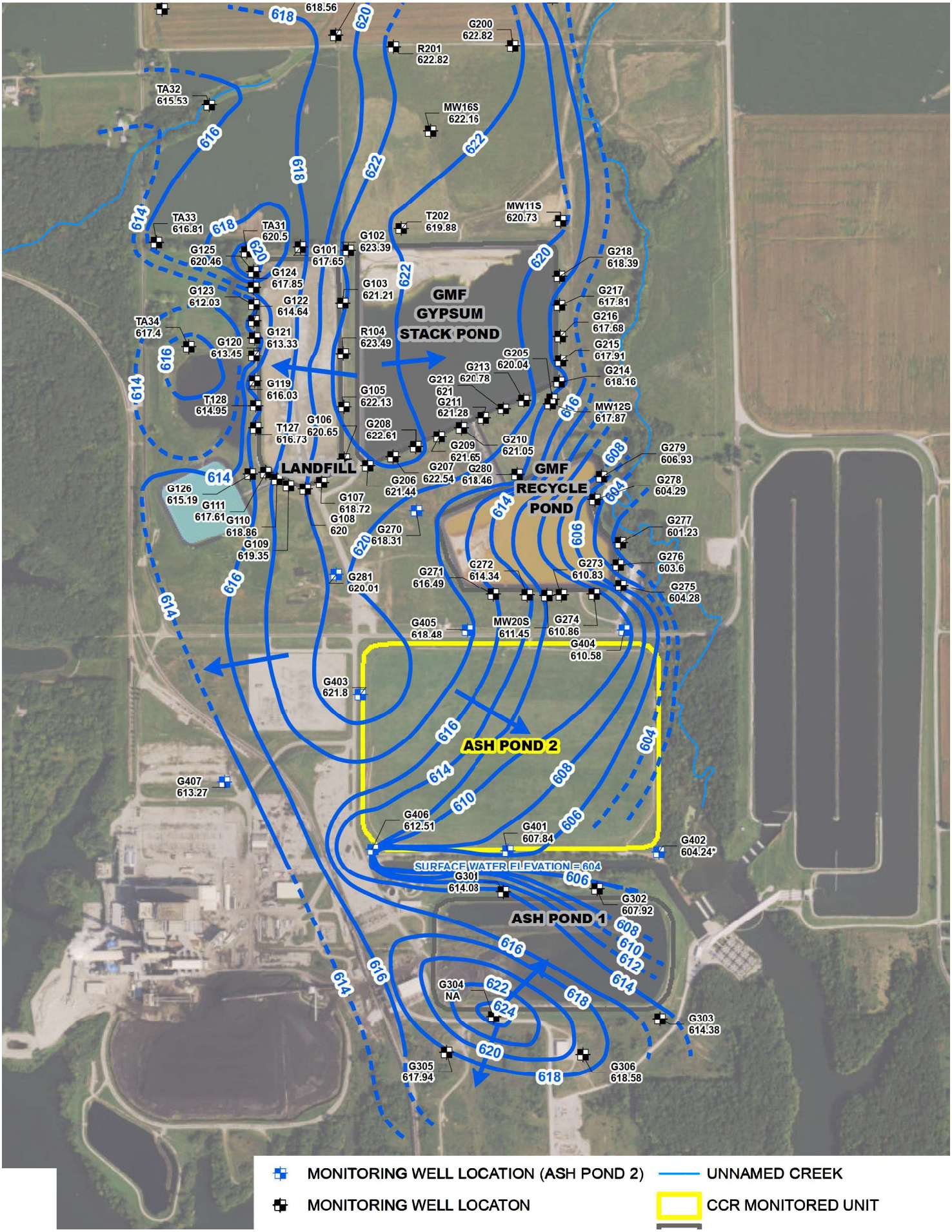
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R201 622.82
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TA31 620.5
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MW11S 620.73
G102 623.39
G101 617.65
G125 620.46
G124 617.85
G123 612.03
G122 614.64
G103 621.21
GMF GYPSUM STACK POND
G218 618.39
G217 617.81
G216 617.68
G215 617.91
G214 618.16
TA34 617.4
G121 613.33
R104 623.49
G120 613.45
G205 620.04
G213 620.78
G212 621
G211 621.28
MW12S 617.87
G119 616.03
G105 622.13
T128 614.95
G106 620.65
G208 622.61
T127 616.73
G210 621.05
G209 621.65
G279 606.93
LANDFILL
G207 622.54
G280 618.46
GMF RECYCLE POND
G278 604.29
G206 621.44
G126 615.19
G111 617.61
G107 618.72
G108 620
G110 618.86
G109 619.35
G270 618.31
G277 601.23
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G273 610.83
G272 614.34
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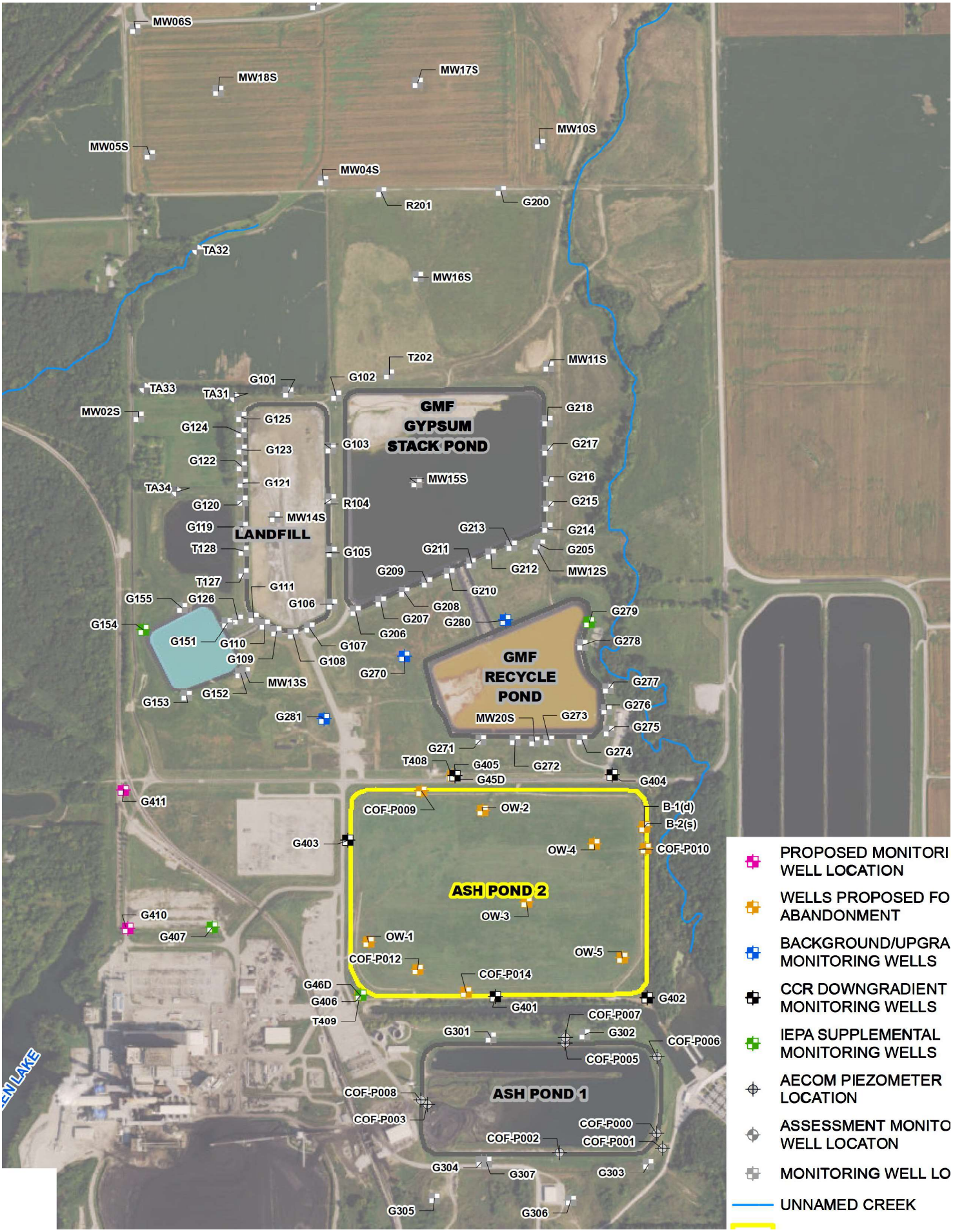
G275 604.28
G281 620.01
G405 618.48
MW20S 611.45
G274 610.86
G404 610.58
G403 621.8
ASH POND 2
G407 613.27
G406 612.51
G401 607.84
G402 604.24
SURFACE WATER ELEVATION = 604
G301 614.08
G302 607.92
ASH POND 1
G304 NA
G303 614.38
G305 617.94
G306 618.58
MONITORING WELL LOCATION (ASH POND 2)
MONITORING WELL LOCATON
UNNAMED CREEK
CCR MONITORED UNIT


MW06S
MW18S
MW17S
MW10S
MW05S
MW04S
R201
G200
TA32
MW16S
T202
MW11S
G101
G102
TA33
TA31
GMF
GYPSUM
STACK POND
G218
MW02S
G125
G124
G103
G217
G123
G122
MW15S
G216
G121
TA34
G215
G120
R104
G213
MW14S
G214
G119
LANDFILL
G211
G205
T128
G105
G212
MW12S
G209
T127
G210
G111
G155
G126
G106
G208
G279
G154
G207
G280
G151
G110
G206
G278
G107
GMF
RECYCLE
POND
G109
G108
G270
G277
MW13S
G276
G153
G152
G281
MW20S
G273
G275
G271
G274
T408
G405
G272
G45D
G404
G411
COF-P009
OW-2
B-1(d)
B-2(s)
G403
OW-4
COF-P010
ASH POND 2
G410
OW-3
G407
OW-1
OW-5
COF-P012
COF-P014
G46D
G406
G401
G402
T409
COF-P007
G301
G302
COF-P006
COF-P005
ASH POND 1
COF-P008
COF-P003
COF-P000
COF-P002
COF-P001
G304
G307
G303
G305
G306
PROPOSED MONITORI
WELL LOCATION
WELLS PROPOSED FO
ABANDONMENT
BACKGROUND/UPGRA
MONITORING WELLS
CCR DOWNGRADIENT
MONITORING WELLS
IEPA SUPPLEMENTAL
MONITORING WELLS
AECOM PIEZOMETER
LOCATION
ASSESSMENT MONITO
WELL LOCATON
MONITORING WELL LO
UNNAMED CREEK

TABLES

Table 1
Summary of Existing Monitoring Well Networks
Groundwater Monitoring Plan - Ash Pond 2
Coffeen Energy Center - Ash Pond 2

Well ID	Easting	Northing	Surface Elevation (ft MSL)	TOC Elevation (ft MSL)	Top of Screen Elevation	Bottom of Screen Elevation	Interpreted Screened Unit
G301	2,515,582.97	872,234.82	620.27	622.65	609.0	604.3	Upper Vandalia Till
G302	2,516,214.19	872,252.95	617.95	620.04	604.7	600.1	Upper Vandalia Till
G303	2,516,639.65	871,382.14	619.10	622.02	609.1	599.1	Hagarstown/Vandalia Till Contact
G304	2,515,519.74	871,397.69	623.46	626.72	613.5	603.5	Hagarstown Beds
G305	2,515,199.36	871,156.33	622.54	625.55	609.1	604.3	Hagarstown Beds
G306	2,516,120.41	871,140.98	622.84	625.72	609.8	605.2	Hagarstown Beds
G307	2,515,553.26	871,398.55	622.08	624.47	609.1	604.3	Hagarstown Beds
G281	2,514,455.48	874,375.37	623.82	626.36	608.31	603.66	Hagarstown Beds
G401	2,515,614.84	872,510.57	623.03	625.57	608.67	604.24	Hagarstown Beds
G402	2,516,632.46	872,500.49	610.56	613.37	600.6	590.6	Upper Vandalia Till
G403	2,514,616.63	873,561.34	623.81	626.47	610.7	606.03	Hagarstown Beds
G404	2,516,397.82	873,999.91	613.10	615.67	606.68	601.93	Hagarstown Beds
G405	2,515,335.67	873,996.63	620.90	623.63	611.89	607.14	Hagarstown Beds
G406	2,514,702.38	872,521.34	621.86	621.86	608.3	603.49	Hagarstown Beds
G407	2,513,705.87	872,973.39	618.35	621.32	604.57	599.74	Hagarstown Beds
T408	2,515,314.91	873,999.36	621.09	624.08	600.43	595.6	Vandalia Till
T409	2,514,693.89	872,517.79	621.85	625.01	600.06	595.26	Vandalia Till (Sand Seam)
G45D	2,515,322.23	873,998.03	620.94	623.81	589.06	579.42	Smithboro Till
G46D	2,514,697.78	872,519.70	621.91	625.24	580.3	570.65	Smithboro Till
OW-1	2,514,754.56	872,875.48	639.80	641.14	634.74	619.74	Ash
OW-2	2,515,525.87	873,761.43	639.70	641.34	629.84	614.84	Ash
OW-3	2,515,824.43	873,147.40	640.40	641.78	631.28	616.28	Ash
OW-4	2,516,277.90	873,535.97	644.70	damaged	629.7	604.7	Ash
OW-5	2,516,466.21	872,770.83	637.70	638.8	627.7	602.7	Ash
B-2(s)	2,516,615.41	873,650.85		639.44			Fill
B-1(d)	2,516,615.78	873,647.93		638.7			Fill
G101	2,514,215.00	876,575.00	625.27	627.6	609.59	604.95	Hagarstown Beds
G102	2,514,537.00	876,554.00	625.70	630.96	613.68	608.92	Hagarstown Beds
G103	2,514,500.93	876,200.00	630.99	633.8	615.11	610.32	Hagarstown Beds
R104	2,514,503.40	875,857.80	629.03	632.84	614.44	609.71	Hagarstown Beds
G105	2,514,509.03	875,500.00	629.26	632.08	613.15	608.36	Hagarstown Beds
G106	2,514,513.08	875,150.00	628.39	631.15	614.02	609.43	Hagarstown Beds
G107	2,514,358.30	874,994.07	627.79	630.23	613.92	609.29	Hagarstown Beds
G108	2,514,248.46	874,948.69	627.50	630.22	610.68	606	Hagarstown Beds (Silt)
G109	2,514,137.80	874,970.13	627.20	629.76	611.81	607.27	Hagarstown Beds
G110	2,514,057.93	875,015.38	627.02	629.65	611.97	607.43	Hagarstown Beds
G111	2,513,981.89	875,058.47	627.24	629.9	612.63	608.09	Hagarstown Beds
G119	2,513,910.00	875,675.00	628.85	631.55	611.56	607.02	Hagarstown Beds
G120	2,513,905.81	875,845.00	629.30	631.87	614.2	609.68	Hagarstown Beds
G121	2,513,910.00	875,965.00	629.57	632.83	612.78	608.1	Hagarstown Beds
G122	2,513,905.00	876,080.00	629.86	632.69	613.35	608.81	Hagarstown Beds
G123	2,513,905.00	876,190.00	630.13	632.96	609.19	604.67	Hagarstown Beds
G124	2,513,900.48	876,305.00	630.42	633.39	614.44	609.91	Hagarstown (Silt)/Vandalia Till Contact
G125	2,513,900.00	876,410.00	630.68	633.51	613.65	609.12	Hagarstown Beds
G126	2,513,878.29	875,049.31	622.96	625.39	610.07	605.53	Hagarstown Beds (Sandy clay)
T127	2,513,915.00	875,360.00	628.07	630.96	610.54	606	Hagarstown Beds
T128	2,513,915.00	875,510.00	628.44	630.93	611.91	607.4	Hagarstown Beds
TA31	2,513,856.77	876,542.25	623.89	626.55	608.8	604.32	Hagarstown Beds
TA32	2,513,605.19	877,532.57	618.93	621.42	607.62	603.25	Hagarstown Beds
TA33	2,513,248.73	876,605.45	622.51	625.27	610.28	605.62	Hagarstown Beds
TA34	2,513,466.73	875,906.10	624.10	626.52	613.18	608.69	Hagarstown Beds

G151	2,513,805.90	875,023.70	622.82	625.93	607.48	602.98	Hagarstown Beds
G152	2,513,894.50	874,687.50	623.06	626.52	609.47	604.97	Hagarstown Beds
G153	2,513,532.70	874,532.70	623.30	626.35	607.4	602.96	Hagarstown Beds
G154	2,513,243.10	874,978.40	623.52	626.35	609.26	604.76	Hagarstown Beds
G155	2,513,501.80	875,127.70	622.89	625.86	607.8	603.31	Hagarstown Beds
G200	2,515,650.00	877,930.60	624.20	625.94	612.01	607.22	Hagarstown Beds
R201	2,514,842.00	877,925.30	624.02	626.34	611.75	607.36	Hagarstown Beds
T202	2,514,895.00	876,699.40	626.22	628.63	613.95	609.57	Hagarstown Beds
G205	2,515,914.90	875,550.20	622.15	624.45	612.11	607.62	Hagarstown Beds
G206	2,514,669.20	875,103.90	630.54	632.82	613.03	608.62	Hagarstown Beds
G207	2,514,837.90	875,166.40	630.61	633.21	612.37	607.84	Hagarstown Beds
G208	2,514,993.60	875,231.50	630.57	633.16	613.04	608.51	Hagarstown Beds
G209	2,515,149.60	875,298.20	630.57	632.91	612.83	608.29	Hagarstown Beds
G210	2,515,299.00	875,359.70	630.48	632.99	611.09	606.55	Hagarstown Beds
G211	2,515,449.10	875,424.50	630.31	632.64	612.97	608.43	Hagarstown (Sandy Clay)/Vandalia Till Contact
G212	2,515,583.00	875,486.50	630.59	632.89	613.85	609.3	Hagarstown Beds
G213	2,515,723.50	875,544.40	630.34	632.81	613.59	609.05	Hagarstown Beds
G214	2,515,960.80	875,668.00	630.39	632.85	612.64	608.25	Hagarstown Beds
G215	2,515,971.60	875,810.20	630.48	633.06	611.07	606.68	Hagarstown Beds
G216	2,515,968.50	875,976.10	630.28	632.76	610.24	605.86	Hagarstown Beds
G217	2,515,963.00	876,185.60	630.67	633.1	610.18	605.79	Hagarstown Beds
G218	2,515,962.20	876,380.90	630.64	633.11	610.31	605.87	Hagarstown Beds
MW02S	2,513,210.04	876,408.86	624.10	sealed	613.76	608.98	
MW04S	2,514,450.58	877,999.73	622.40	625.79	612.57	608.14	Hagarstown Beds
MW05S	2,513,285.49	878,175.59	622.60	625.8	609.94	605.19	Hagarstown Beds
MW06S	2,513,189.40	879,021.15	623.10	626.14	612.06	607.48	Hagarstown Beds
MW07S	2,514,397.54	879,181.12	624.50	627.54	614.59	610.71	Hagarstown Beds
MW08S	2,514,478.83	879,776.62	624.70	627.9	613.19	608.7	Hagarstown Beds
MW09S	2,515,666.24	879,684.90	624.60	627.46	613.39	608.98	Hagarstown Beds
MW10S	2,515,914.37	878,250.50	621.20	624.22	609.92	605.44	Hagarstown Beds
MW11S	2,515,971.16	876,749.44	622.00	625.08	613.11	608.37	Hagarstown Beds
MW12S	2,515,900.54	875,520.08	622.20	625.21	611.59	607.02	Hagarstown Beds
MW13S	2,513,925.29	874,695.66	622.70	625.89	611.27	606.47	Hagarstown Beds
MW14S	2,514,125.95	875,737.78	624.60	sealed	612.34	607.58	Hagarstown Beds
MW15S	2,515,076.27	875,971.13	623.80	sealed	609.39	604.64	Hagarstown Beds
MW16S	2,515,087.98	877,355.14	626.10	629.37	611.51	606.69	Hagarstown Beds
MW17S	2,515,084.76	878,658.54	627.10	630.47	613.08	603.54	Hagarstown Beds
MW18S	2,513,745.20	878,604.67	625.60	628.66	614.29	609.81	Hagarstown Beds
MW20S	2,515,876.50	874,228.00		622.84			
G270	2,514,996.84	874,801.92	622.92	625.92	609.79	605	Hagarstown Beds
G271	2,515,517.12	874,239.38	622.89	625.57	612.93	608.58	Hagarstown Beds
G272	2,515,744.99	874,234.83	620.72	623.81	611.61	606.74	Hagarstown Beds (Silt)
G273	2,515,975.49	874,235.24	620.17	623.02	611.09	605.61	Hagarstown Beds
G274	2,516,195.60	874,239.25	621.67	624.04	608.77	604	Hagarstown Beds
G275	2,516,375.86	874,298.94	616.14	618.26	607.92	603.52	Hagarstown Beds
G276	2,516,358.83	874,438.60	629.14	632.	606.73	601.92	Hagarstown Beds
G277	2,516,370.51	874,581.80	620.79	623.08	606.5	602.02	Hagarstown Beds
G278	2,516,200.66	874,875.37	628.85	631.19	609.92	605.15	Hagarstown Beds
G279	2,516,245.60	875,028.06	629.19	632.04	606.79	602.4	Hagarstown Beds
G280	2,515,679.48	875,045.11	622.95	625.85	610.16	605.32	Hagarstown Beds

Notes:

Ground surface elevations based on information included on boring logs when the well was installed, and top of PVC elevations based on survey completed in Fall 2015.

Table 2
Proposed Monitoring Well Network and Analyses
Groundwater Monitoring Plan - Ash Pond 2
Coffeen Energy Center - Ash Pond 2

Boring/Well ID	Ground Surface at Time of Install	Measuring Point Elevation (2015)	Top of Screen Elevation	Bottom of Screen Elevation	Screen length	Screen Top	Screen Bottom	Proposed Analyses for IEPA Monitoring	Additional Monitoring Programs Performed at Well	Other Analyses (USEPA CCR Rule or IEPA)
G270	622.92	625.92	609.79	605	5	16.1	20.9	Arsenic (d),boron (d), lead (d), manganese (d), sulfate, and total dissolved solids, field parameters [2]	Ash Pond 2 & GRP - CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G281	623.82	626.36	608.31	603.66	5	18.1	22.7			
G401	623.03	625.57	608.67	604.24	4	16.9	21.3		Ash Pond 2 CCR	
G402	610.56	613.37	600.60	590.6	10	12.8	22.8			
G403	623.81	626.47	610.70	606.03	5	15.8	20.4			
G404	613.10	615.67	606.68	601.93	5	9.0	13.7			
G405	620.90	623.63	611.89	607.14	5	11.7	16.5			
G406	621.86	621.86	608.30	603.49	5	13.6	18.4		None	None
G407	618.35	621.32	604.57	599.74	5	16.8	21.6			
G410[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G411[1]	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
G154	623.52	626.35	609.26	604.76	5	17.1	21.6		SW Pond - IEPA	IEPA Approved Parameters
G279	629.19	632.04	606.79	602.40	4	25.3	29.6		GRP - IEPA and CCR	40 CFR 257 - Appendix III and Appendix IV Parameters, Groundwater Elevation
G280	622.95	625.85	610.16	605.32	5	15.7	20.5			

Notes:

[1] Proposed wells to be installed upon approval of Closure Plan and GMZ application

[2] Field parameters include: pH, oxidation -reduction potential, specific conductance, temperature, and dissolved oxygen
Groundwater quality analyses including methods and sampling details are included in Table 4.

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Table 3
Background Groundwater Quality and Applicable Groundwater Quality Standards
Groundwater Monitoring Plan - Ash Pond 2
Coffeen Energy Center

Parameters (totals)	Sampling Program	IL Class I Std[1] (mg/L)	Background Concentration[2] for IEPA (mg/L)	Applicable Groundwater Standard[3] for IEPA (mg/L)	Maximum[4] (mg/L)	Minimum[4] (mg/L)
Antimony	CCR	0.006	**tbd**	**tbd**	<0.003	<0.003
Arsenic	CCR	0.01	**tbd**	**tbd**	**0.014**	<0.001
Arsenic (d)	IEPA	0.01	0.001	0.01	**0.25**	<0.002
Barium	CCR	2.0	**tbd**	**tbd**	0.24	0.014
Beryllium	CCR	0.004	**tbd**	**tbd**	0.0018	<0.001
Boron	CCR	2.0	**tbd**	**tbd**	**17**	<0.02
Boron (d)	IEPA	2.0	0.12	2.0	**8.1**	<0.01
Calcium	CCR	NS	**tbd**	**tbd**	450	<0.1
Cadmium	CCR	0.005	**tbd**	**tbd**	0.008	<0.001
Chloride	CCR	200	**tbd**	**tbd**	160	1.5
Chromium	CCR	0.1	**tbd**	**tbd**	0.034	<0.004
Cobalt	CCR	1.0	**tbd**	**tbd**	0.28	<0.001
Fluoride	CCR	4	**tbd**	**tbd**	1.06	0.031
Lead	CCR	0.0075	**tbd**	**tbd**	**0.018**	<0.001
Lead (d)	IEPA	0.0075	0.001	0.0075	**0.220**	<0.001
Lithium	CCR	NS	**tbd**	**tbd**	0.057	<0.01
Manganese(d)	IEPA	0.150	0.47	0.47	**1.02**	<0.018
Mercury	CCR	0.002	**tbd**	**tbd**	0.00093	<0.0002
Molybdenum	CCR	NS	**tbd**	**tbd**	0.043	<0.001
Selenium	CCR	0.05	**tbd**	**tbd**	0.027	<0.001
Sulfate	CCR, IEPA	400	370	400	**2,500**	2.3
Thallium	CCR	0.002	**tbd**	**tbd**	0.0013	<0.001
TDS (d)	CCR, IEPA	1,200	780	1,200	**3,900**	320
Field pH	CCR, IEPA	6.5 - 9.0	6.64-7.88	6.5-9.0	8.03	**5.80**
Radium 226/228*	CCR	20/20	**tbd**	**tbd**	4.46	0.185

Notes:
All parameters are totals unless noted. Standards apply to dissolved or total concentrations
(d) Dissolved
tbd = To Be Determined for Illinois EPA monitoring program; CCR Appendix III and IV parameters based on future monitoring , started in November 2015
Bold = Background Concentration exceeds Class I Groundwater Standard
Red = Exceeds Applicable Groundwater Standard
na = not applicable; parameter [dissolved and total] not proposed for monitoring program
NS = No Class II Groundwater Standard
USEPA (t) = background concentration for parameter [total] required under USEPA program (40 CFR Part 257)
[1] IPCB 620 Class I: Potable Resource Groundwater Standard
[2] Background Concentration obtained from Appendix B - Statistical Procedure for Calculation of Background
(Table B-1 Tolerance Limits for Background Monitoring Wells G270, G280, and G281 using the Upper and Lower Limits)
[3] Applicable Groundwater Standard is the higher of the Background Concentration and the Class I Groundwater Standard (or the lower if compared to the pH lower limit)
[4] Groundwater concentrations based on historical results for wells in the proposed sampling program
* Radium 226 and 228 reported separately for IPCB Class I Groundwater Standard, reported combined for USEPA 40 CFR Part 257

NATURAL RESOURCE TECHNOLOGY

R001813

Table 4.
Sampling and Analysis Summary
Groundwater Monitoring Plan - Ash Pond 2
Coffeen Energy Center

Parameter	Analytical Method[5]	Number of Samples	Field Duplicates[1]	Field Blanks[2]	Equipment Blanks[2]	MS/MSD[3]	Total	Container Type	Minimum Volume[4]	Preservation (Cool to 4 °C for all samples)	Sample Hold Time from Collection Date
Metals - Appendix III [(1)]											
Boron (total and dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO_3 to pH<2	6 months
Calcium	6020	7	1	0	0	1	9	plastic	601 mL	HNO_3 to pH<3	6 months
Metals - Appendix IV [(2)] and Additional Metals											
Other Metals [(3)]	6020	7	1	0	0	1	9	plastic	600 mL	HNO3 to pH<2	6 months
Arsenic (dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Lead (dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Manganese (dissolved)	6020	14	2	0	0	1	17	plastic	600 mL	HNO3 to pH<2	6 months
Mercury	7470A or 6020	7	1	0	0	1	9	plastic	400 mL	HNO_3 to pH<2	28 days
Inorganic Parameters - Appendix III [(1)]											
Fluoride	9214	7	1	0	0	1	9	plastic	300 mL	Cool to 4 °C	28 days
Chloride	9251	7	1	0	0	1	9	plastic	100 mL	Cool to 4 °C	28 days
Sulfate	9036	14	2	0	0	1	17	plastic	50 mL	Cool to 4 °C	28 days
Total Dissolved Solids	SM 2540 C	14	2	0	0	1	17	plastic	200 mL	Cool to 4 °C	7 days
Radium - Appendix IV [(2)]											
Radium 226	9315 or EPA 903	7	0	0	0	1	8	plastic	1000 mL	HNO3 to pH<2	6 months
Radium 228	9320 or EPA 904	7	0	0	0	1	8	plastic	1000 mL	HNO_3 to pH<2	6 months
Field Parameters											
pH [(1)]	SM 4500-H+ B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Dissolved Oxygen	SM 4500-O/405.1	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Temperature	SM 2550	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Oxidation/Reduction Potential	SM 258O B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Specific Conductivity	SM 2510 B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Turbidity [(4)]	SM 2130 B	14	NA	NA	NA	NA	14	flow-through cell or hand-held turbidity meter	NA	none	immediately

Notes:

[(1)] USEPA Appendix III Parameters (boron, calcium, chloride, fluoride, pH, sulfate, total dissolved solids (TDS))

[(2)] USEPA Appendix IV Parameters
(antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, selenium, thallium, radium 226 and 228 combined)

[(3)] Other Metals = antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, lead, lithium, molybdenum, selenium, thallium

[(4)] If turbidity exceeds 10 NTUs, a duplicate sample filtered through a .45 micron filter may be collected for metals analysis in addition to the unfiltered sample. Both samples would be submitted for analysis.

NA = not applicable

HNO_3 = nitric acid

°C = degrees Celsius

mL = milliliter

1. Field duplicates will be collected at a frequency of one per group of 10 or fewer investigative water sample. Field duplicates will not be collected for radium analysis.
2. Field blanks will be collected at the discretion of the project manager; Equipment blanks will be collected at a rate of 1 per sampling event if non-dedicated equipment is used.
3. Matrix Spike/Matrix Spike Duplicate (MS/MSD) samples will be collected at a frequency of one per group of 20 or fewer investigative water samples per CCR unit/multi-unit. Additional volume to be determined by laboratory.
4. Sample volume is estimated and will be determined by the laboratory.
5. Analytical method numbers are from SW-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as apropriate.

Natural Resource Technology

Table 5
Summary of Detection Limits for Proposed Monitoring Program Class I Groundwater Standards
Groundwater Monitoring Plan - Ash Pond 2
Coffeen Energy Center

Constituent	Unit	Analytical Methods [1]	USEPA MCL [2]	IL Class I Std[1] (ug/L)	RL [4]	MDL [4]
Metals						
Antimony	µg/L	6020	6	6	1	0.25
Arsenic	µg/L	6020	10	10	1	0.25
Arsenic(d)	µg/L	6020	10	10	1	0.13
Barium	µg/L	6020	2000	2000	1	0.4
Beryllium	µg/L	6020	4	4	1	0.5
Boron	µg/L	6020	NS	2000	25	10
Boron(d)	µg/L	6020	NS	2000	2.3	10
Cadmium	µg/L	6020	5	5	1	0.25
Calcium	µg/L	6020	NS	NS	125	100
Chromium	µg/L	6020	100	100	1	0.3
Cobalt	µg/L	6020	NS	1,000	1	0.25
Lead	µg/L	6020	15	7.5	1	0.25
Lead(d)	µg/L	6020	15	7.5	1	0.025
Lithium	µg/L	6020	NS	NS	1	0.5
Manganese (d)	µg/L	6020	50 [3]	150	1	0.055
Mercury	µg/L	6020 or 7470A	2	2	0.2	0.051
Molybdenum	µg/L	6020	NS	NS	1	0.25
Selenium	µg/L	6020	50	50	1	0.9
Thallium	µg/L	6020	2	2	1	0.25
Inorganics						
Fluoride	mg/L	9214	4	4	0.1	0.05
Chloride	mg/L	9251	250 [3]	200	5	1
Sulfate	mg/L	9036	250 [3]	400	10	5
Total Dissolved Solids	mg/L	SM 2540 C	500 [3]	1200	20	10
Other						
Combined Radium 226/228	pCi/L	9315/9320 or EPA 903/904	5	20/20	-- [5]	-- [6]
Field						
pH	SU	SM 4500-H+ B	NS	6.5-9.0	NA	NA
Oxidation/Reduction Potential	mV	SM 2580 B	NS	NS	NA	NA
Dissolved Oxygen	mg/L	SM 4500-O/405.1	NS	NS	NA	NA
Temperature	°C	SM 2550	NS	NS	NA	NA
Specific Conductivity	µS/cm	SM 2510 B	NS	NS	NA	NA
Turbidity	NTU	SM 2130 B	NS	NS	NA	NA

Notes:
NS = No standard
RL = Reporting limit as established by the laboratory
MDL = Method detection limit as established by the laboratory
SM = Standard Methods for the Examination of Water and Wastewater
ug/L = micrograms per liter
mg/L = milligrams per liter
pCi/L = picoCuries per liter
µS/cm = microSiemens per centimeter
NTU = nephelometric turbidity unit
(d) = dissolved analysis

1. Analytical method numbers are from SW-846 unless otherwise indicated.
2. USEPA MCL = United States Environmental Protection Agency Maximum Contaminant Level.
3. USEPA SMCL = United States Environmental Protection Agency Secondary Maximum Contaminant Level.
4. Reporting limits and method detection limits will vary depending on the laboratory performing the work.
5. All radium results will be reported (values may be positive or negative) and will include uncertainty and the calculated MDC.
6. Laboratories calculate a minimum detectable concentration (MDC) based on the sample.

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APPENDIX A

MONITORING WELL NETWORK BORING LOGS AND MONITORING WELL CONSTRUCTION REPORTS

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 12/16/2011
Finish: 12/16/2011
WEATHER: Ptly. cloudy (mid-30's)

CONTRACTOR: Testing Service Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA w/SS samplers
FIELD STAFF: **Driller:** B. Williamson
Helper: R. McCuan
Eng/Geo: R. Fiorito

BOREHOLE ID: G154
Well ID: G154
Surface Elev: 623.52 ft. MSL
Completion: 20.00 ft. BGS
Station: 874,978.38N
2,513,243.10E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 13.45 - While drilling
▼ =
▽ = 11.10 - 12/21/2011

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	14/24 58%	ss	3-4 4-5 N=8				0	FILL - Light yellowish brown (10YR6/4), silty CLAY with trace sand and slight trace gravel.		622	
2A	10/24 42%	ss	woh-1 4-5 N=5				2	Brownish yellow (10YR6/6) with 25% gray (10YR6/1) mottles, silty CLAY with trace sand.		620	
3A	14/24 58%	ss	2-4 6-7 N=10				4	Gray (10YR5/1) with 25% yellowish brown (10YR5/4) mottles, silty CLAY with trace sand.		618	
4A	21/24 88%	ss	6-8 10-10 N=18				6	Gray (10YR6/1) with 25% brownish yellow (10YR6/6) mottles, silty CLAY with trace sand and slight trace gravel.		616	
5A	16/24 67%	ss	1-4 6-8 N=10				8			614	
6A	13/24 54%	ss	1-4 6-8 N=10				10 ▽			612	
7A	20/24 83%	ss	4-6 8-12 N=14				12	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) mottles, silty CLAY with trace sand and slight trace gravel.			
7B							▼	Gray (10YR6/1), silty CLAY with trace sand and slight trace gravel.		610	
8A	23/24 96%	ss	4-18 30-37 N=48				14	Gray (10YR6/1), clayey SAND with trace silt.			
8B								Gray (10YR6/1) with 50% yellowish brown (10YR5/6) mottles, silty SAND with slight trace gravel.		608	
8C							16	Dark yellowish brown (10YR4/4), silty CLAY with sand and trace gravel.			
9A	21/24 88%	ss	40-75 86-84 N=161					Brown (10YR4/3), silty CLAY with sand and trace gravel.		606	
10A	20/24 83%	ss	28-28 30-34 N=58				18	Dark gray (10YR4/1), silty CLAY with sand and trace gravel.		604	
							20	**End of Boring = 20.0 ft. BGS**			

NOTE(S): G154 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 2/26/2008
Finish: 2/26/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers

FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G270
Well ID: G270
Surface Elev: 622.9 ft. MSL
Completion: 18.3 ft. BGS
Station: 874,801.92N
2,514,996.84E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 16.00 - While drilling
▼ = 5.62 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	20/24 83%	ss	2-2 2-4 N=4					Dark grayish brown (10YR4/2), moist, firm, clayey SILT		622	
1A				24				Dark grayish brown (10YR4/2), moist, firm, silty CLAY			
							2	Dark grayish brown (10YR4/2) with 5% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand			
2A	19/24 79%	ss	3-4 5-9 N=9	22		2.33 B				620	
2B				20		5.04 Sh	4	Gray (10YR5/1) with 70% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand and gravel			
	20/24 83%	ss	14-5 7-8 N=12							618	
3A				17		2.52 Sh	▼ 6	Dark gray (10YR4/1) with 5% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
4A	24/24 100%	ss	8-6 7-5 N=13	21		1.24 BSh				616	
4B				21		1.20 B	8	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
	22/24 92%	ss	2-3 4-4 N=7							614	
5A				21		1.36 B	10	Gray (10YR5/1) with 60% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel			
6A	24/24 100%	ss	1-2 2-3 N=4	21		0.74 BSh				612	
6B				24		0.78 B	12	Gray (10YR5/1), moist, soft, sandy CLAY			
	17/24 71%	ss	2-2 2-3 N=4					Gray (10YR5/1), moist, soft, sandy CLAY, trace gravel		610	
7A				21							
8A				20			14	Gray (10YR5/1), moist, soft, fine- to coarse-grained SAND, trace gravel			
	19/24 79%	ss	1-3 5-6 N=8					Dark yellowish brown (10YR4/4), moist, soft, sandy CLAY		608	
8B				17		4.46 Sh	▼ 16	Gray (10YR5/1) with 10% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand and gravel			
9A	24/24 100%	ss	6-8 30-35 N=38	20				Yellowish brown (10YR5/4), wet, soft, fine to coarse SAND		606	
9B				8			18	Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel			

End of Boring = 18.27 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G279
Well ID: G279
Surface Elev: 629.19 ft. MSL
Completion: 28.00 ft. BGS
Station: 875,028.06N
2,516,245.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.60 - While drilling
▼ = 24.68 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	24/24 100%	ss	3-3 5-6 N=8	18			0	FILL - Brown (10YR4/3) with 30% yellowish brown (10YR5/6) mottles, moist, firm, silty CLAY with sand and trace gravel.		628	
2A	24/24 100%	ss	5-9 10-11 N=19	14			4			626	
3A	24/24 100%	ss	5-9 9-10 N=18	17			6			624	
4A	24/24 100%	ss	4-5 7-6 N=12	21			8	FILL - dark gray (10YR4/1) with 10% brownish yellow (10YR6/6) mottles, moist, hard, silty CLAY with sand and trace gravel.		622	
5A	24/24 100%	ss	3-3 5-7 N=8	19			10			620	
6A	24/24 100%	ss	3-4 6-9 N=10	17			12			618	
7A	23/24 96%	ss	2-5 5-6 N=10	23			14	Brownish yellow (10YR6/8) with 30% gray (10YR5/1) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		616	
8A	24/24 100%	ss	2-3 7-6 N=10	23			16	Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, moist, firm, silty CLAY with slight trace sand and gravel.		614	
9A	18/24 75%	ss	4-7 8-9 N=15	25			18			612	
10A	24/24 100%	ss	3-6 7-10 N=13	17			20	Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel.		610	

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 9/10/2009
Finish: 9/10/2009
WEATHER: Sunny, warm (80's)

CONTRACTOR: Layne-Western Co
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** G. Mills
Helper: J. Twellman
Eng/Geo: R. Hasenyager

BOREHOLE ID: G279
Well ID: G279
Surface Elev: 629.19 ft. MSL
Completion: 28.00 ft. BGS
Station: 875,028.06N
2,516,245.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 23.60 - While drilling
▼ = 24.68 - 9/21/09
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	23/24 96%	ss	2-4 5-7 N=9	18				Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel. *[Continued from previous page]*			
							22			608	
12A	19/24 79%	ss	4-9 8-9 N=17	13				Yellowish brown (10YR5/8), moist, firm, clayey SILT and very fine-grained SAND with slight trace gravel.			
										606	
12B				12			24				
13A	17/24 71%	ss	1-5 5-7 N=10	18				Light brownish gray (10YR6/2), wet, loose, very fine- to coarse-grained SAND.		604	
14A				16			26				
14B	24/24 100%	ss	10-10 18-18 N=28	14				Brownish yellow (10YR6/6), moist, hard, very silty CLAY with sand and trace gravel.		602	
								Gray (10YR6/1), moist, hard, very silty CLAY with sand and trace gravel.			
							28				

End of Boring = 28.0 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: AEG Coffeen Power Station
Site: CCB Management Facility
Location: Coffeen, Illinois
Project: 05S3004A
DATES: **Start:** 2/26/2008
Finish: 2/26/2008
WEATHER: Overcast, cold

CONTRACTOR: Testing Service Corporation
Rig mfg/model: CME-650 Track Rig
Drilling Method: 3¼" HSA w/SS & CME samplers
FIELD STAFF: **Driller:** B. Williamson
Helper: R. Keedy
Eng/Geo: S. Simpson

BOREHOLE ID: G280
Well ID: G280
Surface Elev: 623.0 ft. MSL
Completion: 18.0 ft. BGS
Station: 875,045.11N
2,515,679.48E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.60 - While drilling
▼ = 4.34 - 3/12/08
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark grayish brown (10YR4/2), moist, firm, clayey SILT		622	
1A	24/24 100%	ss	5-3 4-4 N=7	23							
1B				26		2.33 B	2	Brown (10YR4/3) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY			
2A	24/24 100%	ss	3-4 4-6 N=8	30		1.28 BSh		Dark yellowish brown (10YR4/4), moist, firm, silty CLAY		620	
2B				25			4	Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY			
3A	19/24 79%	ss	3-4 6-6 N=10	14		3.10 Sh				618	
							6	Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, slight trace sand			
4A	22/24 92%	ss	9-11 10-8 N=21	18		1.67 BSh		Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, trace sand, slight trace gravel		616	
							8				
5A	19/24 79%	ss	2-2 4-4 N=6	20		1.47 B		Dark gray (10YR4/1) with 40% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY, sand, trace gravel		614	
5B				21		1.28 B	10				
6A	22/24 92%	ss	2-3 3-3 N=6	20				Yellowish brown (10YR5/8) with 20% light gray (10YR6/1) mottles, moist, soft, sandy CLAY		612	
							12	Yellowish brown (10YR5/8), moist, soft, fine to coarse SAND, trace gravel			
7A	23/24 96%	ss	3-14 23-21 N=37	13				Yellowish brown (10YR5/8), moist, firm, sandy CLAY, trace gravel		610	
							14	Yellowish brown (10YR5/4), moist, firm, clayey SILT, trace sand and gravel			
8A	23/24 96%	ss	12-17 24-26 N=41	9						608	
8B				15			16	Yellowish brown (10YR5/4), wet, soft, fine- to coarse-grained SAND, trace gravel			
9A	24/24 100%	ss	11-27 54-43 N=81	26				Gray (10YR5/1), moist, hard, silty CLAY, trace sand and gravel		606	
9B				7							

End of Boring = 17.98 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/8/2015
Finish: 9/8/2015
WEATHER: Sunny, hi 70's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G281
Well ID: G281
Surface Elev: 623.82 ft. MSL
Completion: 20.29 ft. BGS
Station: 2,514,455.48N
874,375.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 10, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	17/24 71%	SS	15-10 7-6 N=17	14			0	Light gray (10YR7/2), dry, very stiff, SILT with little clay and trace gravel.			
							1	Yellowish brown (10YR5/4) with 5% dark brown (10YR3/3) mottles, dry, very stiff, SILT with few clay and trace gravel.		622	
2A	19/24 79%	SS	2-4 5-5 N=9	25		1.50	2	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with few clay.			
							3			620	
3A	22/24 92%	SS	2-2 3-4 N=5	23		0.40	4	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) mottles, moist, medium, CLAY with some silt and trace fine-grained sand and small gravel.			
							5			618	
4A	24/24 100%	SS	5-5 6-6 N=11	19		1.20	6	Yellowish brown (10YR5/4) with 15% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, CLAY with some silt and trace fine-grained sand and small gravel.			
							7			616	
5A	20/24 83%	SS	2-2 3-4 N=5	21		1.40	8	Yellowish brown (10YR5/4) with 30% dark yellowish brown (10YR4/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with some clay and trace very fine- to fine-grained sand and small gravel.			
							9			614	
6A	22/24 92%	SS	2-2 3-3 N=5	18		0.50	10	Dark yellowish brown (01YR4/6) with 30% yellowish brown (10YR5/4) mottles, moist, soft, SILT with few clay and little fine- to coarse-grained sand and small gravel, trace wood fragments.			
							11			612	
7A	17/24 71%	SS	3-4 5-5 N=9	19		0.30	12	Dark yellowish brown (01YR4/6) with 15% yellowish brown (10YR5/4) mottles, moist, soft, SILT with few clay and very fine- to fine-grained sand and trace small gravel.			
							13			610	
	19/24 79%	SS	3-11 21-28 N=32				▼ 14	Dark yellowish brown (10YR4/4), wet, dense, very fine- to fine-grained SAND with some silt, few clay and trace small gravel.			
							15			608	
	24/24 100%	SS	21-36 39-50 N=75				16	Dark yellowish brown (10YR4/4), wet, dense, very fine- to fine-grained SAND with few silt, little clay and trace small gravel.			
							17			606	
8A	11/24 46%	SS	16-9 30-50 N=39	7		4.50	18	Yellowish brown (10YR5/6) with 5% strong brown (7.5YR5/6) mottles, moist, hard, SILT with few clay and little fine-grained sand and small gravel.			
	0/3 0%	BD					19	Dark grayish brown (10YR4/2) with 5% strong brown (7.5YR5/6) mottles, moist, hard, SILT with few clay and little fine-grained sand and small gravel.			
							20			604	

End of boring = 20.29 feet

NOTE(S): G281 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/14/2015
Finish: 9/14/2015
WEATHER: Sunny, hi 60's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: R. Hasenyager

BOREHOLE ID: G401
Well ID: G401
Surface Elev: 623.03 ft. MSL
Completion: 19.30 ft. BGS
Station: 2,515,614.84N
872,510.57E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

Number	Recov / Total (in) % Recovery	Type	Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
							0	Dark grayish brown (10YR4/2), moist, soft, CLAY with little silt and trace very fine- to fine-grained sand - FILL.	622	
1A	16/24 67%	ss	2-2 3-7 N=5	17			2	Yellowish brown (10YR5/6) moist, medium, CLAY with some silt and trace very fine- to coarse-grained sand - FILL.		
2A	21/24 88%	ss	8-11 8-9 N=19	17		1.80		Dark gray (10YR4/1), moist, stiff, SILT with little clay and trace very fine-grained sand.	620	
2B				25			4	Yellowish brown (10YR5/6), moist, stiff, CLAY with some silt and trace very fine- to fine-grained sand.		
3A	23/24 96%	ss	3-4 7-8 N=11	23		2.50	6	Gray (10YR5/1) with 20% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with some silt and trace very fine- to fine-grained sand.	618	
4A	24/24 100%	ss	8-9 12-14 N=21	21		3.30			616	
4B				19		2.80	8	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, stiff, SILT and very fine-grained SAND with trace clay.		
5A	24/24 100%	ss	2-3 4-5 N=7	21		1.30			614	
6A	24/24 100%	ss	2-4 5-6 N=9	17		2.50	10	Gray (10YR5/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with some silt and trace very fine- to fine-grained sand.	612	
7A	24/24 100%	ss	9-7 8-9 N=15	21		1.40	12		610	
8A	24/24 100%	ss	2-3 2-4 N=5	17		1.30	14	Gray (10YR6/1), moist soft, CLAY with very fine- to fine-grained sand and little silt.	608	
8B				19			16	Yellowish brown (10YR5/6), wet, loose, very fine- to fine-grained SAND with trace silt.		
9A	20/24 83%	ss	5-4 5-10 N=9	21				Yellowish brown (10YR5/6), wet medium, SILT with some very fine-grained sand and little clay.	606	
9B				16				Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND with trace silt.		
10A	12/16 75%	ss	23-41 50/4"	6		4.50	18	Gray (10YR5/1), moist, very hard, SILT with few clay and little very fine- to very coarse sand.	604	
								End of boring = 19.3 feet		

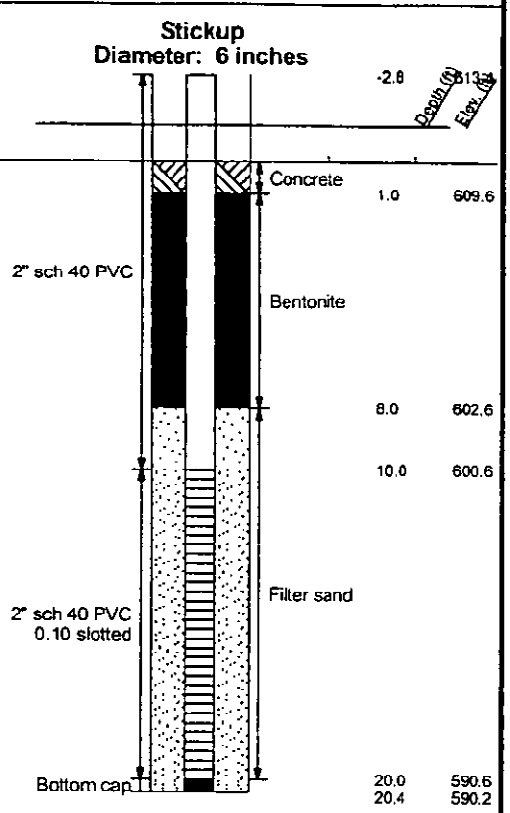
NOTE(S): G401 installed in borehole.

printed 04/29/2015 10:25AM by Sharon.Dowson p. 13/58

Surface Elevation: 610.56 | Completion Date: 8/27/10
Datum msl | Northing: 872502.26 | Easting: 2516632.59

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff, brown, silty CLAY - CL			
			6-3-3	SS1
			1-2-4	SS2
5	Medium stiff, gray, silty CLAY, trace sand - CL			
	▽		1-2-5	SS3
	Hard to stiff, brown to gray, silty CLAY, trace sand seams - CL (TILL)			
10			9-22-28	SS4
15			1-6-12	SS5
20			3-4-9	SS6
	Boring terminated at 20 feet.			
25				
30				
35				

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01- COFFEEN.GPJ GTINC 0638301.GPJ 12/13/10

GROUNDWATER DATA

ENCOUNTERED AT 7 FEET ▽

DRILLING DATA

__ AUGER 4 1/4" HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER SWG LOGGER
CME 55TRK DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KSA	Checked by: DK	App'vd. by: KRB
Date: 9/10/10	Date: 1-4-11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren-Coffeen Ash Pond Evaluation

LOG OF BORING: APW-2

Project No. J017150.01

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 9/11/2015
Finish: 9/11/2015
WEATHER: Raining, hi 60's

CONTRACTOR: Ramsey Geotechnical Engineering, LLC
Rig mfg/model: D-50 Turbo Tracked MST 800ATV
Drilling Method: Hollow Stem Auger (3¼"overdrill / 4¼")
FIELD STAFF: **Driller:** D. Crump
Helper: D. Groves
Eng/Geo: K. Theesfeld

BOREHOLE ID: G403
Well ID: G403
Surface Elev: 623.81 ft. MSL
Completion: 18.15 ft. BGS
Station: 2,514,616.63N
873,561.34E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 15.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	SS	2-2 2-2 N=4	25		0.80	0	Very dark brown (10YR2/2) grading to dark grayish brown (10YR4/2), moist, medium, SILT with some clay, trace roots and grass.		622	
2A	22/24 92%	SS	2-2 3-4 N=5	29			2	Very dark brown (10YR2/2) grading to dark grayish brown (10YR4/2), moist , stiff, SILT with some clay, trace wood.			
2B				26		1.50	4	Yellowish brown (10YR5/4) with 10% very dark brown (10YR2/2) mottles, moist, stiff, CLAY with little silt, trace very fine-grained sand seams (<1/16" thick).		620	
3A	8/24 33%	SS	2-3 4-4 N=7	25		1.50		Yellowish brown (10YR5/4), moist, stiff, CLAY with little silt and trace very fine-grained sand.		618	
4A	21/24 88%	SS	8-7 8-7 N=15	20		1.30	6	Grayish brown (10YR5/2) with 15% yellowish brown (10YR5/6) and 5% very dark grayish brown (10YR3/2) mottles, moist, stiff, CLAY with little silt and trace very fine-grained sand.		616	
5A	20/24 83%	SS	2-2 3-3 N=5	22		0.70	8	Grayish brown (10YR5/2) with 5% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with little silt and trace very fine-grained sand.		614	
6A	24/24 100%	SS	2-2 3-4 N=5	23		1.40	10	Grayish brown (10YR5/2) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, CLAY with little silt, few very fine- to medium-grained sand, and trace gravel.		612	
7A	21/24 88%	SS	5-5 6-5 N=11	20		0.90	12	Grayish brown (10YR5/3) with 45% yellowish brown (10YR5/6) and 5% dark brown (10YR3/3) mottles, moist, stiff, SILT with some clay, few very fine- to coarse-grained sand, and trace gravel.		610	
8A	24/24 100%	SS	3-2 3-6 N=5	17			14	Grayish brown (10YR5/3) with 40% yellowish brown (10YR5/6) mottles, moist, medium, SILT with little clay, few very fine- to coarse-grained sand, and trace gravel.			
							▼	Yellowish brown (10YR5/6) with 30% grayish brown (10YR5/2) mottles, moist, medium, SILT with little clay, few very fine- to coarse-grained sand, and trace gravel.		608	
							16	Yellowish brown (10YR5/6), wet, loose, SAND with some clay and few silt.			
9A	19/24 79%	SS	8-12 21-25 N=33	8		4.50		Yellowish brown (10YR5/6) with 30% grayish brown (10YR5/2) mottles, moist, stiff, SILT with few clay, very fine- to coarse-grained sand, and gravel.		606	
	0/2 0%	BD					18	Yellowish brown (10YR5/6), moist, very stiff, SILT with some clay and few sand and gravel.			
								Very dark grayish brown (10YR3/2), dry, hard, SILT with little clay and few very fine- to coarse-grained sand and gravel.			

End of boring = 18.15 feet

NOTE(S): G403 installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/1/2007
Finish: 5/1/2007
WEATHER: Partly sunny, warm

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" Hollow stem auger with split spoon sampler
FIELD STAFF: **Driller:** A. Rachford
Helper: M. Brown
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB22
Well ID: G404
Surface Elev: 613.10 ft. MSL
Completion: 12.00 ft. BGS
Station: 873,999.77N
2,516,397.85E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 2.07 - 05/10/2007
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1A	19/24 79%	ss		26		0.85 B	0	Black (10YR2/1), moist, firm, clayey SILT (TOPSOIL)		612	
1B				26							
							2	Gray (10YR5/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, firm, clayey SILT with sand and trace gravel		610	
2A	19/24 79%	ss		16		2.47 B					
3A	18/24 75%	ss		19		2.18 B	4			608	
3B				18		2.33 B		Gray (10YR6/1) with 20% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel			
4A	24/24 100%	ss		23		0.58 B	6	Yellowish brown (10YR5/8), moist, soft, sandy CLAY with slight trace gravel			
4B				18				Yellowish brown (10YR5/8), very moist to wet, very soft, clayey, very fine- to medium-grained SAND with trace gravel		606	
							8				
5A	23/24 96%	ss		10				Yellowish brown (10YR5/4) with 30% yellowish brown (10YR5/8) mottles, moist, hard, clayey SILT with sand and trace gravel		604	
5B				19			10	Yellowish brown (10YR5/6), wet, loose, very fine- to medium-grained SAND with coarse-grained sand and slight trace gravel			
6A	19/24 79%	ss		19						602	
6B				11				Dark yellowish brown (10YR4/6) with 40% yellowish brown (10YR5/8) mottles, moist, very hard, very silty CLAY with sand and gravel			
							12	**End of Boring = 12.0 ft. BGS**			

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Energy Center
Location: Coffeen, Illinois
Project: 15E0030
DATES: **Start:** 5/1/2007
Finish: 5/1/2007
WEATHER: Partly sunny, warm

CONTRACTOR: Reynolds Drilling Corp.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" Hollow stem auger with split spoon sampler
FIELD STAFF: **Driller:** A. Rachford
Helper: M. Brown
Eng/Geo: R. Hasenyager

BOREHOLE ID: SB21
Well ID: G405
Surface Elev: 620.90 ft. MSL
Completion: 14.21 ft. BGS
Station: 873,996.79N
2,515,335.70E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen, IL
Township: East Fork
Section 11, **Tier** 7N; **Range** 3W

WATER LEVEL INFORMATION:
▼ = 1.28 - 05/10/2007
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Black (10YR2/1), moist, soft, clayey SILT (TOPSOIL)		620	
1A	19/24 79%	ss		43		0.78 B	2				
1B				26		1.94 B		Gray (10YR6/1) with 30% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY		618	
2A	12/12 100%	ss		27		2.52 BSh	4				
3A				24		3.92 BSh				616	
	24/24 100%	ss						Gray (10YR6/1), moist, firm, silty CLAY slight trace sand			
3B				24		2.33 BSh	6	Gray (10YR5/1), very moist, soft, clayey, very fine- to fine-grained SAND			
4A	24/24 100%	ss		20		2.33 BSh		Gray (10YR6/1) with 25% yellowish brown (10YR5/8) mottles, moist, firm, silty CLAY with sand and trace gravel		614	
							8				
5A	24/24 100%	ss		24		1.55 BSh		Yellowish brown (10YR5/8) with 40% gray (10YR6/1) mottles, moist, firm, silty CLAY with sand and trace gravel		612	
							10				
	24/24 100%	ss						Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND		610	
6A				19				Dark brown (10YR3/3), very moist, soft, clayey, fine- to very coarse-grained SAND with slight trace gravel			
6B				18			12	Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
7A				9		7.42 BSh		Dark yellowish brown (10YR4/4), moist, soft, sandy SILT with trace gravel		608	
	24/24 100%	ss						Yellowish brown (10YR5/4), wet, loose, very fine- to fine-grained SAND			
							14	Gray (10YR5/1), moist, very hard, very silty CLAY with sand and gravel			

End of Boring = 14.2 ft. BGS

NOTE(S):

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Sunny, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G406
Well ID: G406
Surface Elev: 621.86 ft. MSL
Completion: 18.75 ft. BGS
Station: 872,521.34N
2,514,702.38E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description
							0	Dark brown (10YR3/3), moist, stiff, SILT with few clay and trace organics.
							2	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay and trace small gravel.
							4	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay.
								Grayish brown (10YR5/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with few silt and little fine-grained sand.
								Very pale brown (10YR7/4) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with trace silt.
							6	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt and trace fine- to medium-grained sand.
							8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt, little fine- to medium-grained sand and trace small gravel.
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.
							12	Gray (10YR6/1) with 25% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.
							14	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with some fine- to medium-grained sand, little silt, and trace small gravel.
							16	Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, wet, loose, fine-grained SAND with some clay.
								Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, moist, loose, fine-grained SAND with some clay.
							18	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel.

Borehole Detail	Elevation ft. MSL	Remarks
	620	
	618	
	616	
	614	
	612	
	610	
	608	
	606	
	604	

End of Boring = 18.75 ft. BGS

NOTE(S): G406 installed in boring.
Boring was blind drilled adjacent to G406D.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/16/2016
WEATHER: Rain, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G407
Well ID: G407
Surface Elev: 618.35 ft. MSL
Completion: 20.00 ft. BGS
Station: 872,973.39N
2,513,705.87E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 10, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
1A	12/24 50%	ss	4-3 3-3 N=6	14		3.50		Very dark gray (10YR3/1), wet, medium, SILT with some organics. [Fill]	618	
								Gray (10YR6/1), wet, loose, SAND with some gravel and little clay. [Fill]		
2A	20/24 83%	ss	2-2 4-4 N=6	18		1.50	2	Yellowish brown (10YR5/6) with 5% dark yellowish brown (10YR3/6) mottles, moist, very stiff, SILT with some clay and trace very fine- to fine-grained sand.	616	
							4	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with some clay, little fine- to coarse-grained sand, and trace small gravel.	614	
3A	23/24 96%	ss	1-2 3-4 N=5	19		1.75		Brown (10YR5/3) with 25% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, trace fine-grained sand and trace small gravel.		
4A	24/24 100%	ss	1-3 3-5 N=6	19		1.50	6	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.	612	
5A	21/24 88%	ss	1-2 4-4 N=6	19		0.50	8	Yellowish brown (10YR5/6) with 25% brown (10YR5/3) mottles, moist, medium, CLAY with few silt, few fine-grained sand, and trace small gravel.	610	
6A	22/24 92%	ss	1-2 2-1 N=4	17			10	Yellowish brown (10YR5/8) with 5% gray (10YR5/1) mottles, moist, very loose, fine-grained SAND with some clay and trace small gravel.	608	
7A	24/24 100%	ss	7-29 33-17 N=62	8			12	Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, very dense, fine-grained SAND	606	
							14	Brown (10YR5/3), moist, hard, SILT with some clay and little fine- to coarse-grained sand.	604	
8A	24/24 100%	ss	3-7 12-17 N=19	12		4.50		Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6) and 5% black (10YR2/1) mottles, SILT with some clay and little fine- to coarse-grained sand.		
							▼ 16		602	
9A	24/24 100%	ss	4-9 14-20 N=23	13		4.00		Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, moist, hard, SILT with little fine- to coarse-grained sand and trace small gravel.		
							18		600	
10A	24/24 100%	ss	2-8 14-19 N=22	14		4.50		Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, wet, stiff, SILT with little fine- to coarse-grained sand and little small gravel.		
							20	Dark grayish brown (10YR4/2) with 10% dark yellowish brown (10YR3/6) mottles, moist, hard, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.		

End of Boring = 20.0 ft. BGS

NOTE(S): G407 installed in boring.

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/19/2016
Finish: 8/19/2016
WEATHER: Cloudy, (70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: T409
Well ID: T409
Surface Elev: 621.85 ft. MSL
Completion: 26.99 ft. BGS
Station: 872,517.79N
2,514,693.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 11, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Dark brown (10YR3/3), moist, stiff, SILT with few clay and trace organics.			
	0/60 0%	BD					2	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay and trace small gravel.		620	
							4	Brown (10YR5/3) with 10% dark brown (10YR3/3) mottles, SILT with some clay.		618	
								Grayish brown (10YR5/2) with 5% dark yellowish brown (10YR4/6) mottles, moist, stiff, CLAY with few silt and little fine-grained sand.			
							6	Very pale brown (10YR7/4) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with trace silt.		616	
	0/60 0%	BD					8	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt and trace fine- to medium-grained sand.		614	
							10	Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with little silt, little fine- to medium-grained sand and trace small gravel.		612	
								Gray (10YR5/1) with 10% yellowish brown (10YR5/6) and 5% very dark gray (10YR3/1) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.			
	0/60 0%	BD					12	Gray (10YR6/1) with 25% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with few fine- to medium-grained sand, little silt, and trace small gravel.		610	
							14	Gray (10YR6/1) with 10% brownish yellow (10YR6/8) and 5% strong brown (7.5YR4/6) mottles, moist, stiff, CLAY with some fine- to medium-grained sand, little silt, and trace small gravel.		608	
							16	Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, wet, loose, fine-grained SAND with some clay.		606	
	0/60 0%	BD						Gray (10YR6/1) with 5% brownish yellow (10YR6/6) mottles, moist, loose, fine-grained SAND with some clay.			
							18	Gray (10YR5/1), dry, hard, SILT with few clay, few fine- to coarse-grained sand and trace small gravel.		604	
							20			602	

NOTE(S): T409 installed in boring.
Boring was blind drilled to 27.0 feet bgs. Blind drill lithologies from boring G406D.

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G154

Site Name: CCB Management Facility Borehole #: G154

State Plane Coordinate: X 2,513,243.1 Y 874,978.4 (or) Latitude: _____ Longitude: _____

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corp. Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): n/a

Logged By: Ryne M. Fiorito Date Started: 12/16/2011 Date Finished: 12/16/2011

Report Form Completed By: Rhonald W. Hasenyager Date: 12/27/2011

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 24 min

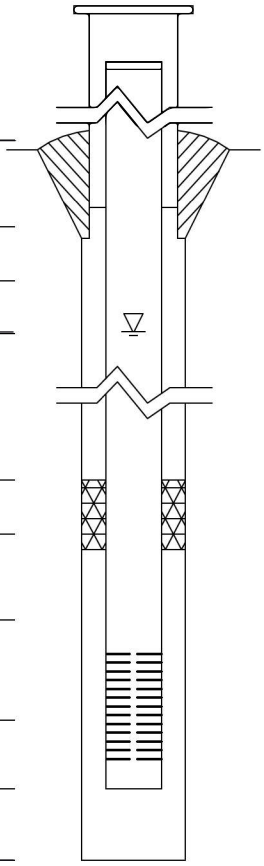
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



	Elevations (MSL)*	Depths (BGS) (0.01 ft.)
Top of Protective Casing	626.55	-3.03
Top of Riser Pipe	626.35	-2.83
Ground Surface	623.52	0.00
Top of Annular Sealant	622.44	1.08
Static Water Level (After Completion) 12/21/2011	612.42	11.10
Top of Seal	613.02	10.50
Top of Sand Pack	610.02	13.50
Top of Screen	609.26	14.26
Bottom of Screen	604.76	18.76
Bottom of Well	604.42	19.10
Bottom of Borehole	603.52	20.00

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.09
Bottom of Screen to End Cap	(feet)	0.34
Screen Length (1st slot to last slot)	(feet)	4.50
Total Length of Casing	(feet)	21.93
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G270

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G270

~~State~~ Plant ~~Plane~~ Coordinate: X 874,801.9 Y 2,514,996.8 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/26/2008 Date Finished: 2/26/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: >24 hr.

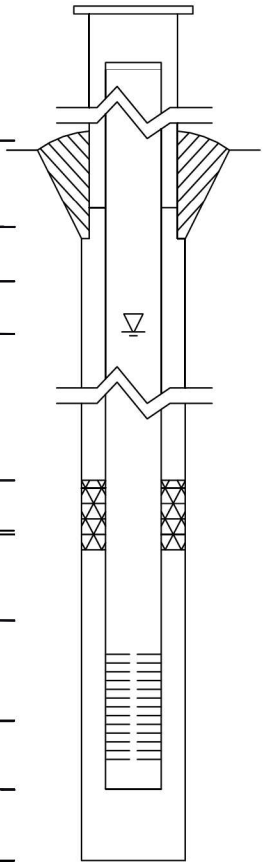
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
626.41	-3.49	Top of Protective Casing
625.97	-3.05	Top of Riser Pipe
622.92	0.00	Ground Surface
619.92	3.00	Top of Annular Sealant
617.30	5.62	Static Water Level (After Completion) 3/12/2008
619.92	3.00	Top of Seal
610.92	12.00	Top of Sand Pack
609.79	13.13	Top of Screen
605.00	17.92	Bottom of Screen
604.65	18.27	Bottom of Well
604.65	18.27	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.18
Bottom of Screen to End Cap	(feet)	0.35
Screen Length (1st slot to last slot)	(feet)	4.79
Total Length of Casing	(feet)	21.32
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G279

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G279

~~State~~ Plane Coordinate: X 2,516,245.6 Y 875,028.1 (or) Latitude: ____° ____' ____" Longitude: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Layne-Western Co Driller: G. Mills

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Rhonald W. Hasenyager Date Started: 9/10/2009 Date Finished: 9/10/2009

Report Form Completed By: Suzanna L. Simpson Date: 10/7/2009

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

~~Setting~~ Time: >24 hr.

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

~~Setting~~ Time: 18 min

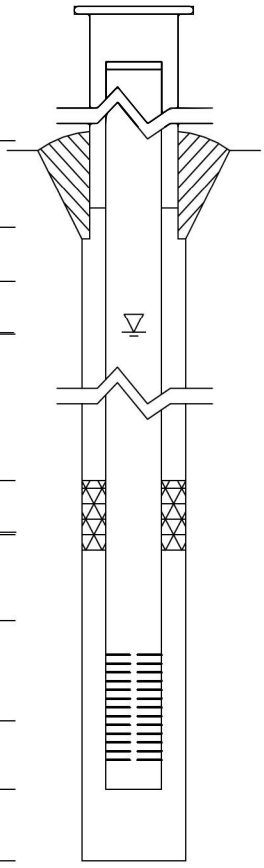
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
632.33	-3.14	Top of Protective Casing
632.04	-2.85	Top of Riser Pipe
629.19	0.00	Ground Surface
626.19	3.00	Top of Annular Sealant
601.66	27.53	Static Water Level (After Completion) 9/21/2009
610.45	18.74	Top of Seal
608.77	20.42	Top of Sand Pack
606.79	22.40	Top of Screen
602.40	26.79	Bottom of Screen
604.51	24.68	Bottom of Well
601.19	28.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	25.25
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	4.39
Total Length of Casing	(feet)	30.17
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

R001833

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G280

Site Name: AEG Coffeen Power Station CCB Management Facility Borehole #: G280

~~State~~ Plant ~~Plane~~ Coordinate: X 875,045.1 Y 2,515,679.5 (or) Latitude: ____° ____' ____" ~~Longitude~~: ____° ____' ____"

Surveyed By: Jeffrey D. Emrick IL Registration #: 035-003507

Drilling Contractor: Testing Service Corporation Driller: B. Williamson

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): _____

Logged By: Suzanna L Simpson Date Started: 2/26/2008 Date Finished: 2/26/2008

Report Form Completed By: Suzanna L Simpson Date: 2/29/2008

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: Gravity

Setting Time: >24 hr.

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: >24 hr.

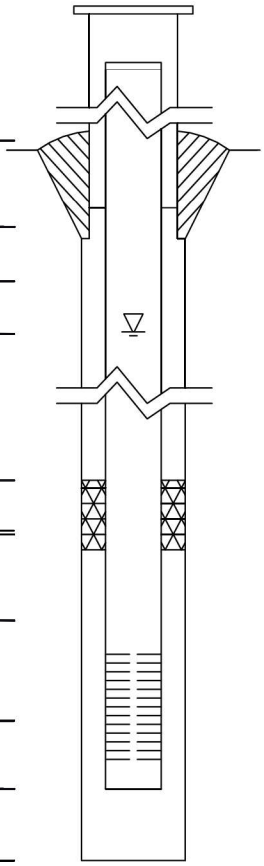
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: n/a



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
625.79	-2.84	Top of Protective Casing
625.30	-2.35	Top of Riser Pipe
622.95	0.00	Ground Surface
620.85	2.10	Top of Annular Sealant
618.61	4.34	Static Water Level (After Completion) 3/12/2008
620.85	2.10	Top of Seal
611.75	11.20	Top of Sand Pack
610.16	12.79	Top of Screen
605.32	17.63	Bottom of Screen
604.97	17.98	Bottom of Well
604.97	17.98	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.14
Bottom of Screen to End Cap	(feet)	0.35
Screen Length (1st slot to last slot)	(feet)	4.84
Total Length of Casing	(feet)	20.33
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

R001834

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G281

Site Name: Coffeen Power Station Borehole #: G281

State Plane Coordinate: X 874,375.4 Y 2,514,455.5 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/8/2015 Date Finished: 9/8/2015

Report Form Completed By: Suzanna L. Keim Date: 10/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 25 minutes

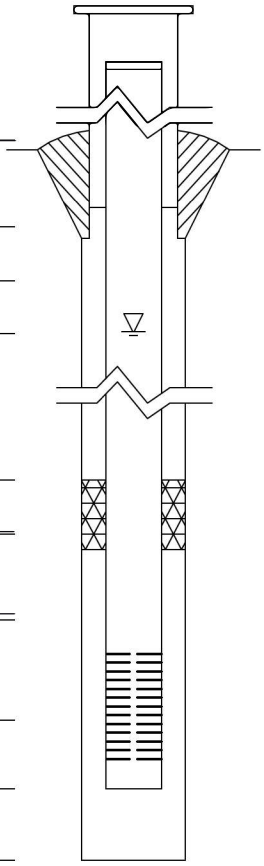
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
626.64	-2.82	Top of Protective Casing
626.36	-2.54	Top of Riser Pipe
623.82	0.00	Ground Surface
622.82	1.00	Top of Annular Sealant
_____	_____	Static Water Level (After Completion)
612.59	11.23	Top of Seal
610.37	13.45	Top of Sand Pack
608.31	15.51	Top of Screen
603.66	20.16	Bottom of Screen
603.53	20.29	Bottom of Well
603.53	20.29	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.80
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.65
Total Length of Casing	(feet)	22.83
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

R001835

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G401

Site Name: Coffeen Power Station Borehole #: G401

State Plane Coordinate: X 872,510.6 Y 2,515,614.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 9/14/2015 Date Finished: 9/14/2015

Report Form Completed By: Suzanna L. Keim Date: 10/7/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >24 hours

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 25 minutes

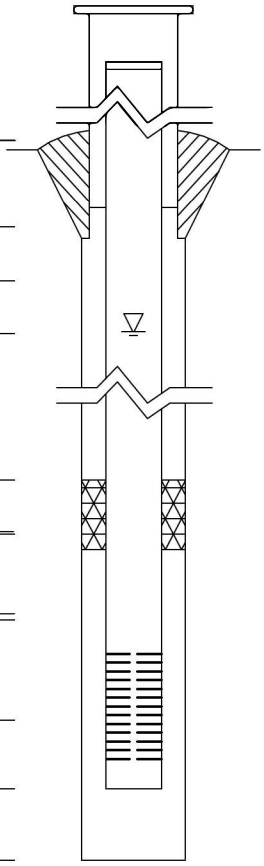
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
625.84	-2.81	Top of Protective Casing
625.57	-2.54	Top of Riser Pipe
623.03	0.00	Ground Surface
621.33	1.70	Top of Annular Sealant
_____	_____	Static Water Level (After Completion)
n/a	n/a	Top of Seal
610.12	12.91	Top of Sand Pack
608.67	14.36	Top of Screen
604.24	18.79	Bottom of Screen
603.74	19.29	Bottom of Well
603.73	19.30	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.70
Bottom of Screen to End Cap	(feet)	0.50
Screen Length (1st slot to last slot)	(feet)	4.63
Total Length of Casing	(feet)	21.83
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

R001836

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G403

Site Name: Coffeen Power Station Borehole #: G403

State Plane Coordinate: X 873,561.3 Y 2,514,616.6 (or) Latitude: _____ Longitude: _____

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Ramsey Driller: D. Crump

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 9/11/2015 Date Finished: 9/11/2015

Report Form Completed By: Suzanna L. Keim Date: 10/7/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Gravity

Setting Time: >24 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: n/a

Setting Time: n/a

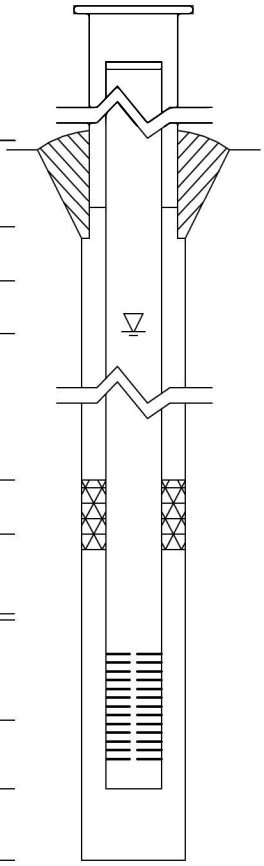
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



	Elevations (MSL)*	Depths (BGS) (0.01 ft.)
Top of Protective Casing	626.72	-2.91
Top of Riser Pipe	626.47	-2.66
Ground Surface	623.81	0.00
Top of Annular Sealant	621.81	2.00
Static Water Level (After Completion)		
Top of Seal	n/a	n/a
Top of Sand Pack	612.64	11.17
Top of Screen	610.70	13.11
Bottom of Screen	606.03	17.78
Bottom of Well	605.66	18.15
Bottom of Borehole	605.66	18.15

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	15.77
Bottom of Screen to End Cap	(feet)	0.37
Screen Length (1st slot to last slot)	(feet)	4.67
Total Length of Casing	(feet)	20.81
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G404

Site Name: Coffeen Energy Center Borehole #: SB22

State Plane Coordinate: X 2,516,397.9 Y 873,999.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: A. Rachford

Consulting Firm: Hanson Professional Services Inc. Geologist: , LPG #

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 5/1/2007 Date Finished: 5/1/2007

Report Form Completed By: Rhonald W. Hasenyager Date: 5/2/2007

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry
(choose one)

Installation Method: _____

Setting Time: _____

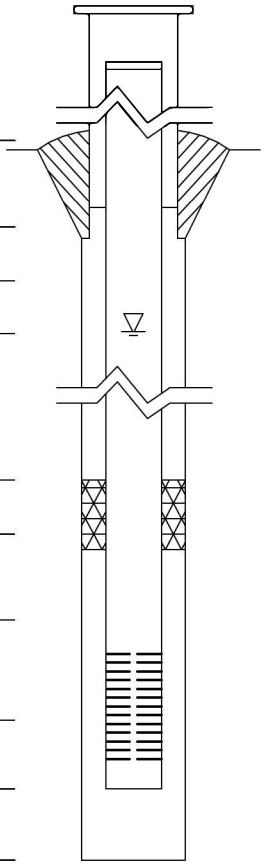
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: gravity

Type of Backfill Material: Formation sand
(if applicable)

Installation Method: slough



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
616.02	-2.92	Top of Protective Casing
615.77	-2.67	Top of Riser Pipe
613.10	0.00	Ground Surface
613.10	0.00	Top of Annular Sealant
611.03	2.07	Static Water Level (After Completion) 5/10/2007
n/a	n/a	Top of Seal
608.05	5.05	Top of Sand Pack
606.68	6.42	Top of Screen
601.93	11.17	Bottom of Screen
601.48	11.62	Bottom of Well
601.10	12.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	9.09
Bottom of Screen to End Cap	(feet)	0.45
Screen Length (1st slot to last slot)	(feet)	4.75
Total Length of Casing	(feet)	14.29
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G405

Site Name: Coffeen Energy Center Borehole #: SB21

State Plane Coordinate: X 2,515,335.7 Y 873,996.8 (or) Latitude: _____ Longitude: _____

Surveyed By: Darren E. Forgy IL Registration #: 035-003637

Drilling Contractor: Reynolds Drilling Corp. Driller: A. Rachford

Consulting Firm: Hanson Professional Services Inc. Geologist: _____, LPG #_____

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Rhonald W. Hasenyager Date Started: 5/1/2007 Date Finished: 5/1/2007

Report Form Completed By: Rhonald W. Hasenyager Date: 5/2/2007

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite chips

Installation Method: gravity

Setting Time: >12 hours

Type of Bentonite Seal -- Granular Pellet Slurry (choose one)

Installation Method: _____

Setting Time: _____

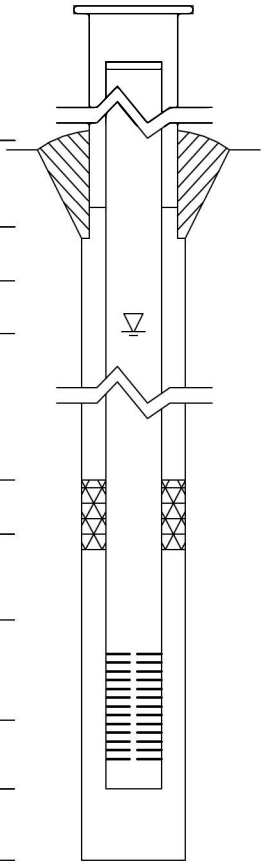
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: gravity

Type of Backfill Material: _____ (if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
624.04	-3.14	Top of Protective Casing
623.78	-2.88	Top of Riser Pipe
620.90	0.00	Ground Surface
620.90	0.00	Top of Annular Sealant
619.67	1.23	Static Water Level (After Completion) 5/10/2007
n/a	n/a	Top of Seal
613.19	7.71	Top of Sand Pack
611.89	9.01	Top of Screen
607.14	13.76	Bottom of Screen
606.69	14.21	Bottom of Well
606.69	14.21	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	11.89
Bottom of Screen to End Cap	(feet)	0.45
Screen Length (1st slot to last slot)	(feet)	4.75
Total Length of Casing	(feet)	17.09
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G406

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G406

State Plane Coordinate: X 2,514,702.4 Y 872,521.3 (or) Latitude: 39° 3' 37.114" Longitude: -89° 23' 54.628"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/19/2016 Date Finished: 8/19/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 30 minutes

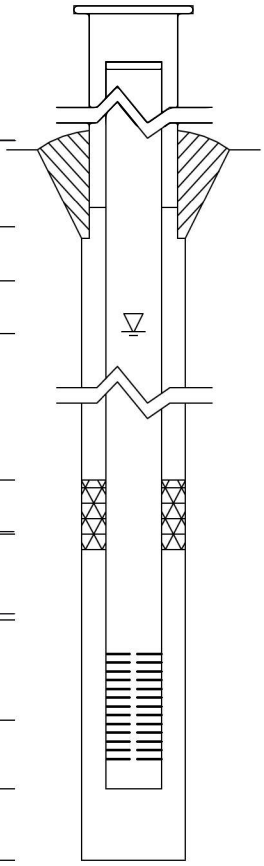
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



	Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
	625.70	-3.84	Top of Protective Casing
	625.36	-3.50	Top of Riser Pipe
	621.86	0.00	Ground Surface
	619.86	2.00	Top of Annular Sealant
			Static Water Level (After Completion)
	610.74	11.12	Top of Seal
	609.65	12.21	Top of Sand Pack
	608.30	13.56	Top of Screen
	603.49	18.37	Bottom of Screen
	603.11	18.75	Bottom of Well
	603.11	18.75	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	17.06
Bottom of Screen to End Cap	(feet)	0.38
Screen Length (1st slot to last slot)	(feet)	4.81
Total Length of Casing	(feet)	22.25
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

R001840

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G407

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G407

State Plane Coordinate: X 2,513,705.9 Y 872,973.4 (or) Latitude: 39° 3' 41.665" Longitude: -89° 24' 7.213"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/16/2016 Date Finished: 8/16/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 minutes

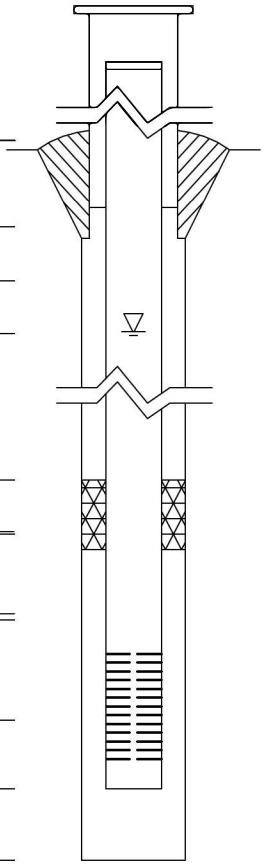
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS)	(0.01 ft.)
621.70	-3.35	Top of Protective Casing
621.32	-2.97	Top of Riser Pipe
618.35	0.00	Ground Surface
616.35	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
607.50	10.85	Top of Seal
605.50	12.85	Top of Sand Pack
604.57	13.78	Top of Screen
599.74	18.61	Bottom of Screen
599.31	19.04	Bottom of Well
598.35	20.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: [Steel]
Riser Pipe Above W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	[PVC]	OTHER:
Screen	SS304	SS316	PTFE	[PVC]	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.75
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.83
Total Length of Casing	(feet)	22.01
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

APPENDIX B

STATISTICAL PROCEDURE FOR BACKGROUND

APPENDIX B
STATISTICAL PROCEDURE FOR CALCULATION OF BACKGROUND
Ash Pond 2
Groundwater Monitoring Plan
Coffeen Energy Center, Montgomery County, IL

Introduction

The purpose of the statistical calculations documented in this appendix is to determine the maximum background concentrations likely to occur upgradient of Ash Pond 2 within the Hagarstown Unit. High predicted background concentrations relative to the Illinois Class I groundwater quality standards may suggest that downgradient concentrations for those parameters in the Hagarstown are due to a background source.

The statistical analysis procedures used here are consistent with procedures described in the document: 2009 Unified Guidance. "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities—Unified Guidance," March 2009, EPA 530/R-09-2007 (USEPA, 2009).

Compliance Data Operations - Limit Calculations

The range of potential background concentrations was statistically determined using parametric and non-parametric tolerance intervals. Tolerance intervals were chosen rather than prediction intervals because a tolerance interval makes no assumption about the future number of samples, while a prediction interval assumes a finite, and known, future number of samples.

The flow diagram (Figure B-1) outlines the logic flow for calculation of limits. Background values were calculated using parametric tolerance intervals for normally distributed data, and non-parametric tolerance intervals for data with no underlying distribution or with non-detect frequencies greater than 50 percent. Parametric tolerance intervals were calculated at a 95 percent coverage rate and a Type I individual comparison error level of 0.01 (i.e., false positive rate). Parameters with 100 percent non-detects were handled with the upper tolerance limit being set to the last Reporting Limit (RL).

Statistical Data Evaluation and Results

The input dataset (attached to this summary) for background calculations were evaluated for the monitoring data from monitoring wells G270, G280, and G281 collected from all historical results, for a subset of the inorganic parameters listed in 35 IAC 620.410(a), specifically arsenic (total and dissolved), boron (total and dissolved), lead (total and dissolved), manganese (dissolved), sulfate, total dissolved solids, and pH (both upper and lower limits). Background concentrations for additional parameters will be calculated following collection of 8 rounds of data. All water quality data were stored, prepared, and statistically analyzed using MANAGES^{TM} Version 3.4.49 software (EPRI, March 2014).

A statistical summary of the background water quality data from G270, G280 and G281 including the mean, median, minimum, maximum, standard deviation, Sen Slope trend, normality determination, and percent non-detects for the background dataset. The statistical analysis procedure inputs and results are also provided in this Appendix.

Calculated background values for the tested inorganic constituents and pH are listed in the following Table B-1 along with the percent non-detects, normal or lognormal distribution, test method, and confidence level.

Figure B-1. Statistical Analysis Flowchart

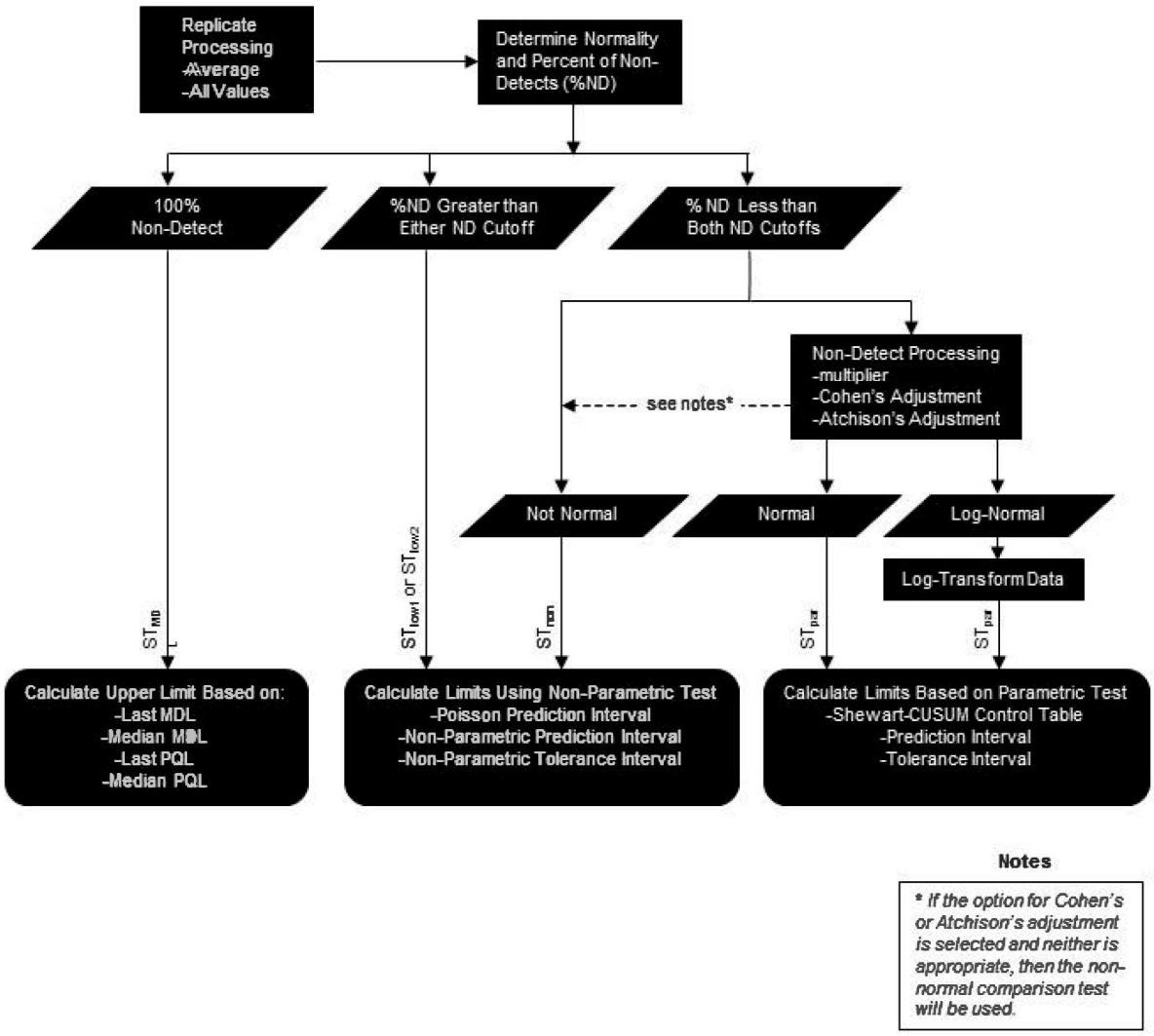


Table B-1. Tolerance Limits for Background Monitoring Wells G270, G280, and G281

Parameter	Count of Background Results	Percent of Non Detects	Normal/ Lognormal	Test	Confidence Level	Upper Limit	Lower Limit
As (dissolved)	69	97.10	No/No	STlow2	97.10	0.001	
Boron (dissolved)	69	60.87	No/No	STlow1	97.10	0.12	
Lead (dissolved)	69	100.0	No/No	STmdl	N/A	0.001	
Manganese (diss)	69	23.19	No/No	STnon	97.10	0.48	
pH	80	0.00	Yes/Yes	STpar	99.00	7.88	6.64
Sulfate (total)	78	0.00	No/No	STnon	98.17	370	
TDS	77	0.00	No/No	STnon	98.70	820	

* Key to Tests

STmdl = Comparison method if all background results are non-detect = Last MDL
STpar = Parametric Tolerance Interval on background
STlow1 = Non-Parametric Tolerance Interval on background (ND Frequency > 50%)
STnon = Non-Parametric Tolerance Interval on background

R001845

Coffeen
Ash Pond 2 - Background Summary

User Supplied Information

Date Range: 03/11/2008 to 11/22/2016 **Option for LT Pts: x 0.5**

Pooled Locations: G270,G280,G281

Parameter	Units	Count	Mean	Median	Maximum	Minimum	Std Dev	Sen Slope Units/yr	Normal / Log Normal	% of Non-Detects
As, diss	mg/L	69	0.001	0.001	0.005	0.001	0.001	0.000	No / No	97.10
B, diss	mg/L	69	0.025	0.010	0.250	0.005	0.038	-0.004	No / No	60.87
Mn, diss	mg/L	69	0.069	0.023	0.480	0.001	0.104	-0.027	No / No	23.19
Pb, diss	mg/L	69	0.001	0.001	0.003	0.000	0.000	0.000	No / No	100.00
pH (field)	STD	83	7.229	7.220	7.870	6.500	0.268	0.029	Yes / Yes	0.00
SO4, tot	mg/L	81	79.116	74.000	370.000	2.300	70.663	12.951	No / No	0.00
TDS	mg/L	80	468.750	445.000	820.000	340.000	101.612	5.988	No / No	0.00

Shapiro-Wilk Normality test performed at 0.05 significance level.

Coffeen

Ash Pond 2- Statistical Analysis

R001846

Background Date Range: 01/01/2008 to 11/22/2016
Background Locations: G270,G280,G281

Compliance Date Range: 01/01/2014 to 11/22/2016
Compliance Locations: G151,G152,G153,G154,G271,G272,G273,G274,G275,G279,G401,G402,G403,G404,G405,G406,G407

Comparison Method if all Background Results are Non-Detect:	STmdl = Last MDL
Statistical Test for Parametric Background Data Distributions:	STpar = Parametric Tolerance Interval on Background
Statistical Test for Cases with High Percentage of Non-Detect Background Data:	STlow1 = Non-Parametric Tolerance Interval on background (ND Frequency > 50%)
Statistical Test for Cases with High Percentage of Non-Detect Background Data:	STlow2 = Non-Parametric Tolerance Interval on background (ND Frequency > 90%)
Statistical Test for Non-Parametric Background Data Distributions:	STnon = Non-Parametric Tolerance Interval on background
Background Comparison:	Interwell
Number of Verification Samples:	1
Default Type 1 Individual Comparison Error Level (False Positive Rate) for tests other than Prediction Interval	0.01
Trend Analysis for Exceedances:	Mann-Kendall Trend Analysis
Trend Analysis Date Range:	Compliance Date Range
Non-Detect Processing (Parametric Tests):	<=50% using MDL * 0.5 >50% using Aitchison's/Cohen's Decision
Non-Detect Processing (All Other):	<=50% using MDL * 0.5 >50% using MDL * 0.5
Tolerance Interval Coverage:	95%

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend

R001847

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G151	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/12/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/08/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/06/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/11/2016	69	97.10	No/No		97.10	0.001		<0.002	No	
G151	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.014	No	
		05/12/2014	69	60.87	No/No		97.10	0.120		0.024	No	
		08/11/2014	69	60.87	No/No		97.10	0.120		<0.010	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		<0.010	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		<0.010	No	
		04/08/2015	69	60.87	No/No		97.10	0.120		<0.020	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		0.018	No	
		10/06/2015	69	60.87	No/No		97.10	0.120		0.036	No	
		02/09/2016	69	60.87	No/No		97.10	0.120		<0.010	No	
		05/11/2016	69	60.87	No/No		97.10	0.120		<0.020	No	
G151	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.072	No	
		05/12/2014	69	23.19	No/No		97.10	0.480		0.069	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		0.140	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.031	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.066	No	
		04/08/2015	69	23.19	No/No		97.10	0.480		0.190	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.093	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G151	Mn, diss, mg/L	10/06/2015	69	23.19	No/No	STnon	97.10	0.480		0.560	Yes	None
		02/09/2016	69	23.19	No/No		97.10	0.480		0.180	No	
		05/11/2016	69	23.19	No/No		97.10	0.480		0.011	No	
G151	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/12/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/08/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/06/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/11/2016	69	100.00	No/No		N/A	0.001		<0.002	No	
G151	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.38	No	
		05/12/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.80	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.30	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.54	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.44	No	
		04/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.12	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.84	No	
		10/06/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.90	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.73	No	
		05/11/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.99	No	
G151	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		560	No	
		10/14/2014	77	0.00	No/No		98.07	820		570	No	
		01/21/2015	77	0.00	No/No		98.07	820		500	No	
		04/08/2015	77	0.00	No/No		98.07	820		600	No	

R001850

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G151	TDS, mg/L	07/23/2015	77	0.00	No/No	STnon	98.07	820		550	No	
		10/06/2015	77	0.00	No/No		98.07	820		600	No	
		02/09/2016	77	0.00	No/No		98.07	820		560	No	
		05/11/2016	77	0.00	No/No		98.07	820		500	No	

R001851

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G152	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/12/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/08/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		0.008	Yes	None
		10/06/2015	69	97.10	No/No		97.10	0.001		0.005	Yes	None
		02/09/2016	69	97.10	No/No		97.10	0.001		0.003	Yes	None
		05/11/2016	69	97.10	No/No		97.10	0.001		<0.002	No	
G152	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.038	No	
		05/12/2014	69	60.87	No/No		97.10	0.120		0.044	No	
		08/11/2014	69	60.87	No/No		97.10	0.120		0.044	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		0.034	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		0.030	No	
		04/08/2015	69	60.87	No/No		97.10	0.120		0.025	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		0.079	No	
		10/06/2015	69	60.87	No/No		97.10	0.120		0.110	No	
		02/09/2016	69	60.87	No/No		97.10	0.120		0.082	No	
		05/11/2016	69	60.87	No/No		97.10	0.120		0.066	No	
G152	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.120	No	
		05/12/2014	69	23.19	No/No		97.10	0.480		0.050	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		0.310	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.150	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.150	No	
		04/08/2015	69	23.19	No/No		97.10	0.480		0.070	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.890	Yes	None

R001852

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G152	Mn, diss, mg/L	10/06/2015	69	23.19	No/No	STnon	97.10	0.480		0.530	Yes	None
		02/09/2016	69	23.19	No/No		97.10	0.480		0.470	No	
		05/11/2016	69	23.19	No/No		97.10	0.480		0.310	No	
G152	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/12/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/08/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/06/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/11/2016	69	100.00	No/No		N/A	0.001		<0.002	No	
G152	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.12	No	
		05/12/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.54	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.25	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.33	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.42	No	
		04/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.94	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.05	No	
		10/06/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.07	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.46	No	
		05/11/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.89	No	
		11/19/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.94	No	
G152	SO4, tot, mg/L	11/19/2016	78	0.00	No/No	STnon	98.17	370.0		130.0	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G152	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		820	No	
		10/14/2014	77	0.00	No/No		98.07	820		620	No	
		01/21/2015	77	0.00	No/No		98.07	820		620	No	
		04/08/2015	77	0.00	No/No		98.07	820		680	No	
		07/23/2015	77	0.00	No/No		98.07	820		730	No	
		10/06/2015	77	0.00	No/No		98.07	820		1,100	Yes	None
		02/09/2016	77	0.00	No/No		98.07	820		920	Yes	None
		05/11/2016	77	0.00	No/No		98.07	820		800	No	
		11/19/2016	77	0.00	No/No		98.07	820		680	No	

R001854

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G153	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/12/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		0.002	Yes	None
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/08/2015	69	97.10	No/No		97.10	0.001		0.003	Yes	None
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/06/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/11/2016	69	97.10	No/No		97.10	0.001		0.004	Yes	None
G153	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.042	No	
		05/12/2014	69	60.87	No/No		97.10	0.120		0.021	No	
		08/11/2014	69	60.87	No/No		97.10	0.120		0.026	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		0.028	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		0.020	No	
		04/08/2015	69	60.87	No/No		97.10	0.120		0.020	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		0.015	No	
		10/06/2015	69	60.87	No/No		97.10	0.120		0.030	No	
		02/09/2016	69	60.87	No/No		97.10	0.120		0.016	No	
		05/11/2016	69	60.87	No/No		97.10	0.120		0.026	No	
G153	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.160	No	
		05/12/2014	69	23.19	No/No		97.10	0.480		0.050	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		0.240	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.510	Yes	None
		01/21/2015	69	23.19	No/No		97.10	0.480		0.200	No	
		04/08/2015	69	23.19	No/No		97.10	0.480		0.024	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.160	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G153	Mn, diss, mg/L	10/06/2015	69	23.19	No/No	STnon	97.10	0.480		0.190	No	
		02/09/2016	69	23.19	No/No		97.10	0.480		0.046	No	
		05/11/2016	69	23.19	No/No		97.10	0.480		0.037	No	
G153	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/12/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/08/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/06/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/11/2016	69	100.00	No/No		N/A	0.001		<0.002	No	
G153	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	6.91	No	
		05/12/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	6.98	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	6.95	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	6.97	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.85	No	
		04/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.52	Yes	None
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.16	No	
		10/06/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.25	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.07	No	
		05/11/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.97	No	
		11/19/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.20	No	
G153	SO4, tot, mg/L	11/19/2016	78	0.00	No/No	STnon	98.17	370.0		2,500.0	Yes	Insufficient Data: Cannot Trend.

R001856

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G153	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		3,500	Yes	Upward
		10/14/2014	77	0.00	No/No		98.07	820		3,400	Yes	Upward
		01/21/2015	77	0.00	No/No		98.07	820		3,600	Yes	Upward
		04/08/2015	77	0.00	No/No		98.07	820		3,700	Yes	Upward
		07/23/2015	77	0.00	No/No		98.07	820		3,900	Yes	Upward
		10/06/2015	77	0.00	No/No		98.07	820		3,700	Yes	Upward
		02/09/2016	77	0.00	No/No		98.07	820		3,800	Yes	Upward
		05/11/2016	77	0.00	No/No		98.07	820		3,800	Yes	Upward
		11/19/2016	77	0.00	No/No		98.07	820		4,000	Yes	Upward

R001857

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G154	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/12/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/08/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/06/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/11/2016	69	97.10	No/No		97.10	0.001		<0.002	No	
G154	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.043	No	
		05/12/2014	69	60.87	No/No		97.10	0.120		0.044	No	
		08/11/2014	69	60.87	No/No		97.10	0.120		0.035	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		0.035	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		0.037	No	
		04/08/2015	69	60.87	No/No		97.10	0.120		0.023	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		0.024	No	
		10/06/2015	69	60.87	No/No		97.10	0.120		0.044	No	
		02/09/2016	69	60.87	No/No		97.10	0.120		0.041	No	
		05/11/2016	69	60.87	No/No		97.10	0.120		0.037	No	
G154	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.018	No	
		05/12/2014	69	23.19	No/No		97.10	0.480		0.014	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		0.081	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.008	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.009	No	
		04/08/2015	69	23.19	No/No		97.10	0.480		0.003	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.140	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G154	Mn, diss, mg/L	10/06/2015	69	23.19	No/No	STnon	97.10	0.480		0.010	No	
		02/09/2016	69	23.19	No/No		97.10	0.480		0.041	No	
		05/11/2016	69	23.19	No/No		97.10	0.480		0.009	No	
G154	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/12/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/08/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/06/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/11/2016	69	100.00	No/No		N/A	0.001		<0.002	No	
G154	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.45	No	
		05/12/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.91	Yes	None
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.65	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.64	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.55	No	
		04/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.25	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.62	Yes	None
		10/06/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.93	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	8.03	Yes	None
		05/11/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.00	No	
G154	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		480	No	
		10/14/2014	77	0.00	No/No		98.07	820		440	No	
		01/21/2015	77	0.00	No/No		98.07	820		450	No	
		04/08/2015	77	0.00	No/No		98.07	820		440	No	

R001859

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G154	TDS, mg/L	07/23/2015	77	0.00	No/No	STnon	98.07	820		430	No	
		10/06/2015	77	0.00	No/No		98.07	820		500	No	
		02/09/2016	77	0.00	No/No		98.07	820		560	No	
		05/11/2016	77	0.00	No/No		98.07	820		460	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G271	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/13/2014	69	97.10	No/No		97.10	0.001		0.160	Yes	None
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/10/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/22/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/08/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/16/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/12/2016	69	97.10	No/No		97.10	0.001		<0.002	No	
G271	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.260	Yes	None
		05/13/2014	69	60.87	No/No		97.10	0.120		0.450	Yes	None
		08/11/2014	69	60.87	No/No		97.10	0.120		0.390	Yes	None
		10/14/2014	69	60.87	No/No		97.10	0.120		0.440	Yes	None
		01/21/2015	69	60.87	No/No		97.10	0.120		0.420	Yes	None
		04/10/2015	69	60.87	No/No		97.10	0.120		0.370	Yes	None
		07/22/2015	69	60.87	No/No		97.10	0.120		0.320	Yes	None
		10/08/2015	69	60.87	No/No		97.10	0.120		0.440	Yes	None
		02/16/2016	69	60.87	No/No		97.10	0.120		0.510	Yes	None
		05/12/2016	69	60.87	No/No		97.10	0.120		0.610	Yes	None
G271	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		05/13/2014	69	23.19	No/No		97.10	0.480		0.220	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.002	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		<0.001	No	
		04/10/2015	69	23.19	No/No		97.10	0.480		<0.002	No	
		07/22/2015	69	23.19	No/No		97.10	0.480		0.001	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G271	Mn, diss, mg/L	10/08/2015	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		02/16/2016	69	23.19	No/No		97.10	0.480		<0.001	No	
		05/12/2016	69	23.19	No/No		97.10	0.480		<0.002	No	
G271	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/13/2014	69	100.00	No/No		N/A	0.001		0.150	Yes	None
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/10/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/22/2015	69	100.00	No/No		N/A	0.001		0.002	Yes	None
		10/08/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/16/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/12/2016	69	100.00	No/No		N/A	0.001		<0.002	No	
G271	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.35	No	
		05/13/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	6.80	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.46	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.42	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.49	No	
		04/10/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.28	No	
		07/22/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.20	No	
		10/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.96	No	
		11/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.27	No	
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.47	No	
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.47	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.19	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.19	No	
		08/05/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.20	No	
		11/21/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.24	No	

R001862

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G271	SO4, tot, mg/L	02/19/2014	78	0.00	No/No	STnon	98.17	370.0		420.0	Yes	None
		05/13/2014	78	0.00	No/No		98.17	370.0		440.0	Yes	None
		08/11/2014	78	0.00	No/No		98.17	370.0		500.0	Yes	None
		10/14/2014	78	0.00	No/No		98.17	370.0		480.0	Yes	None
		01/21/2015	78	0.00	No/No		98.17	370.0		490.0	Yes	None
		04/10/2015	78	0.00	No/No		98.17	370.0		440.0	Yes	None
		07/22/2015	78	0.00	No/No		98.17	370.0		350.0	No	
		10/08/2015	78	0.00	No/No		98.17	370.0		400.0	Yes	None
		11/23/2015	78	0.00	No/No		98.17	370.0		420.0	Yes	None
		02/16/2016	78	0.00	No/No		98.17	370.0		440.0	Yes	None
		02/16/2016	78	0.00	No/No		98.17	370.0		360.0	No	
		05/12/2016	78	0.00	No/No		98.17	370.0		540.0	Yes	None
		05/12/2016	78	0.00	No/No		98.17	370.0		420.0	Yes	None
		08/05/2016	78	0.00	No/No		98.17	370.0		440.0	Yes	None
		11/21/2016	78	0.00	No/No		98.17	370.0		400.0	Yes	None
G271	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		1,000	Yes	None
		10/14/2014	77	0.00	No/No		98.07	820		940	Yes	None
		01/21/2015	77	0.00	No/No		98.07	820		870	Yes	None
		04/10/2015	77	0.00	No/No		98.07	820		1,000	Yes	None
		07/22/2015	77	0.00	No/No		98.07	820		1,000	Yes	None
		10/08/2015	77	0.00	No/No		98.07	820		1,000	Yes	None
		11/23/2015	77	0.00	No/No		98.07	820		860	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		1,000	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		980	Yes	None
		05/12/2016	77	0.00	No/No		98.07	820		940	Yes	None
		05/12/2016	77	0.00	No/No		98.07	820		1,000	Yes	None
		08/05/2016	77	0.00	No/No		98.07	820		840	Yes	None
		11/21/2016	77	0.00	No/No		98.07	820		910	Yes	None

R001863

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend

R001864

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G272	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/13/2014	69	97.10	No/No		97.10	0.001		0.170	Yes	None
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/10/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/08/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/12/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
G272	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		<0.010	No	
		05/13/2014	69	60.87	No/No		97.10	0.120		0.270	Yes	None
		08/11/2014	69	60.87	No/No		97.10	0.120		<0.010	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		0.036	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		<0.010	No	
		04/10/2015	69	60.87	No/No		97.10	0.120		<0.020	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		<0.010	No	
		10/08/2015	69	60.87	No/No		97.10	0.120		<0.010	No	
		02/09/2016	69	60.87	No/No		97.10	0.120		<0.010	No	
		05/12/2016	69	60.87	No/No		97.10	0.120		<0.010	No	
G272	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		05/13/2014	69	23.19	No/No		97.10	0.480		0.230	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		<0.001	No	
		04/10/2015	69	23.19	No/No		97.10	0.480		<0.002	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		<0.001	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G272	Mn, diss, mg/L	10/08/2015	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		02/09/2016	69	23.19	No/No		97.10	0.480		0.001	No	
		05/12/2016	69	23.19	No/No		97.10	0.480		<0.001	No	
G272	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/13/2014	69	100.00	No/No		N/A	0.001		0.150	Yes	None
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/10/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/08/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/12/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
G272	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.75	No	
		05/13/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.84	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.61	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.43	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.64	No	
		04/10/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.18	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.22	No	
		10/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.21	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.54	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.25	No	
G272	SO4, tot, mg/L	02/19/2014	78	0.00	No/No	STnon	98.17	370.0		340.0	No	
		05/13/2014	78	0.00	No/No		98.17	370.0		310.0	No	
		08/11/2014	78	0.00	No/No		98.17	370.0		330.0	No	
		10/14/2014	78	0.00	No/No		98.17	370.0		310.0	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G272	SO4, tot, mg/L	01/21/2015	78	0.00	No/No	STnon	98.17	370.0		380.0	Yes	None
		04/10/2015	78	0.00	No/No		98.17	370.0		340.0	No	
		07/23/2015	78	0.00	No/No		98.17	370.0		270.0	No	
		10/08/2015	78	0.00	No/No		98.17	370.0		340.0	No	
		02/09/2016	78	0.00	No/No		98.17	370.0		290.0	No	
		05/12/2016	78	0.00	No/No		98.17	370.0		310.0	No	
G272	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		740	No	
		10/14/2014	77	0.00	No/No		98.07	820		840	Yes	None
		01/21/2015	77	0.00	No/No		98.07	820		790	No	
		04/10/2015	77	0.00	No/No		98.07	820		800	No	
		07/23/2015	77	0.00	No/No		98.07	820		840	Yes	None
		10/08/2015	77	0.00	No/No		98.07	820		660	No	
		02/09/2016	77	0.00	No/No		98.07	820		660	No	
		05/12/2016	77	0.00	No/No		98.07	820		680	No	

R001867

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G273	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/13/2014	69	97.10	No/No		97.10	0.001		0.240	Yes	None
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/13/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/08/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/16/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/12/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
G273	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.520	Yes	None
		05/13/2014	69	60.87	No/No		97.10	0.120		0.620	Yes	None
		08/11/2014	69	60.87	No/No		97.10	0.120		0.250	Yes	None
		10/14/2014	69	60.87	No/No		97.10	0.120		0.320	Yes	None
		01/21/2015	69	60.87	No/No		97.10	0.120		0.580	Yes	None
		04/13/2015	69	60.87	No/No		97.10	0.120		0.290	Yes	None
		07/23/2015	69	60.87	No/No		97.10	0.120		0.400	Yes	None
		10/08/2015	69	60.87	No/No		97.10	0.120		0.100	No	
		02/16/2016	69	60.87	No/No		97.10	0.120		0.430	Yes	None
		05/12/2016	69	60.87	No/No		97.10	0.120		0.310	Yes	None
G273	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.015	No	
		05/13/2014	69	23.19	No/No		97.10	0.480		0.330	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		0.010	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.013	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.018	No	
		04/13/2015	69	23.19	No/No		97.10	0.480		0.019	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.001	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G273	Mn, diss, mg/L	10/08/2015	69	23.19	No/No	STnon	97.10	0.480		0.014	No	
		02/16/2016	69	23.19	No/No		97.10	0.480		0.010	No	
		05/12/2016	69	23.19	No/No		97.10	0.480		0.012	No	
G273	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/13/2014	69	100.00	No/No		N/A	0.001		0.220	Yes	None
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/13/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/08/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/16/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/12/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
G273	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.40	No	
		05/13/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.76	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.34	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.27	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.28	No	
		04/13/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.96	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.19	No	
		10/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.36	No	
		11/24/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	1.08	Yes	None
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.23	No	
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.23	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.04	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.04	No	
		08/05/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.14	No	
		11/21/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.26	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G273	SO4, tot, mg/L	02/19/2014	78	0.00	No/No	STnon	98.17	370.0		570.0	Yes	None
		05/13/2014	78	0.00	No/No		98.17	370.0		620.0	Yes	None
		08/11/2014	78	0.00	No/No		98.17	370.0		530.0	Yes	None
		10/14/2014	78	0.00	No/No		98.17	370.0		500.0	Yes	None
		01/21/2015	78	0.00	No/No		98.17	370.0		650.0	Yes	None
		04/13/2015	78	0.00	No/No		98.17	370.0		690.0	Yes	None
		07/23/2015	78	0.00	No/No		98.17	370.0		390.0	Yes	None
		10/08/2015	78	0.00	No/No		98.17	370.0		450.0	Yes	None
		11/24/2015	78	0.00	No/No		98.17	370.0		420.0	Yes	None
		02/16/2016	78	0.00	No/No		98.17	370.0		550.0	Yes	None
		02/16/2016	78	0.00	No/No		98.17	370.0		530.0	Yes	None
		05/12/2016	78	0.00	No/No		98.17	370.0		520.0	Yes	None
		05/12/2016	78	0.00	No/No		98.17	370.0		500.0	Yes	None
		08/05/2016	78	0.00	No/No		98.17	370.0		400.0	Yes	None
		11/21/2016	78	0.00	No/No		98.17	370.0		440.0	Yes	None
G273	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		1,000	Yes	None
		10/14/2014	77	0.00	No/No		98.07	820		1,100	Yes	None
		01/21/2015	77	0.00	No/No		98.07	820		1,200	Yes	None
		04/13/2015	77	0.00	No/No		98.07	820		1,300	Yes	None
		07/23/2015	77	0.00	No/No		98.07	820		1,200	Yes	None
		10/08/2015	77	0.00	No/No		98.07	820		930	Yes	None
		11/24/2015	77	0.00	No/No		98.07	820		890	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		1,100	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		1,200	Yes	None
		05/12/2016	77	0.00	No/No		98.07	820		980	Yes	None
		05/12/2016	77	0.00	No/No		98.07	820		1,100	Yes	None
		08/05/2016	77	0.00	No/No		98.07	820		840	Yes	None
		11/21/2016	77	0.00	No/No		98.07	820		900	Yes	None

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend

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R001871

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G274	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/13/2014	69	97.10	No/No		97.10	0.001		0.006	Yes	None
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/13/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/08/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/12/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
G274	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.790	Yes	None
		05/13/2014	69	60.87	No/No		97.10	0.120		0.520	Yes	None
		08/11/2014	69	60.87	No/No		97.10	0.120		0.570	Yes	None
		10/14/2014	69	60.87	No/No		97.10	0.120		0.620	Yes	None
		01/21/2015	69	60.87	No/No		97.10	0.120		0.680	Yes	None
		04/13/2015	69	60.87	No/No		97.10	0.120		0.570	Yes	None
		07/23/2015	69	60.87	No/No		97.10	0.120		0.480	Yes	None
		10/08/2015	69	60.87	No/No		97.10	0.120		0.430	Yes	None
		02/09/2016	69	60.87	No/No		97.10	0.120		0.870	Yes	None
		05/12/2016	69	60.87	No/No		97.10	0.120		0.970	Yes	None
G274	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		05/13/2014	69	23.19	No/No		97.10	0.480		0.006	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.004	No	
		04/13/2015	69	23.19	No/No		97.10	0.480		<0.002	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.002	No	

R001872

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G274	Mn, diss, mg/L	10/08/2015	69	23.19	No/No	STnon	97.10	0.480		<0.001	No	
		02/09/2016	69	23.19	No/No		97.10	0.480		<0.001	No	
		05/12/2016	69	23.19	No/No		97.10	0.480		0.046	No	
G274	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/13/2014	69	100.00	No/No		N/A	0.001		0.003	Yes	None
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/13/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/08/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/12/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
G274	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.53	No	
		05/13/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.61	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.40	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.23	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.33	No	
		04/13/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.84	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.30	No	
		10/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.17	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.43	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.35	No	
G274	SO4, tot, mg/L	02/19/2014	78	0.00	No/No	STnon	98.17	370.0		300.0	No	
		05/13/2014	78	0.00	No/No		98.17	370.0		370.0	No	
		08/11/2014	78	0.00	No/No		98.17	370.0		400.0	Yes	None
		10/14/2014	78	0.00	No/No		98.17	370.0		320.0	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G274	SO4, tot, mg/L	01/21/2015	78	0.00	No/No	STnon	98.17	370.0		260.0	No	
		04/13/2015	78	0.00	No/No		98.17	370.0		390.0	Yes	None
		07/23/2015	78	0.00	No/No		98.17	370.0		320.0	No	
		10/08/2015	78	0.00	No/No		98.17	370.0		320.0	No	
		02/09/2016	78	0.00	No/No		98.17	370.0		290.0	No	
		05/12/2016	78	0.00	No/No		98.17	370.0		350.0	No	
G274	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		880	Yes	None
		10/14/2014	77	0.00	No/No		98.07	820		770	No	
		01/21/2015	77	0.00	No/No		98.07	820		770	No	
		04/13/2015	77	0.00	No/No		98.07	820		770	No	
		07/23/2015	77	0.00	No/No		98.07	820		890	Yes	None
		10/08/2015	77	0.00	No/No		98.07	820		770	No	
		02/09/2016	77	0.00	No/No		98.07	820		820	No	
		05/12/2016	77	0.00	No/No		98.07	820		770	No	

R001874

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G275	As, diss, mg/L	05/13/2014	69	97.10	No/No	STlow2	97.10	0.001		0.250	Yes	None
		08/11/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/13/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/09/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/12/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
G275	B, diss, mg/L	05/13/2014	69	60.87	No/No	STlow1	97.10	0.120		2.800	Yes	None
		08/11/2014	69	60.87	No/No		97.10	0.120		4.200	Yes	None
		10/14/2014	69	60.87	No/No		97.10	0.120		1.900	Yes	None
		01/21/2015	69	60.87	No/No		97.10	0.120		4.600	Yes	None
		04/13/2015	69	60.87	No/No		97.10	0.120		0.910	Yes	None
		07/23/2015	69	60.87	No/No		97.10	0.120		3.000	Yes	None
		02/09/2016	69	60.87	No/No		97.10	0.120		4.000	Yes	None
		05/12/2016	69	60.87	No/No		97.10	0.120		2.500	Yes	None
G275	Mn, diss, mg/L	05/13/2014	69	23.19	No/No	STnon	97.10	0.480		0.340	No	
		08/11/2014	69	23.19	No/No		97.10	0.480		<0.001	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.003	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.025	No	
		04/13/2015	69	23.19	No/No		97.10	0.480		0.002	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.012	No	
		02/09/2016	69	23.19	No/No		97.10	0.480		0.006	No	
		05/12/2016	69	23.19	No/No		97.10	0.480		0.004	No	
G275	Pb, diss, mg/L	05/13/2014	69	100.00	No/No	STmdl	N/A	0.001		0.200	Yes	None
		08/11/2014	69	100.00	No/No		N/A	0.001		<0.001	No	

R001875

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G275	Pb, diss, mg/L	10/14/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/13/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/09/2016	69	100.00	No/No		N/A	0.001		0.004	Yes	None
		05/12/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
G275	pH (field), STD	05/13/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.72	No	
		08/11/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.11	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	6.81	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.02	No	
		04/13/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.68	No	
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.07	No	
		02/09/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.24	No	
		05/12/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.09	No	
G275	SO4, tot, mg/L	05/13/2014	78	0.00	No/No	STnon	98.17	370.0		750.0	Yes	None
		08/11/2014	78	0.00	No/No		98.17	370.0		880.0	Yes	None
		10/14/2014	78	0.00	No/No		98.17	370.0		500.0	Yes	None
		01/21/2015	78	0.00	No/No		98.17	370.0		940.0	Yes	None
		04/13/2015	78	0.00	No/No		98.17	370.0		650.0	Yes	None
		07/23/2015	78	0.00	No/No		98.17	370.0		750.0	Yes	None
		02/09/2016	78	0.00	No/No		98.17	370.0		470.0	Yes	None
		05/12/2016	78	0.00	No/No		98.17	370.0		310.0	No	
G275	TDS, mg/L	08/11/2014	77	0.00	No/No	STnon	98.07	820		1,500	Yes	None
		10/14/2014	77	0.00	No/No		98.07	820		840	Yes	None
		01/21/2015	77	0.00	No/No		98.07	820		1,500	Yes	None
		04/13/2015	77	0.00	No/No		98.07	820		1,500	Yes	None
		07/23/2015	77	0.00	No/No		98.07	820		1,500	Yes	None

R001876

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G275	TDS, mg/L	02/09/2016	77	0.00	No/No	STnon	98.07	820		1,500	Yes	None
		05/12/2016	77	0.00	No/No		98.07	820		1,300	Yes	None

R001877

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G279	As, diss, mg/L	02/19/2014	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
		05/13/2014	69	97.10	No/No		97.10	0.001		0.017	Yes	None
		08/12/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/14/2014	69	97.10	No/No		97.10	0.001		<0.001	No	
		01/21/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		04/13/2015	69	97.10	No/No		97.10	0.001		<0.002	No	
		07/23/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		10/08/2015	69	97.10	No/No		97.10	0.001		<0.001	No	
		02/16/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
		05/13/2016	69	97.10	No/No		97.10	0.001		<0.001	No	
G279	B, diss, mg/L	02/19/2014	69	60.87	No/No	STlow1	97.10	0.120		0.022	No	
		05/13/2014	69	60.87	No/No		97.10	0.120		0.038	No	
		08/12/2014	69	60.87	No/No		97.10	0.120		0.015	No	
		10/14/2014	69	60.87	No/No		97.10	0.120		0.025	No	
		01/21/2015	69	60.87	No/No		97.10	0.120		0.032	No	
		04/13/2015	69	60.87	No/No		97.10	0.120		0.047	No	
		07/23/2015	69	60.87	No/No		97.10	0.120		0.031	No	
		10/08/2015	69	60.87	No/No		97.10	0.120		1.300	Yes	None
		02/16/2016	69	60.87	No/No		97.10	0.120		0.290	Yes	None
		05/13/2016	69	60.87	No/No		97.10	0.120		0.110	No	
G279	Mn, diss, mg/L	02/19/2014	69	23.19	No/No	STnon	97.10	0.480		0.029	No	
		05/13/2014	69	23.19	No/No		97.10	0.480		0.034	No	
		08/12/2014	69	23.19	No/No		97.10	0.480		0.024	No	
		10/14/2014	69	23.19	No/No		97.10	0.480		0.026	No	
		01/21/2015	69	23.19	No/No		97.10	0.480		0.017	No	
		04/13/2015	69	23.19	No/No		97.10	0.480		0.003	No	
		07/23/2015	69	23.19	No/No		97.10	0.480		0.013	No	

R001878

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G279	Mn, diss, mg/L	10/08/2015	69	23.19	No/No	STnon	97.10	0.480		0.032	No	
		02/16/2016	69	23.19	No/No		97.10	0.480		0.011	No	
		05/13/2016	69	23.19	No/No		97.10	0.480		0.006	No	
G279	Pb, diss, mg/L	02/19/2014	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
		05/13/2014	69	100.00	No/No		N/A	0.001		0.022	Yes	None
		08/12/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/14/2014	69	100.00	No/No		N/A	0.001		<0.001	No	
		01/21/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		04/13/2015	69	100.00	No/No		N/A	0.001		<0.002	No	
		07/23/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		10/08/2015	69	100.00	No/No		N/A	0.001		<0.001	No	
		02/16/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
		05/13/2016	69	100.00	No/No		N/A	0.001		<0.001	No	
G279	pH (field), STD	02/19/2014	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.37	No	
		05/13/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.00	No	
		08/12/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.22	No	
		10/14/2014	80	0.00	Yes/Yes		99.00	7.86	6.64	7.09	No	
		01/21/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.14	No	
		04/13/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	6.59	Yes	None
		07/23/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.11	No	
		10/08/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.04	No	
		11/24/2015	80	0.00	Yes/Yes		99.00	7.86	6.64	7.21	No	
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.19	No	
		02/16/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.19	No	
		05/13/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.91	No	
		05/13/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.91	No	
		08/03/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.11	No	
		11/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.16	No	

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G279	SO4, tot, mg/L	02/19/2014	78	0.00	No/No	STnon	98.17	370.0		110.0	No	
		05/13/2014	78	0.00	No/No		98.17	370.0		110.0	No	
		08/12/2014	78	0.00	No/No		98.17	370.0		120.0	No	
		10/14/2014	78	0.00	No/No		98.17	370.0		140.0	No	
		01/21/2015	78	0.00	No/No		98.17	370.0		230.0	No	
		04/13/2015	78	0.00	No/No		98.17	370.0		470.0	Yes	Upward
		07/23/2015	78	0.00	No/No		98.17	370.0		470.0	Yes	Upward
		10/08/2015	78	0.00	No/No		98.17	370.0		810.0	Yes	Upward
		11/24/2015	78	0.00	No/No		98.17	370.0		520.0	Yes	Upward
		02/16/2016	78	0.00	No/No		98.17	370.0		610.0	Yes	Upward
		02/16/2016	78	0.00	No/No		98.17	370.0		590.0	Yes	Upward
		05/13/2016	78	0.00	No/No		98.17	370.0		230.0	No	
		05/13/2016	78	0.00	No/No		98.17	370.0		270.0	No	
		08/03/2016	78	0.00	No/No		98.17	370.0		570.0	Yes	Upward
		11/22/2016	78	0.00	No/No		98.17	370.0		720.0	Yes	Upward
G279	TDS, mg/L	08/12/2014	77	0.00	No/No	STnon	98.07	820		600	No	
		10/14/2014	77	0.00	No/No		98.07	820		650	No	
		01/21/2015	77	0.00	No/No		98.07	820		810	No	
		04/13/2015	77	0.00	No/No		98.07	820		800	No	
		07/23/2015	77	0.00	No/No		98.07	820		1,200	Yes	None
		10/08/2015	77	0.00	No/No		98.07	820		1,700	Yes	None
		11/24/2015	77	0.00	No/No		98.07	820		1,100	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		1,400	Yes	None
		02/16/2016	77	0.00	No/No		98.07	820		1,500	Yes	None
		05/13/2016	77	0.00	No/No		98.07	820		600	No	
		05/13/2016	77	0.00	No/No		98.07	820		700	No	
		08/03/2016	77	0.00	No/No		98.07	820		1,300	Yes	None
		11/22/2016	77	0.00	No/No		98.07	820		1,300	Yes	None

R001880

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend

R001881

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G401	pH (field), STD	11/21/2015	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	5.98	Yes	None
		02/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	5.80	Yes	None
		05/19/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	5.96	Yes	None
		08/01/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.15	Yes	None
		11/17/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.24	Yes	None
G401	SO4, tot, mg/L	11/21/2015	78	0.00	No/No	STnon	98.17	370.0		2,300.0	Yes	None
		02/22/2016	78	0.00	No/No		98.17	370.0		2,500.0	Yes	None
		05/19/2016	78	0.00	No/No		98.17	370.0		2,200.0	Yes	None
		08/01/2016	78	0.00	No/No		98.17	370.0		2,100.0	Yes	None
		11/17/2016	78	0.00	No/No		98.17	370.0		3,400.0	Yes	None
G401	TDS, mg/L	11/21/2015	77	0.00	No/No	STnon	98.07	820		3,000	Yes	None
		02/22/2016	77	0.00	No/No		98.07	820		3,000	Yes	None
		05/19/2016	77	0.00	No/No		98.07	820		2,800	Yes	None
		08/01/2016	77	0.00	No/No		98.07	820		2,900	Yes	None
		11/17/2016	77	0.00	No/No		98.07	820		3,200	Yes	None

R001882

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G402	pH (field), STD	11/21/2015	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	6.81	No	
		02/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.74	No	
		05/19/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.77	No	
		08/02/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.60	Yes	None
		11/17/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.62	Yes	None
G402	SO4, tot, mg/L	11/21/2015	78	0.00	No/No	STnon	98.17	370.0		1,200.0	Yes	None
		02/22/2016	78	0.00	No/No		98.17	370.0		1,000.0	Yes	None
		05/19/2016	78	0.00	No/No		98.17	370.0		960.0	Yes	None
		08/02/2016	78	0.00	No/No		98.17	370.0		890.0	Yes	None
		11/17/2016	78	0.00	No/No		98.17	370.0		1,100.0	Yes	None
G402	TDS, mg/L	11/21/2015	77	0.00	No/No	STnon	98.07	820		1,700	Yes	None
		02/22/2016	77	0.00	No/No		98.07	820		1,700	Yes	None
		05/19/2016	77	0.00	No/No		98.07	820		1,500	Yes	None
		08/02/2016	77	0.00	No/No		98.07	820		1,500	Yes	None
		11/17/2016	77	0.00	No/No		98.07	820		1,700	Yes	None

R001883

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G403	pH (field), STD	11/23/2015	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.15	No	
		02/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.96	No	
		05/18/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.89	No	
		08/01/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.91	No	
		11/17/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.74	No	
G403	SO4, tot, mg/L	11/23/2015	78	0.00	No/No	STnon	98.17	370.0		35.0	No	
		02/22/2016	78	0.00	No/No		98.17	370.0		17.0	No	
		05/18/2016	78	0.00	No/No		98.17	370.0		11.0	No	
		08/01/2016	78	0.00	No/No		98.17	370.0		9.9	No	
		11/17/2016	78	0.00	No/No		98.17	370.0		8.9	No	
G403	TDS, mg/L	11/23/2015	77	0.00	No/No	STnon	98.07	820		320	No	
		02/22/2016	77	0.00	No/No		98.07	820		340	No	
		05/18/2016	77	0.00	No/No		98.07	820		320	No	
		08/01/2016	77	0.00	No/No		98.07	820		320	No	
		11/17/2016	77	0.00	No/No		98.07	820		350	No	

R001884

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G404	pH (field), STD	11/21/2015	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	6.72	No	
		02/15/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.24	No	
		05/19/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.82	No	
		08/02/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.08	No	
		11/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.09	No	
G404	SO4, tot, mg/L	11/21/2015	78	0.00	No/No	STnon	98.17	370.0		180.0	No	
		02/15/2016	78	0.00	No/No		98.17	370.0		150.0	No	
		05/19/2016	78	0.00	No/No		98.17	370.0		140.0	No	
		08/02/2016	78	0.00	No/No		98.17	370.0		190.0	No	
		11/22/2016	78	0.00	No/No		98.17	370.0		380.0	Yes	None
G404	TDS, mg/L	11/21/2015	77	0.00	No/No	STnon	98.07	820		580	No	
		02/15/2016	77	0.00	No/No		98.07	820		560	No	
		05/19/2016	77	0.00	No/No		98.07	820		460	No	
		08/02/2016	77	0.00	No/No		98.07	820		620	No	
		11/22/2016	77	0.00	No/No		98.07	820		880	Yes	None

R001885

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G405	pH (field), STD	11/21/2015	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	6.82	No	
		02/15/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	7.07	No	
		05/18/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.85	No	
		08/02/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.81	No	
		11/22/2016	80	0.00	Yes/Yes		99.00	7.86	6.64	6.90	No	
G405	SO4, tot, mg/L	11/21/2015	78	0.00	No/No	STnon	98.17	370.0		1,700.0	Yes	None
		02/15/2016	78	0.00	No/No		98.17	370.0		1,700.0	Yes	None
		05/18/2016	78	0.00	No/No		98.17	370.0		1,800.0	Yes	None
		08/02/2016	78	0.00	No/No		98.17	370.0		1,600.0	Yes	None
		11/22/2016	78	0.00	No/No		98.17	370.0		1,400.0	Yes	None
G405	TDS, mg/L	11/21/2015	77	0.00	No/No	STnon	98.07	820		2,400	Yes	None
		02/15/2016	77	0.00	No/No		98.07	820		2,500	Yes	None
		05/18/2016	77	0.00	No/No		98.07	820		2,200	Yes	None
		08/02/2016	77	0.00	No/No		98.07	820		2,200	Yes	None
		11/22/2016	77	0.00	No/No		98.07	820		2,100	Yes	None

R001886

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G406	As, diss, mg/L	08/30/2016	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
G406	B, diss, mg/L	08/30/2016	69	60.87	No/No	STlow1	97.10	0.120		1.600	Yes	Insufficient Data: Cannot Trend.
G406	Mn, diss, mg/L	08/30/2016	69	23.19	No/No	STnon	97.10	0.480		5.500	Yes	Insufficient Data: Cannot Trend.
G406	Pb, diss, mg/L	08/30/2016	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
G406	pH (field), STD	11/18/2016	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.32	No	
G406	SO4, tot, mg/L	11/18/2016	78	0.00	No/No	STnon	98.17	370.0		910.0	Yes	Insufficient Data: Cannot Trend.
G406	TDS, mg/L	08/30/2016	77	0.00	No/No	STnon	98.07	820		1,300	Yes	Insufficient Data: Cannot Trend.
		11/18/2016	77	0.00	No/No		98.07	820		1,400	Yes	Insufficient Data: Cannot Trend.

R001887

Compliance Location	Parameter	Sample Date	Count Of Bkg Results	Percent of Non detects	Normal / Lognormal	Test	Confidence Level	Upper Limit	Lower Limit	Analysis Result	Exceedance	Trend
G407	As, diss, mg/L	08/30/2016	69	97.10	No/No	STlow2	97.10	0.001		<0.001	No	
G407	B, diss, mg/L	08/30/2016	69	60.87	No/No	STlow1	97.10	0.120		0.052	No	
G407	Mn, diss, mg/L	08/30/2016	69	23.19	No/No	STnon	97.10	0.480		0.210	No	
G407	Pb, diss, mg/L	08/30/2016	69	100.00	No/No	STmdl	N/A	0.001		<0.001	No	
G407	pH (field), STD	11/18/2016	80	0.00	Yes/Yes	STpar	99.00	7.86	6.64	7.75	No	
G407	SO4, tot, mg/L	11/18/2016	78	0.00	No/No	STnon	98.17	370.0		830.0	Yes	Insufficient Data: Cannot Trend.
G407	TDS, mg/L	08/30/2016	77	0.00	No/No	STnon	98.07	820		1,400	Yes	Insufficient Data: Cannot Trend.
		11/18/2016	77	0.00	No/No		98.07	820		1,400	Yes	Insufficient Data: Cannot Trend.

APPENDIX C

GROUNDWATER MONITORING DATA

R001889

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.0218								< 0.002			0.257				
0.057	< 0.001		0.026	< 0.001		50	< 0.004	< 0.002	0.691		< 0.001			< 0.0002		0.0021	
0.069	< 0.001		0.019	< 0.001		67	< 0.004	< 0.002	0.486		< 0.001			< 0.0002		0.0029	
		0.052								< 0.001			0.11				
0.067	< 0.001		0.01	< 0.001		58	< 0.004	< 0.002	0.649		< 0.001			< 0.0002		0.0024	
		0.013								< 0.001			0.091				
		< 0.02								< 0.001			0.071				
		< 0.005								< 0.001			0.031				
		0.02								< 0.001			0.12				
		0.014								< 0.001			0.072				
		0.024								< 0.001			0.069				
		< 0.01								< 0.001			0.14				
		< 0.01								< 0.001			0.031				
		< 0.01								< 0.001			0.066				
		< 0.02								< 0.002			0.19				
		0.018								< 0.001			0.093				
		0.036								< 0.001			0.56				
		< 0.01								< 0.001			0.18				
		< 0.02								< 0.002			0.011				
		0.0513								< 0.002			0.927				
0.13	< 0.001		0.047	< 0.001		40	0.008	0.0023	0.642		0.0026			< 0.0002		0.003	
0.13	< 0.001		0.036	< 0.001		42	< 0.004	< 0.002	0.422		< 0.001			< 0.0002		0.0043	
		0.044								< 0.001			0.21				
0.1	< 0.001		0.032	< 0.001		45	< 0.004	< 0.002	0.587		< 0.001			< 0.0002		0.0035	
		0.031								< 0.001			0.14				
		0.033								< 0.001			0.14				
		0.015								< 0.001			0.034				
		0.024								0.0014			0.21				
		0.038								< 0.001			0.12				
		0.044								< 0.001			0.05				
		0.044								< 0.001			0.31				
		0.034								< 0.001			0.15				
		0.03								< 0.001			0.15				
		0.025								< 0.002			0.07				
		0.079								< 0.001			0.89				
		0.11								< 0.001			0.53				
		0.082								< 0.001			0.47				
		0.066								< 0.002			0.31				
0.073			0.017			51			0.509								
		0.0575								< 0.002			1.02				
0.036	< 0.001		0.064	< 0.001		130	0.0053	0.0068	0.369		< 0.001			< 0.0002		0.021	
0.022	< 0.001		0.036	< 0.001		160	0.0041	0.0034	0.293		< 0.001			< 0.0002		0.027	
		0.032								< 0.001			0.42				
0.016	< 0.001		0.031	< 0.001		130	0.0041	< 0.002	0.341		< 0.001			< 0.0002		0.021	
		0.04								< 0.001			0.19				
		0.039								< 0.001			0.28				
		0.012								< 0.001			0.13				

R001890

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.026								< 0.001			0.24				
		0.028								< 0.001			0.51				
		0.02								< 0.001			0.2				
		0.02								< 0.002			0.024				
		0.015								< 0.001			0.16				
		0.03								< 0.001			0.19				
		0.016								< 0.001			0.046				
		0.026								< 0.002			0.037				
0.017			0.013			230			0.491								
		0.0452								< 0.002			0.462				
0.037	< 0.001		0.031	< 0.001		10	< 0.004	< 0.002	1.01		< 0.001			< 0.0002		0.0042	
0.032	< 0.001		0.021	< 0.001		4.6	< 0.004	< 0.002	0.971		< 0.001			< 0.0002		0.0062	
		0.025								< 0.001			0.038				
0.033	< 0.001		0.038	< 0.001		4.9	< 0.004	< 0.002	1.06		< 0.001			< 0.0002		0.0058	
		0.04								< 0.001			0.043				
		0.043								< 0.001			0.032				
		0.021								< 0.001			0.046				
		0.035								< 0.001			0.045				
		0.043								< 0.001			0.018				
		0.044								< 0.001			0.014				
		0.035								< 0.001			0.081				
		0.035								< 0.001			0.0077				
		0.037								< 0.001			0.0092				
		0.023								< 0.002			0.003				
		0.024								< 0.001			0.14				
		0.044								< 0.001			0.01				
		0.041								< 0.001			0.041				
		0.037								< 0.002			0.0085				
0.076	< 0.005	< 0.25	< 0.25	< 0.0025	77	9.5	< 0.025	< 0.005	0.36	< 0.0025	< 0.0025		0.19	< 0.0002		< 0.012	
0.076	< 0.001	0.078	0.071	< 0.0005	72	11	< 0.005	0.0017	0.36	< 0.0005	0.0021		0.21	< 0.0002		< 0.0025	
0.072	< 0.001	< 0.05	< 0.05	< 0.0005	70	< 10	< 0.005	0.001	0.33	< 0.0005	0.0021		0.21	< 0.0002		< 0.0025	
0.069	< 0.001	0.052	< 0.05	< 0.0005	67	8.9	< 0.005	< 0.001	0.38	< 0.0005	< 0.0005		0.26	< 0.0002		< 0.0025	
0.068	< 0.001	0.073	< 0.05	< 0.0005	71	9.4	< 0.005	< 0.001	0.35	< 0.0005	< 0.0005		0.22	< 0.0002		< 0.0025	
0.068	< 0.001	0.052	0.051	< 0.0005	69	9.6	< 0.005	< 0.001	0.31	< 0.0005	0.00054		0.22	< 0.0002		< 0.0025	
		0.054	0.058	< 0.0005	77	9.4				< 0.0005	0.0011		0.26				
		0.054	0.057	< 0.0005	75	11				< 0.0005	0.0011		0.23				
		0.053	0.052	< 0.0005	74	19				< 0.0005	0.0031		0.14				
0.056	< 0.001						< 0.005	< 0.001	0.3					< 0.0002		< 0.0025	
		< 0.01	< 0.01	< 0.001	61	39				< 0.001	< 0.001		0.058				
		0.011	< 0.01	< 0.001	58	40				< 0.001	< 0.001		0.062				
		0.013	0.016	< 0.001	60	40				< 0.001	0.0021		0.069				
0.064	< 0.001	< 0.01	0.012	< 0.001	80	45	< 0.004	0.002	0.36	< 0.001	0.0041		0.032	< 0.0002		0.002	
		0.01	< 0.01	< 0.001	57	57				< 0.001	< 0.001		0.023				
		< 0.01	< 0.01	< 0.001	59	57				< 0.001	< 0.001		0.046				
		< 0.01	< 0.01	< 0.001	61	64				< 0.001	< 0.001		0.05				
0.049	< 0.001	< 0.01	< 0.01	< 0.001	64	73	< 0.004	< 0.002	0.363	< 0.001	< 0.001		0.0094	< 0.0002		0.0046	
		< 0.01	< 0.01	< 0.001	67	83				< 0.001	< 0.001		0.04				
		0.092	0.018	< 0.001	73	66				< 0.001	< 0.001		0.045				
		< 0.01	< 0.01	< 0.001	65	76				< 0.001	< 0.001		0.017				
0.062	< 0.001	< 0.01	< 0.01	< 0.001	65	91	< 0.004	< 0.002	0.372	< 0.001	< 0.001		0.011	< 0.0002		0.0078	
		< 0.01	< 0.01	< 0.001	72	85				< 0.001	< 0.001		0.025				

R001891

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.041	< 0.001	< 0.01	< 0.01	< 0.001	67	56	< 0.004	< 0.002	0.279	< 0.001	< 0.001		0.0029	< 0.0002		0.0022	
		0.026	0.025	< 0.001	68	30				< 0.001	< 0.001		0.016				
		< 0.01	< 0.01	< 0.001	62	34				< 0.001	< 0.001		0.04				
		0.12	0.057	0.008	67	21				< 0.001	0.0073		0.04				
		0.011	< 0.01	< 0.001	70	18				< 0.001	< 0.001		0.011				
0.05	< 0.001	0.025	0.047	< 0.001	70	20	< 0.004	< 0.002	0.334	< 0.002	< 0.001		0.0055	< 0.0002		0.0016	
0.049	< 0.001	< 0.01	< 0.01	< 0.001		15	< 0.004	< 0.002	0.427	< 0.001	0.0018		0.47	< 0.0002	0.0011	< 0.001	
0.037	< 0.001	0.013	< 0.01	< 0.001		11	< 0.004	< 0.002	0.411	< 0.001	< 0.001		0.056	< 0.0002	< 0.001	< 0.001	
0.045	< 0.001		< 0.01	< 0.001	59	12	< 0.004	< 0.002	0.362		0.0015	< 0.01		< 0.0002	0.001	< 0.001	
0.037	< 0.001	0.02	< 0.01	< 0.001	49	16	< 0.004	< 0.002	0.472	< 0.001	< 0.001	< 0.01	0.012	< 0.0002	< 0.001	0.0013	
0.034	< 0.001	< 0.02	< 0.01	< 0.001	57	15	< 0.004	< 0.002	0.504	< 0.002	< 0.001	< 0.01	0.029	< 0.0002	< 0.001	< 0.001	
0.037	< 0.001		< 0.01	< 0.001	50	15	< 0.004	< 0.002	0.397		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.08	< 0.001		0.33	< 0.0005	110	37	0.0064	0.0023	0.46		0.0054			< 0.0002		0.0038	
0.11	< 0.001		0.33	< 0.0005	140	34	0.014	0.0047	0.41		0.011			< 0.0002		0.0034	
		0.34								< 0.0005			0.11				
0.055	< 0.001	0.18	0.24	< 0.0005	110	33	< 0.005	< 0.001	0.34	< 0.0005	0.0018		0.007	< 0.0002		0.0035	
0.055	< 0.001	0.25	0.23	< 0.0005	120	36	< 0.005	< 0.001	0.39	0.00061	0.0023		< 0.0025	< 0.0002		0.0053	
0.053	< 0.001	0.26	0.16	< 0.001	130	40	0.0056	< 0.002	0.42	< 0.001	0.0029		0.028	< 0.0002		0.0051	
0.041	< 0.001	0.24	0.15	< 0.001	120	40	< 0.004	< 0.002	0.34	< 0.001	< 0.001		0.016	< 0.0002		0.005	
		0.16								< 0.001			0.0015				
		0.14	0.15	< 0.001	110	44				< 0.001	< 0.001		< 0.001				
0.05	< 0.001	0.17	0.14	< 0.001	110	44	< 0.004	< 0.002	0.48	< 0.001	0.0035		0.0013	< 0.0002		0.0079	
		0.16	0.11	< 0.001	100	53				< 0.001	< 0.001		< 0.001				
		0.13	0.17	< 0.001	96	49				< 0.001	< 0.001		< 0.001				
		0.15	0.21	< 0.001	110	50				< 0.001	< 0.001		< 0.001				
0.034	< 0.001	0.19	0.18	< 0.001	110	44	< 0.004	< 0.002	0.393	< 0.001	< 0.001		< 0.001	< 0.0002		0.0099	
		0.16	0.14	< 0.001	110	5.1				< 0.001	< 0.001		< 0.001				
		0.18	0.13	< 0.001	110	45				< 0.001	< 0.001		< 0.001				
		0.28	0.19	< 0.001	130	50				< 0.001	0.0012		0.0021				
0.063	< 0.001	0.32	0.32	< 0.001	150	58	0.0066	0.0026	0.458	< 0.001	0.005		0.024	< 0.0002		0.005	
		0.17	0.19	< 0.001	120	47				< 0.001	< 0.001		< 0.001				
		0.16	0.15	< 0.001	99	49				< 0.001	< 0.001		< 0.001				
		0.3	0.18	< 0.001	120	47				< 0.001	< 0.001		< 0.001				
0.062	< 0.001	0.26	0.24	< 0.001	150	51	0.0087	0.0023	0.298	< 0.001	0.0056		< 0.001	< 0.0002		0.0045	
		0.45	0.33	< 0.001	140	47				0.15	0.0018		0.22				
		0.39	0.44	< 0.001	140	42				< 0.001	0.0061		< 0.001				
		0.44	0.5	< 0.001	150	45				< 0.001	0.0062		0.0021				
		0.42	0.51	< 0.001	120	39				< 0.001	0.0014		< 0.001				
0.029	< 0.001	0.37	0.31	< 0.001	130	45	< 0.004	< 0.002	0.406	< 0.002	< 0.001		< 0.002	< 0.0002		0.0035	
0.028	< 0.001	0.32	0.24	< 0.001		35	< 0.004	< 0.002	0.406	0.0017	0.0036		0.001	< 0.0002	< 0.001	0.0026	
0.03	< 0.001	0.44	0.33	< 0.001		38	< 0.004	< 0.002	0.402	< 0.001	< 0.001		< 0.001	< 0.0002	0.0036	0.0035	
0.031	< 0.001		0.5	< 0.001	130	38	< 0.004	< 0.002	0.347		0.0012	< 0.01		< 0.0002	0.0012	0.0024	
0.029	< 0.001	0.51	0.61	< 0.001	130	38	< 0.004	< 0.002	0.481	< 0.001	< 0.001	< 0.01	< 0.001	< 0.0002	< 0.001	0.0032	
0.028	< 0.001	0.61	0.98	< 0.001	170	39	< 0.004	< 0.002	0.562	< 0.002	< 0.001	< 0.01	< 0.002	< 0.0002	< 0.001	0.0021	
0.032	< 0.001		0.63	< 0.001	110	37	< 0.004	< 0.002	0.414		0.0027	< 0.01		< 0.0002	< 0.001	0.0022	
0.031	< 0.001		0.4	< 0.001		29	< 0.004	< 0.002	0.484		< 0.001	< 0.01		< 0.0002	< 0.001	0.0029	
0.079	< 0.001		0.06	< 0.0005	84	53	< 0.005	0.0017	0.48		0.0039			< 0.0002		< 0.0025	
0.073	< 0.001	0.057	< 0.05	< 0.0005	88	46	< 0.005	0.0012	0.5	< 0.0005	0.0025		0.056	< 0.0002		< 0.0025	
0.068	< 0.001	< 0.05	0.051	< 0.0005	85	45	< 0.005	< 0.001	0.42	< 0.0005	0.002		0.006	< 0.0002		< 0.0025	
0.061	< 0.001	< 0.05	0.05	< 0.0005	93	44	< 0.005	< 0.001	0.41	< 0.0005	0.00058		< 0.0025	< 0.0002		< 0.0025	

R001892

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		< 0.01								< 0.001			< 0.001				
		< 0.01	< 0.01	< 0.001	84	42				< 0.001	< 0.001		< 0.001				
0.07	< 0.001	< 0.01	0.013	< 0.001	98	43	< 0.004	< 0.002	0.48	< 0.001	< 0.001		< 0.001	< 0.0002		0.0042	
		< 0.01	< 0.01	< 0.001	92	42				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	99	< 100				< 0.001	< 0.001		< 0.001				
		< 0.01	0.01	< 0.001	98	41				< 0.001	< 0.001		< 0.001				
0.068	< 0.001	< 0.01	< 0.01	< 0.001	98	43	< 0.004	< 0.002	0.459	< 0.001	< 0.001		< 0.001	< 0.0002		0.0021	
		< 0.01	< 0.01	< 0.001	82	42				< 0.001	< 0.001		< 0.001				
		0.032	< 0.01	< 0.001	100	43				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	110	40				< 0.001	0.0011		0.0012				
0.072	< 0.001	< 0.01	< 0.01	< 0.001	110	44	< 0.004	< 0.002	0.461	< 0.001	< 0.001		< 0.001	< 0.0002		0.0029	
		< 0.01	< 0.01	< 0.001	98	37				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	100	35				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	100	32				< 0.001	< 0.001		< 0.001				
0.06	< 0.001	< 0.01	< 0.01	< 0.001	110	40	< 0.004	< 0.002	0.355	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		0.27	0.015	< 0.001	93	36				0.15	< 0.001		0.23				
		< 0.01	< 0.01	< 0.001	110	34				< 0.001	0.0014		< 0.001				
		0.036	0.022	< 0.001	110	37				< 0.001	0.0026		< 0.001				
		< 0.01	< 0.01	< 0.001	99	31				< 0.001	0.0022		< 0.001				
0.059	< 0.001	< 0.02	< 0.01	< 0.001	110	37	< 0.004	< 0.002	0.399	< 0.002	< 0.001		< 0.002	< 0.0002		0.0012	
0.06	< 0.001	< 0.01	0.031	< 0.001		29	< 0.004	< 0.002	0.493	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.058	< 0.001	< 0.01	0.046	< 0.001		33	< 0.004	< 0.002	0.361	< 0.001	< 0.001		< 0.001	< 0.0002	0.0024	0.0016	
0.099	< 0.001	< 0.01	< 0.01	< 0.001		29	0.011	0.0022	0.516	< 0.001	0.0049		0.0013	< 0.0002	0.0013	< 0.001	
0.059	< 0.001	< 0.01	< 0.01	< 0.001		29	< 0.004	< 0.002	0.561	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.094	< 0.001		< 0.05	< 0.0005	120	35	< 0.005	< 0.001	0.38		< 0.0005			< 0.0002		< 0.0025	
0.09	< 0.001	< 0.05	0.051	< 0.0005	140	28	< 0.005	< 0.001	0.33	< 0.0005	0.00093		0.097	< 0.0002		< 0.0025	
0.085	< 0.001	0.054	< 0.05	< 0.0005	150	30	< 0.005	< 0.001	0.29	< 0.0005	< 0.0005		0.063	< 0.0002		< 0.0025	
0.079	< 0.001	< 0.05	< 0.05	< 0.0005	190	25	< 0.005	< 0.001	0.26	< 0.0005	< 0.0005		0.055	< 0.0002		< 0.0025	
0.055	< 0.001	0.019	0.016	< 0.001	180	31	0.034	< 0.002	0.33	< 0.001	< 0.001		0.041	< 0.0002		0.0016	
0.048	< 0.001	0.023	0.023	< 0.001	160	30	< 0.004	< 0.002	0.37	< 0.001	< 0.001		0.048	< 0.0002		< 0.001	
		0.024								< 0.001			0.052				
		0.035	0.039	< 0.001	130	27				< 0.001	< 0.001		0.058				
0.05	< 0.001	0.16	0.21	< 0.001	170	33	< 0.004	< 0.002	0.38	< 0.001	< 0.001		0.047	< 0.0002		< 0.001	
		0.16	0.14	< 0.001	160	59				< 0.001	< 0.001		0.042				
		0.097	0.12	< 0.001	150	29				< 0.001	< 0.001		0.029				
		0.13	0.15	< 0.001	150	29				< 0.001	< 0.001		0.041				
0.043	< 0.001	0.27	0.26	< 0.001	180	27	< 0.004	< 0.002	0.359	< 0.001	< 0.001		0.033	< 0.0002		0.0012	
		0.21	0.2	< 0.001	160	27				< 0.001	< 0.001		0.028				
		0.12	0.094	< 0.001	140	32				< 0.001	< 0.001		0.022				
		0.27	0.2	< 0.001	160	33				< 0.001	0.0037		0.026				
0.046	< 0.001	0.48	0.46	< 0.001	180	37	< 0.004	< 0.002	0.33	< 0.001	< 0.001		0.03	< 0.0002		< 0.002	
		0.18	0.29	< 0.001	180	4				< 0.001	< 0.001		0.013				
		0.21	0.25	< 0.001	160	35				< 0.001	< 0.001		0.022				
		0.18	0.18	< 0.001	140	37				< 0.001	< 0.001		0.015				
0.039	< 0.001	0.52	0.36	< 0.001	150	38	< 0.004	< 0.002	0.286	< 0.001	< 0.001		0.015	< 0.0002		< 0.001	
		0.62	0.35	< 0.001	160	47				0.22	< 0.001		0.33				
		0.25	0.26	< 0.001	140	37				< 0.001	< 0.001		0.01				
		0.32	0.29	< 0.001	150	37				< 0.001	0.0011		0.013				
		0.58	0.45	< 0.001	150	46				< 0.001	< 0.001		0.018				
0.028	< 0.001	0.29	0.48	< 0.001	200	41	< 0.004	< 0.002	0.32	< 0.002	< 0.001		0.019	< 0.0002		< 0.001	
0.044	< 0.001	0.4	0.12	< 0.001		39	< 0.004	< 0.002	0.382	< 0.001	< 0.001		0.0011	< 0.0002	< 0.001	< 0.001	

R001893

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.043	< 0.001	0.43	0.42	< 0.001	150	45	< 0.004	< 0.002	0.401	< 0.001	< 0.001	< 0.01	0.01	< 0.0002	< 0.001	< 0.001	
0.031	< 0.001	0.31	0.29	< 0.001	170	44	< 0.004	< 0.002	0.537	< 0.001	< 0.001	< 0.01	0.012	< 0.0002	< 0.001	< 0.001	
0.032	< 0.001		0.17	< 0.001	120	46	< 0.004	< 0.002	0.294		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.036	< 0.001		0.15	< 0.001		48	< 0.004	< 0.002	0.39		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.12	< 0.001		0.053	< 0.0005	100	55	0.0059	0.0028	0.34		0.0091			< 0.0002		< 0.0025	
0.092	< 0.001	0.057	< 0.05	< 0.0005	100	54	< 0.005	< 0.001	0.35	< 0.0005	0.0012		0.007	< 0.0002		< 0.0025	
0.09	< 0.001	< 0.05	< 0.05	< 0.0005	100	50	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.0039	< 0.0002		< 0.0025	
0.091	< 0.001	< 0.05	< 0.05	< 0.0005	110	49	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.0056	< 0.0002		< 0.0025	
0.09	< 0.001	< 0.01	< 0.01	< 0.001	110	45	< 0.004	< 0.002	0.32	< 0.001	0.0015		< 0.001	< 0.0002		0.0022	
0.08	< 0.001	< 0.01	< 0.01	< 0.001	110	44	< 0.004	< 0.002	0.35	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		< 0.01								< 0.001			< 0.001				
		< 0.01	0.012	< 0.001	120	38				< 0.001	< 0.001		< 0.001				
0.077	0.0018	< 0.01	0.012	0.0014	110	39	< 0.004	< 0.002	0.36	< 0.001	0.0018		< 0.001	< 0.0002		< 0.001	
		< 0.01	< 0.01	< 0.001	120	36				< 0.001	< 0.001		< 0.001				
		0.013	< 0.01	< 0.001	120	37				< 0.001	< 0.001		< 0.001				
		0.035	0.039	< 0.001	120	37				< 0.001	< 0.001		< 0.001				
0.068	< 0.001	0.076	0.052	< 0.001	110	34	< 0.004	< 0.002	0.379	< 0.001	< 0.001		0.001	< 0.0002		0.0014	
		0.12	0.11	< 0.001	120	36				< 0.001	< 0.001		< 0.001				
		0.15	0.13	< 0.001	120	40				< 0.001	< 0.001		< 0.001				
		0.18	0.16	< 0.001	120	37				< 0.001	0.0031		< 0.001				
0.059	< 0.001	0.26	0.25	< 0.001	130	36	< 0.004	< 0.002	0.382	< 0.001	< 0.001		< 0.001	< 0.0002		0.0015	
		0.25	0.27	< 0.001	120	3.6				< 0.001	< 0.001		0.0073				
		0.31	0.31	< 0.001	110	32				< 0.001	0.0015		< 0.001				
		0.52	0.46	< 0.001	110	31				< 0.001	< 0.001		< 0.001				
0.063	< 0.001	0.79	0.47	< 0.001	110	32	< 0.004	< 0.002	0.262	< 0.001	< 0.001		< 0.001	< 0.0002		< 0.001	
		0.52	0.52	< 0.001	98	27				0.0034	< 0.001		0.0059				
		0.57	0.61	< 0.001	120	25				< 0.001	< 0.001		< 0.001				
		0.62	0.55	< 0.001	100	23				< 0.001	0.01		< 0.001				
		0.68	0.5	< 0.001	110	19				< 0.001	0.0029		0.0036				
0.052	< 0.001	0.57	0.53	< 0.001	110	24	< 0.004	< 0.002	0.341	< 0.002	< 0.001		< 0.002	< 0.0002		< 0.001	
0.068	< 0.001	0.48	0.49	< 0.001		24	< 0.004	< 0.002	0.403	< 0.001	0.0018		0.0015	< 0.0002	< 0.001	0.0014	
0.061	< 0.001	0.43	0.74	< 0.001		22	< 0.004	< 0.002	0.265	< 0.001	< 0.001		< 0.001	< 0.0002	0.0012	< 0.001	
0.07	< 0.001	0.87	0.65	< 0.001		22	< 0.004	< 0.002	0.455	< 0.001	0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.057	< 0.001	0.97	0.63	< 0.001		22	< 0.004	< 0.002	0.417	< 0.001	< 0.001		0.046	< 0.0002	< 0.001	< 0.001	
0.12	< 0.001		4.5	< 0.0005	300	14	< 0.025	< 0.005	0.22		0.01			< 0.0002		< 0.012	
0.032	< 0.001	2.4	2.5	< 0.0005	140	12	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.032	< 0.0002		< 0.0025	
0.032	< 0.001	1.2	1.2	< 0.0005	120	13	< 0.005	< 0.001	0.32	< 0.0005	< 0.0005		0.023	< 0.0002		< 0.0025	
0.035	< 0.001	1.3	1.3	< 0.0005	160	23	< 0.005	< 0.001	0.27	< 0.0005	0.00053		0.029	< 0.0002		< 0.0025	
0.047	< 0.001	2.9	2.9	< 0.001	180	18	0.0087	< 0.002	0.33	< 0.001	0.0017		0.018	< 0.0002		0.0014	
0.038	< 0.001	2.9	2.8	< 0.001	180	9.9	< 0.004	< 0.002	0.4	< 0.001	< 0.001		0.019	< 0.0002		< 0.001	
		2.6								< 0.001			0.026				
		3.7	4.1	< 0.001	260	9.7				< 0.001	0.0045		0.16				
0.046	< 0.001	3.6	3.6	< 0.001	230	11	< 0.004	< 0.002	0.34	< 0.001	< 0.001		0.016	< 0.0002		< 0.001	
		3.6	3.8	< 0.001	240	13				< 0.001	< 0.001		0.04				
		4.3	4.2	< 0.001	200	9.2				< 0.001	< 0.001		0.03				
		4.3	4.4	< 0.001	260	17				< 0.001	0.0059		0.09				
0.039	< 0.001	3.8	3.6	< 0.001	310	15	0.0047	< 0.002	0.281	< 0.001	< 0.001		0.0081	< 0.0002		0.0015	
		3.7	3.4	< 0.001	240	11				< 0.001	0.0015		0.01				
		4.6	4.2	< 0.001	260	13				< 0.001	0.0024		0.09				
		3.7	3.9	< 0.001	270	19				< 0.001	0.0037		0.28				
		3.4	3.8	< 0.001	250	24				< 0.001	0.0015		< 0.001				

R001894

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		4.2	4.1	< 0.001	240	20				< 0.001	0.0078		< 0.001				
		1.9	3.5	< 0.001	200	16				< 0.001	0.0012		0.003				
		4.6	4.6	< 0.001	230	20				< 0.001	0.0079		0.025				
0.056	< 0.001	0.91	1.8	< 0.001	180	22	< 0.004	< 0.002	< 0.25	< 0.002	< 0.001		0.0024	< 0.0002		0.0012	
0.035	< 0.001	3	4	< 0.001		30	< 0.004	< 0.002	0.307	< 0.001	0.001		0.012	< 0.0002	0.0014	0.0014	
0.042	< 0.001	4	2.3	< 0.001		26	< 0.004	< 0.002	0.349	0.0044	0.0016		0.0064	< 0.0002	< 0.001	< 0.001	
0.039	< 0.001	2.5	2.4	< 0.001		14	< 0.004	< 0.002	0.452	< 0.001	< 0.001		0.0036	< 0.0002	< 0.001	< 0.001	
0.16	0.0026		0.087	< 0.0025	94	38	< 0.025	< 0.005	0.75		0.035			< 0.0002		< 0.012	
0.079	< 0.001	0.057	0.062	< 0.0005	91	40	0.0059	< 0.001	0.57	< 0.0005	0.0037		0.03	< 0.0002		< 0.0025	
0.075	< 0.001	0.057	0.052	< 0.0005	91	36	< 0.005	< 0.001	0.53	< 0.0005	0.00079		0.0093	< 0.0002		< 0.0025	
						38			0.51								
0.083	< 0.001	0.057	0.058	< 0.0005	110		< 0.005	< 0.001		< 0.0005	0.0016		0.01	< 0.0002		< 0.0025	
0.067	< 0.001	0.035	0.033	< 0.001	100	40	0.0051	< 0.002	0.49	< 0.001	< 0.001		0.012	< 0.0002		0.0014	
0.063	< 0.001	0.023	0.022	< 0.001	93	40	< 0.004	< 0.002	0.54	< 0.001	< 0.001		0.0054	< 0.0002		< 0.001	
		0.024								< 0.001			0.005				
		0.013	0.044	< 0.001	96	35				< 0.001	< 0.001		0.0018				
0.078	< 0.001	0.036	0.052	< 0.001	96	36	< 0.004	< 0.002	0.53	< 0.001	0.001		0.0041	< 0.0002		< 0.001	
		0.043	0.039	< 0.001	95	36				< 0.001	< 0.001		0.0016				
		0.011	< 0.01	< 0.001	96	37				< 0.001	< 0.001		0.001				
		0.081	0.08	< 0.001	94	35				< 0.001	< 0.001		< 0.001				
0.075	< 0.001	< 0.01	0.06	< 0.001	130	32	0.0052	< 0.002	0.501	< 0.001	< 0.001		< 0.001	< 0.0002		0.0022	
		0.066	0.073	< 0.001	97	38				< 0.001	< 0.001		0.0014				
		< 0.01	< 0.01	< 0.001	100	38				< 0.001	< 0.001		< 0.001				
		0.012	0.083	< 0.001	100	36				< 0.001	< 0.001		< 0.001				
0.081	< 0.001	0.014	0.023	< 0.001	110	35	< 0.004	< 0.002	0.51	< 0.001	0.0011		< 0.001	< 0.0002		0.0031	
		0.036	0.031	< 0.001	99	3.8				< 0.001	< 0.001		< 0.001				
		0.022	< 0.01	< 0.001	100	32				< 0.001	< 0.001		< 0.001				
		< 0.01	0.021	< 0.001	130	31				< 0.001	< 0.001		< 0.001				
		0.018	0.027	< 0.001	120	29				< 0.001	0.006		< 0.001				
		0.028	0.019	< 0.001	100	28				< 0.001	0.0024		< 0.001				
		0.015	0.021	< 0.001	100	30				< 0.001	< 0.001		< 0.001				
0.34	0.0016	< 0.02	0.036	< 0.001	170	34	0.043	0.0047	0.486	< 0.002	0.022		< 0.002	< 0.0002		0.0034	
0.096	< 0.001	0.037	0.015	< 0.001		26	< 0.004	< 0.002	0.377	< 0.001	0.0012		< 0.001	< 0.0002	0.0012	0.001	
0.077	< 0.001		0.043	< 0.001	120	28	< 0.004	< 0.002	0.345		< 0.001	0.013		< 0.0002	0.0017	< 0.001	
0.09	< 0.001		0.021	< 0.001	120	23	< 0.004	< 0.002	0.456		0.0014	0.015		< 0.0002	0.0013	0.0018	
0.089	< 0.001	0.027	0.029	< 0.001		28	< 0.004	< 0.002	0.456	< 0.001	< 0.001		< 0.001	< 0.0002	< 0.001	< 0.001	
0.079	< 0.001	0.013	< 0.01	< 0.001	130	22	< 0.004	< 0.002	0.549	< 0.001	< 0.001	0.012	< 0.001	< 0.0002	< 0.001	0.0017	
0.085	< 0.001		0.019	< 0.001	110	23	< 0.004	< 0.002	0.443		< 0.001	< 0.01		< 0.0002	< 0.001	0.0017	
0.081	< 0.001		< 0.01	< 0.001		23	< 0.004	< 0.002	0.445		< 0.001	0.011		< 0.0002	< 0.001	0.002	
0.61	0.0027		0.11	< 0.0025	190	41	0.052	0.04	0.79		0.072			0.00023		< 0.012	
0.22	0.0011	< 0.05	0.074	< 0.0005	110	43	0.037	0.017	0.47	0.028	0.029		1.6	< 0.0002		< 0.0025	
0.093	< 0.001	< 0.05	0.062	< 0.0005	92	39	0.0094	0.0019	0.41	< 0.0005	0.0037		0.02	< 0.0002		< 0.0025	
0.075	< 0.001		0.065	< 0.0005	93	43	< 0.005	< 0.001	0.4		0.00092			< 0.0002		< 0.0025	
		0.073								< 0.0005			0.0037				
0.092	< 0.001	0.02	0.021	< 0.001	100	46	0.033	< 0.002	0.4	< 0.001	0.0031		0.0011	< 0.0002		0.0032	
0.085	< 0.001	0.015	0.019	< 0.001	85	46	0.0092	< 0.002	0.42	< 0.001	0.0029		0.003	< 0.0002		0.0021	
		0.012								< 0.001			0.0055				
		< 0.01	< 0.01	< 0.001	86					< 0.001	< 0.001		0.0021				
0.085	< 0.001	0.016	0.025	< 0.001	97	40	< 0.004	< 0.002	0.38	< 0.001	0.0024		0.0031	< 0.0002		0.003	

R001895

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
		0.031	0.044	< 0.001	110	36				< 0.001	0.0056		0.0054				
0.12	< 0.001		0.027	< 0.001	160	37	0.012	0.0022	0.326		0.0035			< 0.0002		0.0014	
		0.021	0.026	< 0.001	110	30				< 0.001	< 0.001		0.0052				
						34											
		< 0.01	< 0.01	< 0.001	110					< 0.001	0.0011		0.013				
			< 0.01	< 0.001	120	11					0.0012						
		0.022	0.018	< 0.001	110	3.3				< 0.001	< 0.001		< 0.001				
		0.02	0.021	< 0.001	93	18				< 0.001	< 0.001		< 0.001				
		0.012	0.053	< 0.001	130	30				< 0.001	0.0019		< 0.001				
			0.024	< 0.001	84	3.6					0.0033						
		0.032								< 0.001			0.003				
0.09	< 0.001	0.047	0.025	< 0.001		1.2	< 0.004	< 0.002	0.495	< 0.001	0.0013		0.0017	< 0.0002	0.001	< 0.001	
0.078	< 0.001		0.026	< 0.001	93	82	0.016	< 0.002	0.41		< 0.001			< 0.0002		0.0058	
		0.012								< 0.001			0.052				
0.069	< 0.001	0.014	0.014	< 0.001	90	55	0.0063	< 0.002	0.55	< 0.001	0.0025		0.1	< 0.0002		0.0019	
0.15	< 0.001	< 0.01	0.026	< 0.001	97	60	0.022	0.0055	0.43	< 0.001	0.013		0.027	< 0.0002		0.0032	
0.34	0.0018	< 0.01	0.023	< 0.001	170	62	0.034	0.018	0.42	< 0.001	0.033		0.032	< 0.0002		0.0029	
0.086	< 0.001	0.093	0.023	< 0.001	100	85	0.048	< 0.002	0.51	< 0.001	0.0031		0.04	< 0.0002		0.012	
0.098	< 0.001	0.017	0.017	< 0.001	110	82	0.007	0.0028	0.359	< 0.001	0.0059		0.46	< 0.0002		0.0025	
0.11	< 0.001	0.54	0.54	< 0.001		310	0.0092	0.0034	0.336	< 0.001	0.008		0.14	< 0.0002	0.0014	0.041	
0.19	< 0.001	0.5	0.2	< 0.001		180	0.017	0.0066	0.441	< 0.001	0.015		0.39	< 0.0002	0.0026	0.014	
0.095	< 0.001		0.062	< 0.0005	90	59	0.01	0.0059	0.5		0.0092			< 0.0002		< 0.0025	
0.065	< 0.001	0.062	0.056	< 0.0005	81	50	< 0.005	< 0.001	0.5	< 0.0005	0.00068		0.26	< 0.0002		< 0.0025	
0.067	< 0.001	< 0.05	0.057	< 0.0005	80	54	< 0.005	< 0.001	0.43	< 0.0005	0.0013		0.094	< 0.0002		< 0.0025	
0.065	< 0.001	< 0.05	< 0.05	< 0.0005	85	57	< 0.005	< 0.001	0.42	< 0.0005	0.00068		0.059	< 0.0002		< 0.0025	
0.068	< 0.001	< 0.01	0.01	< 0.001	89	69	0.011	< 0.002	0.42	< 0.001	< 0.001		0.022	< 0.0002		0.005	
0.062	< 0.001	< 0.01	< 0.01	< 0.001	91	64	< 0.004	< 0.002	0.43	< 0.001	< 0.001		0.019	< 0.0002		0.0015	
		< 0.01								< 0.001			0.014				
		< 0.01	< 0.01	< 0.001	89	52				< 0.001	< 0.001		0.0088				
0.098	< 0.001	< 0.01	0.016	< 0.001	100	50	< 0.004	0.0029	0.44	< 0.001	0.0052		0.014	< 0.0002		0.0038	
		< 0.01	< 0.01	< 0.001	130	49				< 0.001	< 0.001		0.0033				
		< 0.01	< 0.01	< 0.001	83	51				< 0.001	< 0.001		0.0071				
		0.017	0.019	< 0.001	84	53				< 0.001	< 0.001		0.0035				
0.05	< 0.001	< 0.01	< 0.01	< 0.001	120	51	< 0.004	< 0.002	0.54	< 0.001	< 0.001		0.0049	< 0.0002		0.0041	
		< 0.01	< 0.01	< 0.001	69	54				< 0.001	< 0.001		0.042				
		< 0.01	< 0.01	< 0.001	98	71				< 0.001	< 0.001		0.002				
		< 0.01	< 0.01	< 0.001	97	62				< 0.001	0.001		0.019				
0.06	< 0.001	< 0.01	< 0.01	< 0.001	120	60	< 0.004	< 0.002	0.418	< 0.001	< 0.001		0.0019	< 0.0002		0.0034	
		0.01	0.011	< 0.001	87	56				< 0.001	< 0.001		0.0011				
		< 0.01	< 0.01	< 0.001	88	55				< 0.001	< 0.001		0.0078				
		0.015	0.011	< 0.001	97	55				< 0.001	< 0.001		0.078				
0.058	< 0.001	0.022	0.015	< 0.001	86	54	< 0.004	< 0.002	0.331	< 0.001	< 0.001		0.029	< 0.0002		< 0.001	
		0.038	0.016	< 0.001	94	50				0.022	< 0.001		0.034				
		0.015	0.11	< 0.001	97	56				< 0.001	< 0.001		0.024				
		0.025	0.012	< 0.001	92	63				< 0.001	< 0.001		0.026				
		0.032	0.031	< 0.001	100	74				< 0.001	< 0.001		0.017				
0.029	< 0.001	0.047	0.016	< 0.001	170	46	< 0.004	< 0.002	0.518	< 0.002	< 0.001		0.0033	0.00024		0.0056	
0.11	< 0.001	0.031	0.065	< 0.001		96	0.0042	0.0025	0.361	< 0.001	0.0041		0.013	< 0.0002	0.0015	0.02	
0.096	< 0.001	1.3	1.4	< 0.001		120	0.0047	0.0033	< 0.25	< 0.001	0.0025		0.032	< 0.0002	0.0015	0.017	
0.053	< 0.001		0.63	< 0.001	140	61	< 0.004	< 0.002	0.334		0.0015	0.014		< 0.0002	< 0.001	0.0041	
0.082	< 0.001	0.29	0.26	< 0.001	180	130	< 0.004	< 0.002	0.392	< 0.001	< 0.001	0.012	0.011	< 0.0002	0.043	0.017	

R001896

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.057	< 0.001		0.49	< 0.001		130	< 0.004	< 0.002	0.272		< 0.001	0.011		< 0.0002	< 0.001	0.017	
0.049	< 0.01	< 0.5	< 0.5	< 0.005	63	47	< 0.05	< 0.01	0.37	< 0.005	< 0.005		0.11	< 0.0002		< 0.025	
0.058	< 0.001	0.06	0.062	< 0.0005	59	51	< 0.005	< 0.001	0.37	< 0.0005	0.00055		0.18	< 0.0002		0.0028	
0.052	< 0.001	< 0.05	< 0.05	< 0.0005	66	43	< 0.005	< 0.001	0.33	< 0.0005	< 0.0005		0.13	< 0.0002		0.0027	
0.053	< 0.001	0.05	< 0.05	< 0.0005	63	44	< 0.005	< 0.001	0.39	< 0.0005	< 0.0005		0.13	< 0.0002		0.0026	
0.05	< 0.001	< 0.05	< 0.05	< 0.0005	69	45	< 0.005	< 0.001	0.35	< 0.0005	< 0.0005		0.078	< 0.0002		< 0.0025	
0.11	< 0.001	< 0.05	< 0.05	< 0.0005	120	110	< 0.005	< 0.001	0.26	< 0.0005	0.0007		0.24	< 0.0002		< 0.0025	
		< 0.05	< 0.05	< 0.0005	59	40				< 0.0005	< 0.0005		0.012				
		< 0.05	< 0.05	< 0.0005	61	40				< 0.0005	< 0.0005		0.019				
		< 0.05	< 0.05	< 0.0005	60	41				< 0.0005	0.0006		0.0069				
0.039	< 0.001						< 0.005	< 0.001	0.32					< 0.0002		0.0042	
		< 0.01	< 0.01	< 0.001	66	65				< 0.001	< 0.001		0.0031				
		0.01	< 0.01	< 0.001	60	60				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	58	35				< 0.001	< 0.001		0.018				
0.082	< 0.001	< 0.01	0.012	< 0.001	100	57	< 0.004	0.0024	0.36	< 0.001	0.0055		< 0.001	< 0.0002		0.0051	
		< 0.01	< 0.01	< 0.001	< 0.1	87				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	63	45				< 0.001	< 0.001		0.015				
		< 0.01	< 0.01	< 0.001	60	51				< 0.001	< 0.001		0.0033				
0.047	< 0.001	< 0.01	< 0.01	< 0.001	81	54	< 0.004	< 0.002	0.44	< 0.001	< 0.001		< 0.001	< 0.0002		0.0055	
		< 0.01	< 0.01	< 0.001	65	67				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	72	48				< 0.001	0.0026		0.0073				
		< 0.01	< 0.01	< 0.001	63	46				< 0.001	0.0014		0.0081				
0.036	< 0.001	< 0.01	< 0.01	< 0.001	63	46	< 0.004	< 0.002	0.423	< 0.001	< 0.001		< 0.001	< 0.0002		0.0042	
		< 0.01	< 0.01	< 0.001	67	59				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	73	52				< 0.001	< 0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	72	51				< 0.001	< 0.001		< 0.001				
0.041	< 0.001	< 0.01	< 0.01	< 0.001	69	56	< 0.004	< 0.002	0.338	< 0.001	< 0.001		< 0.001	< 0.0002		0.0031	
		0.017	0.029	< 0.001	73	55				< 0.001	0.001		< 0.001				
		< 0.01	< 0.01	< 0.001	75	55				< 0.001	< 0.001		< 0.001				
		0.013	< 0.01	< 0.001	76	60				< 0.001	0.002		< 0.001				
		< 0.01	< 0.01	< 0.001	74	62				< 0.001	< 0.001		< 0.001				
0.045	< 0.001	0.025	< 0.01	< 0.001	71	67	< 0.004	< 0.002	0.358	< 0.002	< 0.001		0.026	< 0.0002		0.0037	
0.049	< 0.001	0.01	< 0.01	< 0.001		53	< 0.004	< 0.002	0.415	< 0.001	< 0.001		0.074	< 0.0002	0.0019	0.0033	
0.056	< 0.001	0.025	0.024	< 0.001		54	< 0.004	< 0.002	0.318	< 0.001	< 0.001		0.0035	< 0.0002	0.0074	0.0017	
0.11	< 0.001		0.029	< 0.001	120	54	0.019	0.0059	0.343		0.012	0.019		< 0.0002	0.0045	0.0032	
0.048	< 0.001	0.012	< 0.01	< 0.001	60	55	< 0.004	< 0.002	0.466	< 0.001	0.0019	< 0.01	< 0.001	< 0.0002	0.0016	0.0033	
0.045	< 0.001		< 0.01	< 0.001	63	50	< 0.004	< 0.002	0.429		< 0.001	< 0.01		< 0.0002	0.0014	0.0044	
0.044	< 0.001	< 0.01	< 0.01	< 0.001		45	< 0.004	< 0.002	0.497	< 0.001	0.0014		< 0.001	< 0.0002	0.0014	0.0035	
0.045	< 0.001		< 0.01	< 0.001	65	46	< 0.004	< 0.002	0.397		0.0014	< 0.01		< 0.0002	0.0016	0.0048	
0.044	< 0.001		< 0.01	< 0.001		49	< 0.004	< 0.002	0.473		< 0.001	< 0.01		< 0.0002	0.0014	0.0034	
0.14	< 0.001		< 0.01	< 0.001	150	74	0.011	0.0056	0.349		0.0063	0.013		< 0.0002	0.0015	< 0.001	
0.067	< 0.001		0.01	< 0.001	120	55	< 0.004	< 0.002	0.411		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.072	< 0.001		< 0.01	< 0.001	130	72	< 0.004	< 0.002	0.405		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.078	< 0.001		0.012	< 0.001	140	70	< 0.004	< 0.002	0.368		0.0011	< 0.01		< 0.0002	< 0.001	< 0.001	
		< 0.01								< 0.001			0.48				
0.037	< 0.001		3.3	< 0.001	440	3.6	0.0053	0.25	< 0.25		0.0031	0.055		< 0.0002	< 0.001	0.002	
0.015	< 0.001		3.4	< 0.001	330	6	< 0.004	0.24	< 0.25		< 0.001	0.05		< 0.0002	< 0.001	< 0.002	
0.014	< 0.001		3.5	< 0.001	380	3	< 0.004	0.27	0.758		< 0.001	0.046		< 0.0002	< 0.001	< 0.001	
0.053	< 0.001		4.1	0.0012	450	5.3	0.0096	0.28	< 0.25		0.0048	0.051		0.00093	< 0.001	0.0055	
0.021	< 0.001		4	0.0013		< 5	< 0.004	0.27	< 0.25		0.0029	0.054		< 0.0002	< 0.001	0.001	
0.082	< 0.001		6.6	0.001	270	2.8	0.019	0.014	< 0.25		0.015	0.054		< 0.0002	0.006	0.002	

R001897

Barium, total	Beryllium, total	Boron, dissolved	Boron, total	Cadmium, total	Calcium, total L	Chloride, total	Chromium, total	Cobalt, total	Fluoride, total	Lead, dissolved	Lead, total	Lithium, total	Manganese, dissolved	Mercury, total	Molybdenum, total	Selenium, total	Su
0.047	< 0.001		7.4	< 0.001	240	2.2	0.0085	0.0074	0.33		0.0072	0.033		< 0.0002	0.0033	< 0.001	
0.054	< 0.001		6.9	< 0.001		2.6	0.011	0.007	0.463		0.0079	0.047		< 0.0002	0.0034	0.0012	
0.14	< 0.001		0.039	< 0.001	78	6.8	0.0062	< 0.002	0.442		0.0021	< 0.01		< 0.0002	0.004	< 0.001	
0.13	< 0.001		0.064	< 0.001	69	4.1	< 0.004	< 0.002	0.518		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.16	< 0.001		0.014	< 0.001	71	2.7	< 0.004	< 0.002	0.478		< 0.001	< 0.01		< 0.0002	0.0012	< 0.001	
0.24	< 0.001		0.027	< 0.001	140	4.5	0.0073	0.0029	0.485		0.0021	< 0.01		< 0.0002	0.0055	0.0068	
0.2	< 0.001		0.042	< 0.001		4	< 0.004	0.0024	0.539		< 0.001	< 0.01		< 0.0002	0.001	< 0.001	
0.05	< 0.001		2.1	< 0.001	110	53	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.043	< 0.001		1.6	< 0.001	110	49	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.041	< 0.001		1.4	< 0.001	89	46	< 0.004	< 0.002	0.287		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.055	< 0.001		3.2	< 0.001	120	62	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.052	< 0.001		3.4	< 0.001		61	< 0.004	< 0.002	< 0.25		< 0.001	< 0.01		< 0.0002	< 0.001	< 0.001	
0.051	< 0.001		17	0.0012	330	14	0.0051	0.0034	0.454		0.0085	< 0.01		< 0.0002	0.001	< 0.001	
0.018	< 0.001		16	< 0.001	320	11	< 0.004	< 0.002	0.459		0.0023	< 0.01		< 0.0002	< 0.001	< 0.001	
0.02	< 0.001		15	< 0.001	320	9.3	< 0.004	< 0.002	0.544		0.0011	< 0.01		< 0.0002	< 0.001	< 0.001	
0.028	< 0.001		17	< 0.001	280	3.4	< 0.004	0.0038	< 0.25		0.0018	< 0.01		< 0.0002	0.0016	< 0.001	
0.022	< 0.001		13	< 0.001		19	< 0.004	0.0021	0.525		0.0023	< 0.01		< 0.0002	0.0011	< 0.001	
		1.6								< 0.001			5.5				
0.024			1.9			4.4			0.345								
		0.052								< 0.001			0.21				
0.024			0.078			14			0.289								
		0.35								< 0.001			0.035				
		0.14								< 0.001			0.094				

APPENDIX D

GROUNDWATER SAMPLING PROTOCOL

Groundwater Sampling Protocol

The following procedures shall be used in sampling groundwater at the site. This sampling protocol shall apply to the routine quarterly (or modified semi-annual or annual) sampling events. A sample collector's worksheet, comparable to the one located in Exhibit 1, may be used for noting relevant information in regard to each well.

Water Levels

Water levels shall be taken in each well prior to purging and/or sampling. Water levels should be taken as close together as practical, to prevent any time distortion of the water surface data. The following steps shall be followed to obtain accurate water level readings:

1. Note the general condition of the monitoring well on the worksheet. This shall include, but is not limited to the condition of the casing, the lock, evidence of tampering, condition of the pad, and any standing water.
2. Remove the lock and open the monitoring well. Note the condition of the interior of the casing and the condition of the well cap and riser. Open the cap, taking care not to allow dirt or foreign material into the monitoring well.
3. The technician shall rinse the probe and cable of the water level meter with decon water.
4. Slowly lower the probe into the monitoring well until the meter indicates the water surface has been reached.
5. Note the depth to water (to the nearest 0.01 ft) and the time on the worksheet.
6. Lower the probe to the bottom of well. (If a dedicated pump is installed in the well, skip this step). Note the well depth on the worksheet. The depth of the well will be measured on an annual basis, at wells that do not contain dedicated pumps. The depth of wells with dedicated pumps will be measured at least once every 5 years, or whenever the pump is removed.
7. Slowly remove the probe from the well. Rinse the probe and line with decon water.
8. Replace cap. Close and lock the well. Proceed to the next well, and repeat.

Purging of Monitoring Well – Pump Method

After all water level measurements have been taken, the monitoring wells shall be purged to provide a representative sample. Each groundwater monitoring well shall be purged by using a dedicated pump. The pump construction shall consist of inert materials consistent with the monitoring well construction (e.g., stainless steel pump bodies installed in stainless steel wells).

Purging shall be conducted utilizing a "low-flow" or minimal drawdown technique. Flow rates for this technique will typically fall below 0.5 liters/minutes, with an overall goal of not reducing the water level in the monitoring well by more than 0.3 ft during purging. Water levels should be checked frequently to ensure that the drawdown in the well does not exceed the 0.3-ft limits. Every 3 minutes to 5 minutes, readings shall be taken on the following water quality indicators to determine if a representative water sample is available.

- pH (in SU),
- Specific Conductance (in µmhos/cm or µS/cm),
- Temperature (in ºF),
- And, it is suggested, at least one of the following:
  - Redox Potential (in mV);
  - Dissolved Oxygen (in mg/L); and/or
  - Turbidity (in NTU).

The water quality indicators will be considered stabilized when the following tolerances are reached after three consecutive readings:

- pH..... ±0.05 SU
- Specific Conductance ..... ±5 percent
- Temperature..... ±0.5°F
- Redox Potential .....±10 percent
- Dissolved Oxygen.....±10 percent
- Turbidity.....±10 percent

Slow recovering wells require special consideration. If a well is dry, or is purged below the bottom of the pump intake, the well will be allowed to recharge for at least 12 hours. Samples shall be collected until all sample containers have been filled or the well becomes dry. Notes shall be kept on the worksheet with regard to water levels, times, volume of water removed, and any other parameters considered to be relevant.

Purging of Monitoring Well – Bailer Method

Purging and sample collection with a bailer shall be performed in the event of a non-functioning pump or from a well that does not have a dedicated pump installed. A sample shall be collected utilizing a factory packaged, clean, disposable bailer with an appropriate length of new, clean rope attached.

Calculate the number of bailer volumes of water needed to remove one (1) well volume of water.

Well Volume Calculations (2-inch well):

Schedule 40 PVC has an inside diameter of 2.067 inches.

$\therefore ((2.067 \text{ inches}/12 \text{ inches/ft})/2)^2 \cdot \pi \cdot 1 \text{ ft of water} = 0.0233 \text{ ft}^3/\text{ft of water}.$

$0.0233 \text{ ft}^3/\text{ft} \cdot 7.48 \text{ gallons/ft}^3 = 0.174 \text{ gallon/ft}$

Schedule 5 Stainless Steel (304 or 316) has an inside diameter of 2.245 inches.

$\therefore ((2.245 \text{ inches}/12 \text{ inches/ft})/2)^2 \cdot \pi \cdot 1 \text{ ft of water} = 0.0275 \text{ ft}^3/\text{ft of water}.$

$0.0275 \text{ ft}^3/\text{ft} \cdot 7.48 \text{ gallons/ft}^3 = 0.206 \text{ gallon/ft}$

Volume of well (in gallons) = well type gallon/ft • (DTB - DTW); where,
DTB ≡ depth to bottom of well (from measuring point), and
DTW ≡ depth to water (from measuring point)

Bailer Volumes:

Disposable bailer volumes will vary by type and manufacturer. Volume information should be obtained before going to the site. For comparison, a 3 ft stainless steel bailer has a volume of approximately 1220 cc or 0.322 gallon and a 5 ft PVC bailer of approximately 1085 cc or 0.287 gallon.

Open monitoring well, being careful that no potential contaminant enters the well.

Remove one (1) bailer volume of water from the monitoring well. Test pH, specific conductance and temperature. Note values on worksheet. (Turbidity, redox potential and dissolved oxygen will vary considerably due to the agitation a bailer will cause in the well. Testing for these parameters is not recommended with this method.)

Remove one-half (½) gallon of water from the monitoring well. Test pH, specific conductance and temperature. Note values on worksheet.

Remove ½ to 1 gallon of water. Test pH, specific conductance and temperature. Record data on worksheet.

Repeat until pH, specific conductance and temperature stabilize or three (3) well volumes of water have been removed.

If the monitoring well becomes dry, or there is insufficient water to obtain all necessary samples, the monitoring well will be allowed to recharge for 24 hours. Samples shall be collected until all sample containers are filled or the well becomes dry. Notes shall be kept on the worksheet regarding water levels, times, volume of water removed, and any other parameters considered by the technician to be relevant.

If there is sufficient water volume in the monitoring well to obtain all samples, sample collection shall begin at this time.

Sample Collection Order

Samples shall be collected starting at the monitoring well with the least likelihood for contamination. Sampling shall proceed from the well with the lowest potential for contamination to the well with the highest potential for contamination.

Field Measurements

General

Upon arrival at each groundwater monitoring well, the technician shall note on the sampler's worksheet or in a field notebook the date, time, ambient air temperature, general weather conditions, and individuals present, including sample team members and any observers. (Note: Any observers shall need at a minimum, the same personal protective gear as the members of the sample team.)

Establish a "clean area" near the monitoring well where the sample containers and equipment can be stored while not in use. Every effort should be made to keep the sampling equipment and containers from contacting the ground surface. If necessary, a disposable, plastic tarp can be used as a ground cover to prevent potential contamination of the sample containers and equipment. Typically, the back of the field vehicle will be used as the "clean area".

Any non-dedicated sampling equipment (meter probes, thermometers, etc.) shall be washed in a commercial, laboratory cleaner (Alconox®, Liquinox®, or equivalent), and thoroughly rinsed in decon water before each use. Calibration shall be performed at each new monitoring location after the initial decontamination. After use, each device shall be powered down (if necessary) decontaminated, and stored in its manufacturer-approved container.

Temperature

Obtain a water sample from the well. Place the sample aliquot in a disposable container, insert the thermometer (or electronic probe), wait until the readings have stabilized, and record the temperature on the worksheet. Temperature for a glass thermometer should be noted to the nearest degree Fahrenheit (1°F). For electronic thermometers (thermocouples), temperature should be noted to the nearest tenth degree Fahrenheit (0.1°F). The thermometer or probe shall be cleaned and rinsed with decon water after use.

pH

Confirm calibration of the instrument by comparing with an appropriate buffer solution. Adjust for temperature compensation (if meter is not self-compensating). Rinse probe with decon water. Obtain a sample from the well and place the probe in sample aliquot. Note the pH and record on the sample worksheet. Note pH readings to the nearest tenth unit (0.1).

Specific Conductance

Confirm calibration of the instrument by comparing against an appropriate buffer solution. Adjust for temperature compensation (if meter is not self-compensating). Rinse the probe with decon water. Obtain a sample from the well and place the probe in sample aliquot. Note the specific conductance and record on the sample worksheet. Specific conductance should be noted to the nearest micromhos per centimeter (µmhos/cm) or microSiemens per centimeter (µS/cm).

Sample Collection Procedures

Jars and vials may ship pre-labeled from the laboratory, identifying the analysis and preservative for each type of sample. Dependent upon circumstances, sample containers may be prepared by non-laboratory personnel. If so, this should be noted on the sample worksheet or in the field notebook.

A technician shall remove a sample container from the cooler, affix a label, and in indelible, waterproof ink write the well number and/or sample I.D., the facility name, the sample collection date and time, the type of sample in the container, and the sample collector's name. A technician shall organize the containers in the following sampling order:

- Metals and Minerals (dissolved)
- Anions (dissolved)
- Total Dissolved Solids (TDS)
- Cyanides (total)

Dissolved parameters include dissolved metals and minerals, total dissolved solids (TDS), and nitrogen should be field filtered. Samples should be filtered using a 0.45-micron filter attached to the sample pump line. Other filter apparatus may be utilized as long as Illinois EPA guidelines are followed. Filters should be replaced no less frequently than at each new well, and may need to be replaced more often if flow is restricted due to particulate matter in the sample water.

Transportation of Monitoring Samples

Sample Preservation Techniques

The preservation techniques utilized in the groundwater samples will typically adhere to those listed in *Handbook for Sampling and Sample Preservation of Water and Wastewater*, U.S. EPA, EPA-600/4-82-029, September 1982 and/or *Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods*, EPA/530/SW-846, 3rd. Edition, Final Update IV (January 2008).

Transportation of Samples

Samples shall be transported to the laboratory in sealed, insulated shipping containers, ice chests, or coolers. The shipping containers should be sturdy, and if samples are contained in glass bottles, dividers and/or bubble wrap should be used to restrict potential breakage. All samples will be packed in ice or a packaged refrigerant as necessary for proper preservation. Samples should be packed to maintain sample temperatures as close to 4°C (degrees Celsius) or 39°F as possible from the time the samples are collected to the time the samples are received by the laboratory. The samples should be shipped/delivered to the laboratory as soon as practical, preferably within 24 hours of sample collection.

All samples shall be accompanied by a chain-of-custody record. The sampler shall retain a copy of the record and forward the original with the samples to the analytical laboratory. Once the laboratory has received the samples, a representative from the laboratory is to complete the record, retain the original and return a copy with the chemical analysis reports to the sampler. The chain-of-custody shall contain the facility name, the wells sampled, time and date of sampling, members of the sampling party, type of samples (i.e. water, soil, leachate, etc.), number of sample bottles, requested analysis, overnight courier, etc. A sample chain-of-custody record is provided in Exhibit 2.

Attachments
Exhibit 1: Groundwater Sampling Worksheet
Exhibit 2: Example Chain-of-Custody Record

ATTACHMENT J

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 I.A.C. Section 845.430 – Slope Maintenance Documentation for Ash Pond No. 2 at Coffeen Power Plant

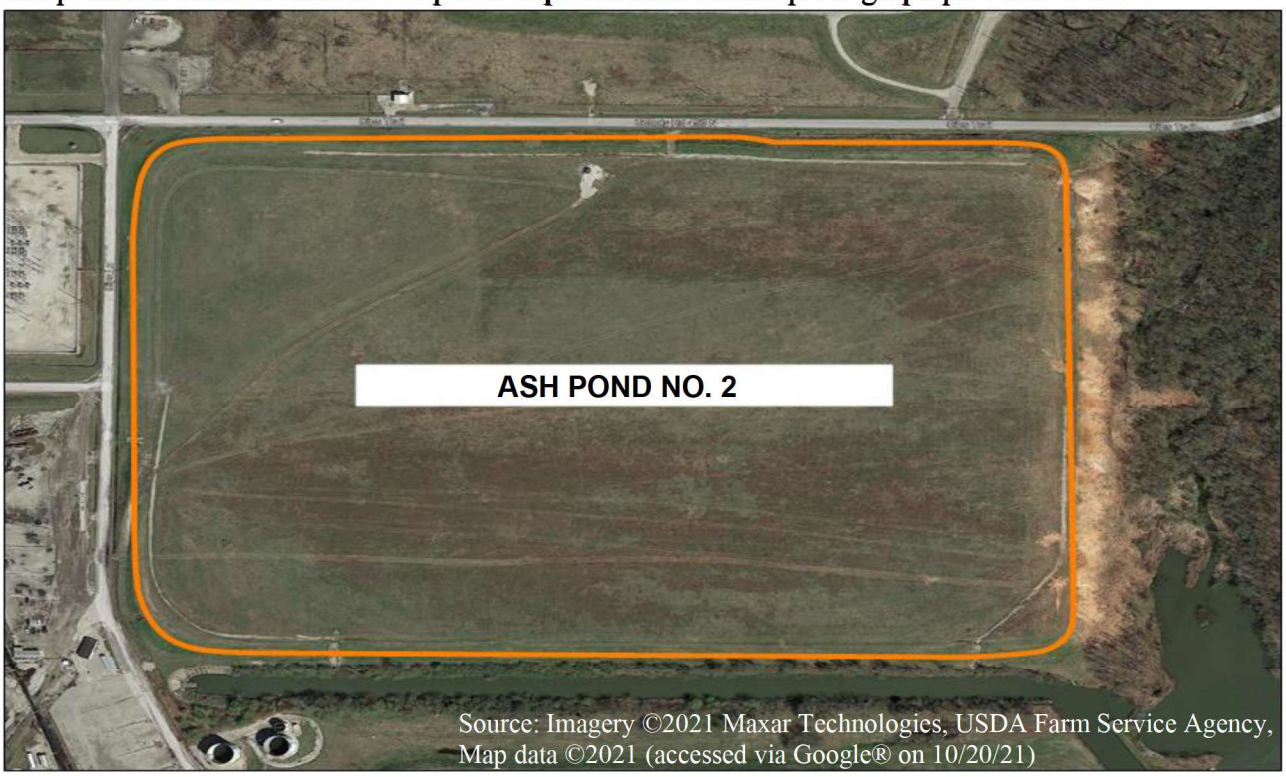
Illinois Power Generating Company operates the coal fired Coffeen Power Plant (Plant) located in Montgomery County, Illinois. The Ash Pond No. 2 is a closed inactive surface impoundment storing coal combustion residuals (CCR). The requirements for the Ash Pond No. 2 are found in 35 Ill. Admin. Code 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845).

Pursuant to Part 845, Section 845.230(d)(3)(C), the initial operating permit application for inactive closed CCR surface impoundments that have completed an Agency approved closure before prior to July 30, 2021, must contain documentation that the CCR surface impoundment, if not incised, will be operated, and maintained with one of the forms of slope protection specified in Section 845.430. This statement addresses the requirements of Part 845, Section 845.430 Slope Maintenance, which states:

> *Section 845.430: The slopes and pertinent surrounding areas of the CCR surface impoundment must be designed, constructed, operated, and maintained with one of the forms of slope protection specified in subsection (a) that meets all the performance standards of subsection (b).*
>
> *Section 845.430(a): Slope protection must consist of one of the following: 1) A vegetative cover consisting of grassy vegetation; 2) An engineered cover consisting of a single form or combination of forms of engineered slope protection measures; or 3) A combination of the forms of cover specified in subsections (a)(1) or (a)(2).*
>
> *Section 845.430(b): Any form of cover for slope protection must meet the following performance standards: 1) The cover must be installed and maintained on the slopes and pertinent surrounding areas of the CCR surface impoundment; 2) The cover must provide protection against surface erosion, wave action, and adverse effects of rapid drawdown; 3) The cover must be maintained to allow for the observation of, and access to, the slopes and pertinent surrounding areas during routine and emergency events; 4) Woody vegetation must be removed from the slopes or pertinent surrounding areas. Any removal of woody vegetation with a diameter greater than 1/2 inch must be directed by a person familiar with the design and operation of the CCR surface impoundment and in consideration of the complexities of removal of a tree or a shrubbery, who must ensure the removal does not create a risk of destabilizing the CCR surface impoundment or otherwise adversely affect the stability and safety of the CCR surface impoundment or*

personnel undertaking the removal; and 5) The height of vegetation must not exceed 12 inches.

Slope protection, consisting of vegetative cover, was installed on the slopes and pertinent surrounding areas of the Coffeen Ash Pond 2, and is inspected, maintained, and repaired as needed. Based on observations from weekly inspections conducted in accordance with Section 845.540(a), and the 2020 annual inspections conducted by Hanson Professional Services Inc., the vegetative cover is described to be in good working condition with a maximum vegetation height of 12 inches. The owner's Operations and Maintenance Plan (O&M Plan) provides details for maintaining grass and removing woody vegetation and addressing erosion features on the slopes. Based on a review of the documentation described above, the owner is implementing the O&M Plan, including the completion of repairs and maintenance as needed and when issues are identified during weekly and/or annual inspections. The slope maintenance portion of the O&M Plan and the Annual Inspection performed by Hanson in 2020 are included in Attachment J. The surface impoundment slope protection (vegetative cover) installed and maintained on the slopes and pertinent areas around the slopes is depicted in the aerial photograph provided below.



Excerpt from the Coffeen AP2 Operations and Maintenance Manual

1.0 Dam Safety Requirements

1.1 Dam Safety Inspections - The plant's impoundment and flood prevention structures shall be inspected and maintained in a manner to ensure safe and environmentally responsible operations. A regular maintenance program shall be performed and shall consist of the following inspection items:

1. Earth embankments: Walk the crest, side slopes, and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlement, slumps, slides, and animal burrows. Frequency of inspection: Weekly.
2. Vegetation: Grass should be a thick vigorous growth to stabilize the earth embankment soils and prevent erosion form occurring. There should be N● trees on the earth embankment and none within a minimum of 20 feet of the embankment toe or other structures. Mowing frequency: Semiannually.
3. Well Readings: Record level of wells on the crest and toe of the berm. Frequency: Quarterly.
4. Special Inspections – Special inspections of the levees and ash pond berms shall be performed after earthquakes, floods, water level exceedance in the ponds, or heavy rainfall events. Inspection and report shall be equal to an annual inspection level of detail. Water level in the pond should be noted after a heavy rainfall. Dam Safety staff shall accompany plant personnel on special inspections. Frequency: As required.

Dam Inspection Report

Name of Dam Coffeen Ash Pond #2 Dam **Dam ID No.** None

Permit Number None **Class of Dam** NA

Location SW 1/4 **Section** 11 **Township** 7N **Range** 3W

Owner Dynegy Midwest Generation, LLC (Name) 217-534-7668 (Telephone Number (Day))

134 CIPS Lane (Street) 217-534-7668 (Telephone Number (Night))

Coffeen, IL (City) 52017 (Zip Code) **County** Montgomery

Type of Dam Earth Embankment

Type of Spillway Surface Riprapped Channels Around Perimeter of Embankment

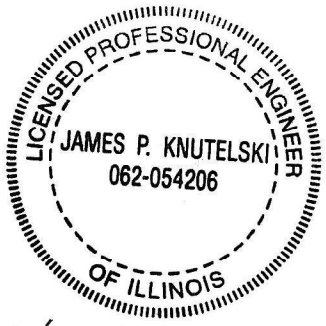
Date(s) Inspected 16-Nov-20

Weather When Inspected Clear

Temperature When Inspected 50° F

Pool Elevation When Inspected NA - pond is closed and capped

Tailwater Elevation When Inspected NA



12/30/2020

Exp 11/30/21

Professional Engineer's Seal

Inspection Personnel:

Name	Title
James Knutelski, PE	Geotechnical Engineer
Jason Campbell, PE	Dynegy Dam Safety Manager
Gina Kramer	IDNR-OWR
John Romang	Coffeen Plant

The Department of Nautural Resources is requesting information that is necessary to accomplish the statutory purpose as outlined under the River, Lakes and Streams Act, 615 ILCS 5. Submittal of this information is REQUIRED. Failure to provide the required information could result in the initiation of non-compliance procedures as outlined in Section 3702.160 of the "Rules for Construction and Maintenance of Dams".

CONDITION CODES

NE - No evidence of a problem

GC - Good condition

MM - Item needing minor maintenance and/or repairs within the year, the safety or integrity of the item is not yet imperiled

IM - Item needing immediate maintenance to restore or ensure its safety or integrity

EC - Emergency condition which if not immediately repaired or other appropriate measures taken could lead to failure of the dam

OB - Condition requires regular observation to ensure that the condition does not become worse

NA - Not applicable to this dam

NI - Not inspected - list the reason for non-inspection under deficiencies

R001909

EARTH EMBANKMENT

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Surface Cracks	NE		
Vertical and Horizontal Alignment of Crest	GC		Pond has been closed and re-graded.
Unusual Movement or Cracking At or Beyond Toe	NE		
Sloughing or Erosion of Embankment and Abutment Slopes	NE		
Upstream Face Slope Protection	NA		
Seepage	NA		
Filter and Filter Drains	NA		

EARTH EMBANKMENT
(Continued)

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Animal Damage	NE		Ash pond is under construction for capping and closure. Contractor is responsible for all items during construction.
Embankment Drainage Ditches	GC		
Vegetative Cover	NE		
Let-down Channels	GC		
Other			
Other			
Other			

R001911

PRINCIPAL SPILLWAY
APPROACH CHANNEL

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Debris	NE		Ash pond is under construction for capping and closure. Contractor is responsible for all items during construction.
Side Slope Stability	NE		
Slope Protection	GC		
Other (Name)	NA		
Other	NA		
Other	NA		
Other	NA		

R001912

EMERGENCY SPILLWAY

☐ Earth

Other: Name None

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Erosion	NA		
Weeds, Logs, Other Obstructions	NA		
Side Slope Sloughing	NA		
Vegetation	NA		
Sedimentation	NA		
Riprap	NA		
Settlement of Crest	NA		
Downstream Channel	NA		
Other (Name)	NA		

SUMMARY OF MAINTENANCE DONE AND/OR

REPAIRS MADE SINCE THE LAST INSPECTION

DATE OF PRESENT INSPECTION 16-Nov-20

DATE OF LAST INSPECTION 22-Oct-19

1. EARTH EMBANKMENT DAMS
   Ash pond is under construction for capping and closure. Contractor is responsible for all items during construction.

2. CONCRETE MASONRY DAMS

   NA

3. PRINCIPAL SPILLWAY

   None Noted

4. OUTLET WORKS

   NA

5. EMERGENCY SPILLWAY

   NA

Owner's Maintenance Statement

I, _____, owner of Coffeen Ash Pond #2 Dam,

Dam Identification Number None, in Montgomery County,

am maintaining the dam in accordance with the accepted maintenance plan which is part of

Permit Number None.

_____
Signature

_____
Date

Owner's Operation and Maintenance Plan Statement

I, _____, owner of Coffeen Ash Pond #2 Dam,

Dam Identification Number None, in Montgomery County,

have reviewed the operation and maintenance plan including the Emergency Action Plan (EAP),

which is part of, Permit Number None.

I _____ have enclosed the appropriate revisions or

_____ have determined that no revisions to the plan are necessary.

_____
Signature

_____
Date

The Department of Nautural Resources is requesting information that is necessary to accomplish the statutory purpose as outlined under the River, Lakes and Streams Act, 615 ILCS 5. Submittal of this information is REQUIRED. Failure to provide the required information could result in the initiation of non-compliance procedures as outlined in Section 3702.160 of the "Rules for Construction and Maintenance of Dams".



East slope and interior



East slope



East toe area



South slope



South slope and interior



West slope



North slope



Southwest corner – lined ditch



Let-down structure - typical

ATTACHMENT K

POST-CLOSURE PLAN FOR EXISTING CCR SURFACE IMPOUNDMENT
40 C.F.R. § 257.104 and 35 I.A.C. 845.780
REV 0 –10/30/2021

SITE INFORMATION			
Site Name / Address	Coffeen Power Plant / 134 Cips Lane, Coffeen, IL 61207		
Owner Name / Address	Illinois Power Generating Company / 6555 Sierra Drive Irving, Texas 75039		
CCR Unit	Ash Pond No. 2	Closure Method and Final Cover Type	Closed In-Place Geomembrane with Soil and Vegetation Cover

POST-CLOSURE PLAN DESCRIPTION	
40 C.F.R. § 257.104(c)(1) and 35 I.A.C. 845.780(c)(1) – Length of post-closure care period.	Post-closure care will be conducted for a period of 30 years as required by 40 C.F.R. § 257.104(c)(1) and 35 I.A.C. 845.780(c)(1), except as provided by 40 C.F.R. § 257.104(c)(2) and 35 I.A.C. 845.780(c)(2).
40 C.F.R. § 257.104(c)(2) and 35 I.A.C. 845.780(c)(2) – Circumstances extending the post closure care period.	If at the end of the post-closure care period the CCR unit is operating under assessment monitoring in accordance with §257.95, the post-closure care as described in this plan will continue until returning to detection monitoring in accordance with §257.95. Under 35 I.A.C. 845.780(c)(2), the post-closure care period will be extended until groundwater monitoring data demonstrate that concentrations are below the groundwater protection standards in Section 845.600 and are not increasing for those constituents over background, using the statistical procedures and performance standards in Section 845.640(f) and (g), provided that concentrations have been reduced to the maximum extent feasible and concentrations are protective of human health and the environment.
40 C.F.R. § 257.104(d)(1)(i) and 35 I.A.C. 845.780(d)(1)(A) – A description of the monitoring and maintenance activities required in40 C.F.R. § 257.104(b) and 35 I.A.C. 845.780(b), and the frequency at which these activities will be performed, to maintain the integrity and effectiveness of the final cover system, maintain the groundwater monitoring system and monitor the groundwater.	Pursuant to § 257.104(b)(1) and 35 I.A.C. 845.780(b)(1), throughout the post-closure care period, periodic visual observations of the final cover system and stormwater management system will be performed at least annually for evidence of settlement, subsidence, erosion, or other damage that may adversely affect the integrity and effectiveness of the final cover system. When practical, visual observations of the final cover will be made concurrent with groundwater monitoring activities. Noted evidence of damage, such as damage to the geosynthetic components, rills, surface cracks and settlement, will be repaired to maintain the integrity and effectiveness of the final cover system. Vegetation will be established and maintained on the final cover system, including storm drainage areas, where appropriate, to provide long-term erosion control. Established vegetation and the slope design of the final cover system will prevent potential erosion and damage that may be caused by run-on and run-off. Repair activities may include, but are not limited to, repairing or replacing damaged geosynthetic components, replacing and

	compacting soil cover, repairing drainage channels that have been eroded, filling in depressions with soil, regrading, and reseeding areas of failed vegetation, as necessary. Pursuant to § 257.104(b)(3) and 35 I.A.C. 845.780(b)(3), the groundwater monitoring system will be maintained, and groundwater will be monitored as required by 40 C.F.R. § 257.90 through 40 C.F.R. § 257.98 and 35 I.A.C. 845.600 through 35 I.A.C. 845.680. Monitoring wells will be inspected during each groundwater sampling event. Monitoring wells and associated instrumentation will be maintained so that they perform to the design specifications throughout the life of the monitoring program. Groundwater monitoring frequency will be at least quarterly, except as provided in 40 C.F.R. § 257.94(d), 257.94(c), and 35 I.A.C. 845.650(b)(4).
40 C.F.R. § 257.104(d)(1)(ii) and 35 I.A.C. 845.780(d)(1)(B) – The name, address, telephone number and email address of the person or office to contact about the facility during the post-closure care period.	Illinois Power Generating Company 6555 Sierra Drive Irving, Texas 75039 800.633.4704 ccr@dynegy.com
40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780(d)(1)(C) – A description of the planned uses of the property during the post-closure period.	The CCR unit is located at a retired electric generation facility. Planned uses of the property during the post-closure period are currently unknown, except for post-closure care of the CCR unit. Post-closure use of the property will not disturb the integrity of the final cover system or other components of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements of 40 C.F.R. Part § 257, Subpart D and 35 I.A.C. Part 845. Any other disturbance will be conducted following a demonstration that it will not increase the potential threat to human health or the environment, as required by 40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780 (d)(1)(C). The demonstration will be certified by a qualified professional engineer and submitted to the Illinois Environmental Protection Agency (IEPA). Per 40 C.F.R. § 257.104(d)(1)(iii) notification shall be provided to the State Director that the demonstration has been placed in the operating record and on the owners or operator's publicly accessible internet site. This CCR unit is closed. A notation on the deed to the property, or some other instrument that is normally examined during title search, will be recorded in accordance with 40 C.F.R. § 257.102(i) and 35 I.A.C. 845.760(h). The notation will notify potential purchasers of the property that the land has been used as a CCR unit and its use is restricted under the post-closure care requirements in 40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780(d)(1)(C) or groundwater monitoring requirements per 35 I.A.C. 845.740(b). Within 30 days of recording the deed notation, a notification stating that the notation has been recorded will be submitted to the IEPA and placed in the facility's operating record per 35 I.A.C. 845.760(h)(3). The notification will be placed on the owner or operator's publicly accessible CCR Web site in accordance with 40 C.F.R. § 257.107(i)(9) and 35 I.A.C. 845.810(e) and placed in the facility's operating record as required by 35 I.A.C. 845.800(d)(26) and §257.105(i)(9).

40 C.F.R. § 257.104(d)(3)(and 35 I.A.C. 845.780(d)(3) – Amendments to the initial or subsequent written post-closure plan.	Pursuant to 40 C.F.R. § 257.104(d), the initial post closure care plan for the Coffeen Ash Pond No. 2 was prepared on October 17, 2016. That plan is being amended pursuant to 40 C.F.R. § 257.104(d)(3)(i). This plan also serves as the initial post-closure care plan, prepared in accordance with 35 I.A.C. 845.780(d). Pursuant to § 257.104(d)(3) and 35 I.A.C. 845.780(d)(3), an operating permit modification application to amend the initial or any subsequent written post-closure care plan developed under 35 I.A.C. 845.780 (d)(1) and § 257.104(d)(1) will be submitted to IEPA. The written post-closure care plan will be amended whenever there is a change in the operation of the CCR surface impoundment that would substantially affect the written post-closure care plan in effect; or unanticipated events necessitate a revision of the written post-closure care plan, after post-closure activities have started. The written post-closure care plan will be amended at least 60 days before a planned change in the operation of the facility or CCR surface impoundment, or within 60 days after an unanticipated event requires the need to revise the existing plan. If the plan is revised after post-closure activities have started, a request to modify the operating permit, including an amended written post-closure care plan, will be submitted to the IEPA within 30 days following the triggering event.
40 C.F.R. § 257.104(d)(4) and 35 I.A.C. 845.780(d)(4) – Qualified professional engineering certification.	Certification by a qualified professional engineer will be appended to this plan and any amendment of this plan.
35 I.A.C. 845.780(e) – Termination of post-closure care.	Upon completion of the post-closure period, a request to terminate post-closure care will be submitted to the IEPA. The request will include a certification by a qualified professional engineer verifying that post-closure care has been completed in accordance with the post-closure care plan specified in 35 I.A.C. 845.780(d) and the requirements of 35 I.A.C. 845.780.
40 C.F.R. § 257.104(e) and 35 I.A.C. 845.780(f) – Notification of completion of the post-closure care period.	A notification of completion of post-closure care will be prepared and placed in the facility's operating record within 30 days after IEPA approval of the request to terminate post-closure care. The notification will be placed in the facility's operating record in accordance with 35 I.A.C. 845.800(d)(31) and § 257.105(i)(13). The notification will be placed on the owner or operator's publicly accessible CCR Internet site in accordance with the requirements of § 257.107(i)(13) and 35 I.A.C. 845.810(e). The IEPA will be notified when the notification has been placed in the operating record and on the owner or operator's publicly accessible Internet site in accordance with the requirements of § 257.106(i)(13).

Certification Statement 40 C.F.R. § 257.104 (d)(4) and 35 I.A.C. 845.780(d)(4) – Amended/Initial Written Post Closure Plan for a CCR Surface Impoundment

CCR Unit: Illinois Power Generating Company; Coffeen Power Plant; Ash Pond No. 2

I, John R. Hesemann, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief, that the information contained in this certification has been prepared in accordance with the accepted practice of engineering. I certify, for the above referenced CCR Unit, that the information contained in the amended/initial written post closure plan, dated October 30, 2021, meets the requirements of 40 C.F.R. § 257.104 and 35 I.A.C. 845.780.

John R. Hesemann

Printed Name

9/27/2021

Date



ATTACHMENT M

RAMBOLL

HISTORY OF POTENTIAL EXCEEDANCES

This presentation of the History of Potential Exceedances, and any corrective action taken to remediate groundwater, is provided to meet the requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.230(d)(2)(M) for the Coffeen Power Plant Ash Pond No. 2, Illinois Environmental Protection Agency (IEPA) ID No. W1350150004-02.

Note

Groundwater concentrations observed from 2015 to 2021 in monitoring wells included in an existing groundwater monitoring program or installed in 2021 have been evaluated and summarized in the following tables. These concentrations are considered potential exceedances because the methodology used to determine them is proposed in the Statistical Analysis Plan (Appendix A to Groundwater Monitoring Plan [GMP]), which has not been reviewed or approved by IEPA at the time of submittal of the 35 I.A.C. § 845 Operating Permit application.

Alternate sources for potential exceedances as allowed by 35 I.A.C. § 845.650(e) have not yet been evaluated. These will be evaluated and presented in future submittals to IEPA as appropriate.

Table 1 summarizes how the potential exceedances were determined. Table 2 is a summary of all potential exceedances.

Results for G154, G279, G410, and G411 are provided in Tables 1 and 2 because they were included in the previously approved GMP. As discussed in the GMP Addendum, wells G154, G279, G410, and G411 have been removed from the monitoring program because these locations are not downgradient of Ash Pond No. 2.

Background Concentrations

Background monitoring wells identified in the GMP include G281, G270, and G280.

Background concentrations calculated from sampling events in 2015-2017 were compared to the standards identified in 35 I.A.C. § 845.600(a)(1). For constituents with calculated background concentrations in 2015-2017 greater than the standards in 35 I.A.C. § 845.600(a)(1), those calculated background concentrations were used as Groundwater Protection Standards (GWPSs) for comparing to statistical calculation results for each compliance well to determine potential exceedances. Compliance well statistical calculations consider concentrations from all sampling events in 2015-2021.

Corrective Action

A Corrective Measures Assessment (CMA) was completed to address statistically significant levels of total cobalt and total lithium, as required by 40 C.F.R. § 257.96. The CMA indicated the source control measure consists of closure in place with a geomembrane cover system in accordance with the Closure and Post Closure Care Plan submitted to the IEPA in January 2017 and approved on January 30, 2018. Closure construction began in July of 2019 and was completed on November 17, 2020.

Activities completed associated with the selection of a groundwater remedy include review of existing groundwater and source water data, and collection of additional samples of groundwater, source water, surface water, and aquifer solids to support analysis of natural attenuation

mechanisms, rates, and aquifer capacity. Preliminary results indicate that site-specific conditions are favorable for implementation of monitored natural attenuation (MNA) in combination with the recently completed closure referenced above.

R001928

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Antimony, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/13/2020 - 08/18/2021	CI around median	0	0.010	0.0043	0.01
A	Barium, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	0.036	2.0	0.18	2
A	Beryllium, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	0.010	2.0	0.022	2
A	Cadmium,total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	8.3	200	75	200
A	Chromium, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	0.61	4.0	0.49	4
A	Lead, total	mg/L	10/13/2020 - 08/18/2021	CI around median	0	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.020	0.040	0.013	0.04
A	Mercury, total	mg/L	10/13/2020 - 08/18/2021	CI around median	0	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	0.000919	0.10	0.0015	0.1
A	pH (field)	SU	01/21/2015 - 08/18/2021	CI around mean	6.9	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	10/13/2020 - 08/18/2021	CI around mean	-0.901	5.0	2.0	5
A	Selenium, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	0.00111	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/13/2020 - 08/18/2021	CI around mean	66	400	370	400
A	Thallium, total	mg/L	10/13/2020 - 08/18/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	01/21/2015 - 08/18/2021	CI around mean	422	1200	840	1200
A	Antimony, total	mg/L	04/13/2015 - 08/18/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	01/21/2015 - 08/18/2021	CI around median	0.001	0.010	0.0043	0.01
A	Barium, total	mg/L	04/13/2015 - 08/18/2021	CB around linear reg	0.020	2.0	0.18	2
A	Beryllium, total	mg/L	04/13/2015 - 08/18/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	01/21/2015 - 08/18/2021	CI around geomean	0.085	2.0	0.022	2
A	Cadmium,total	mg/L	01/21/2015 - 08/18/2021	All ND - Last	0.001	0.005	0.001	0.005

R001929

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Chloride, total	mg/L	01/21/2015 - 08/18/2021	CI around median	57	200	75	200
A	Chromium, total	mg/L	04/13/2015 - 08/18/2021	CI around median	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	04/13/2015 - 08/18/2021	CI around median	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	04/13/2015 - 08/18/2021	CI around mean	0.33	4.0	0.49	4
A	Lead, total	mg/L	01/21/2015 - 08/18/2021	CI around median	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/24/2015 - 08/18/2021	CI around median	0.010	0.040	0.013	0.04
A	Mercury, total	mg/L	04/13/2015 - 08/18/2021	CI around median	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	07/23/2015 - 08/18/2021	CB around T-S line	0.000541	0.10	0.0015	0.1
A	pH (field)	SU	01/21/2015 - 08/18/2021	CI around mean	6.9	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/24/2015 - 08/18/2021	CI around mean	0.65	5.0	2.0	5
A	Selenium, total	mg/L	04/13/2015 - 08/18/2021	CB around linear reg	-0.0027	0.050	0.0012	0.05
A	Sulfate, total	mg/L	01/21/2015 - 08/18/2021	CI around geomean	323	400	370	400
A	Thallium, total	mg/L	04/13/2015 - 08/18/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	01/21/2015 - 08/18/2021	CI around geomean	938	1200	840	1200
A	Antimony, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	11/21/2015 - 08/17/2021	CI around geomean	0.00191	0.010	0.0043	0.01
A	Barium, total	mg/L	11/21/2015 - 08/17/2021	CI around geomean	0.019	2.0	0.18	2
A	Beryllium, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	11/21/2015 - 08/17/2021	CI around median	3.5	2.0	0.022	2
A	Cadmium,total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	11/21/2015 - 08/17/2021	CI around geomean	2.7	200	75	200
A	Chromium, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	11/21/2015 - 08/17/2021	CI around mean	0.22	0.006	0.0056	0.006
A	Fluoride, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.25	4.0	0.49	4
A	Lead, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/21/2015 - 08/17/2021	CI around geomean	0.039	0.040	0.013	0.04

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Mercury, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.001	0.10	0.0015	0.1
A	pH (field)	SU	11/21/2015 - 08/17/2021	CI around mean	6.0	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/21/2015 - 08/17/2021	CI around geomean	0.74	5.0	2.0	5
A	Selenium, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	11/21/2015 - 08/17/2021	CI around median	2000	400	370	400
A	Thallium, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	11/21/2015 - 08/17/2021	CI around median	2800	1200	840	1200
A	Antimony, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	-0.00803	0.010	0.0043	0.01
A	Barium, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	-0.00763	2.0	0.18	2
A	Beryllium, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	11/21/2015 - 08/17/2021	CI around mean	5.5	2.0	0.022	2
A	Cadmium,total	mg/L	11/21/2015 - 08/17/2021	Most recent sample	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	11/21/2015 - 08/17/2021	CI around mean	1.8	200	75	200
A	Chromium, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	-0.00638	0.10	0.011	0.1
A	Cobalt, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	-0.00375	0.006	0.0056	0.006
A	Fluoride, total	mg/L	11/21/2015 - 08/17/2021	CI around median	0.30	4.0	0.49	4
A	Lead, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	-0.00606	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	0.011	0.040	0.013	0.04
A	Mercury, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	0.000642	0.10	0.0015	0.1
A	pH (field)	SU	11/21/2015 - 08/17/2021	CB around linear reg	6.7	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/21/2015 - 08/17/2021	CB around linear reg	-1.04	5.0	2.0	5
A	Selenium, total	mg/L	11/21/2015 - 08/17/2021	CB around T-S line	-0.00028	0.050	0.0012	0.05
A	Sulfate, total	mg/L	11/21/2015 - 08/17/2021	CB around T-S line	421	400	370	400

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SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Thallium, total	mg/L	11/21/2015 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	11/21/2015 - 08/17/2021	CI around mean	1600	1200	840	1200
A	Antimony, total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.001	0.010	0.0043	0.01
A	Barium, total	mg/L	11/23/2015 - 08/17/2021	CB around linear reg	0.079	2.0	0.18	2
A	Beryllium, total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	11/23/2015 - 08/17/2021	CI around mean	0.020	2.0	0.022	2
A	Cadmium,total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	11/23/2015 - 08/17/2021	CI around mean	3.7	200	75	200
A	Chromium, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	11/23/2015 - 08/17/2021	CI around mean	0.36	4.0	0.49	4
A	Lead, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.020	0.040	0.013	0.04
A	Mercury, total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.001	0.10	0.0015	0.1
A	pH (field)	SU	11/23/2015 - 08/17/2021	CI around mean	6.9	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/23/2015 - 08/17/2021	CI around mean	0.49	5.0	2.0	5
A	Selenium, total	mg/L	11/23/2015 - 08/17/2021	CI around median	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	11/23/2015 - 08/17/2021	CB around linear reg	28	400	370	400
A	Thallium, total	mg/L	11/23/2015 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	11/23/2015 - 08/17/2021	CI around geomean	317	1200	840	1200
A	Antimony, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.001	0.010	0.0043	0.01
A	Barium, total	mg/L	10/07/2015 - 08/17/2021	CI around mean	0.040	2.0	0.18	2
A	Beryllium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004

R001932

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Boron, total	mg/L	10/07/2015 - 08/17/2021	CI around mean	2.6	2.0	0.022	2
A	Cadmium,total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	164	200	75	200
A	Chromium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.25	4.0	0.49	4
A	Lead, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/21/2015 - 08/17/2021	CB around linear reg	0.017	0.040	0.013	0.04
A	Mercury, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.10	0.0015	0.1
A	pH (field)	SU	10/07/2015 - 08/17/2021	CI around mean	6.9	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/21/2015 - 08/17/2021	CI around mean	0.57	5.0	2.0	5
A	Selenium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/07/2015 - 08/17/2021	CI around mean	203	400	370	400
A	Thallium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	837	1200	840	1200
A	Antimony, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/07/2015 - 08/17/2021	CB around T-S line	-0.0105	0.010	0.0043	0.01
A	Barium, total	mg/L	10/07/2015 - 08/17/2021	CI around geomean	0.020	2.0	0.18	2
A	Beryllium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	3.2	2.0	0.022	2
A	Cadmium,total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/07/2015 - 08/17/2021	CI around geomean	9.2	200	75	200
A	Chromium, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/07/2015 - 08/17/2021	CI around mean	0.42	4.0	0.49	4

R001933

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Lead, total	mg/L	10/07/2015 - 08/17/2021	CB around T-S line	-0.00599	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	11/21/2015 - 08/17/2021	CB around T-S line	0.010	0.040	0.013	0.04
A	Mercury, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.001	0.10	0.0015	0.1
A	pH (field)	SU	10/07/2015 - 08/17/2021	CI around mean	6.8	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	11/21/2015 - 08/17/2021	CI around geomean	0.57	5.0	2.0	5
A	Selenium, total	mg/L	10/07/2015 - 08/17/2021	CI around median	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	195	400	370	400
A	Thallium, total	mg/L	10/07/2015 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	720	1200	840	1200
A	Antimony, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	0.010	0.0043	0.01
A	Barium, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	2.0	0.18	2
A	Beryllium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	2.0	0.022	2
A	Cadmium,total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.99	200	75	200
A	Chromium, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.066	4.0	0.49	4
A	Lead, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.020	0.040	0.013	0.04
A	Mercury, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/14/2020 - 08/17/2021	CI around median	0	0.10	0.0015	0.1
A	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.2	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	10/14/2020 - 08/17/2021	CI around mean	-0.441	5.0	2.0	5

R001934

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Selenium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	-191	400	370	400
A	Thallium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/14/2020 - 08/17/2021	CI around median	0	1200	840	1200
A	Antimony, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.010	0.0043	0.01
A	Barium, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.011	2.0	0.18	2
A	Beryllium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.038	2.0	0.022	2
A	Cadmium,total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	8.1	200	75	200
A	Chromium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.25	4.0	0.49	4
A	Lead, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.033	0.040	0.013	0.04
A	Mercury, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.00122	0.10	0.0015	0.1
A	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.4	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	10/14/2020 - 08/17/2021	CI around mean	-0.476	5.0	2.0	5
A	Selenium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	177	400	370	400
A	Thallium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/14/2020 - 08/17/2021	CI around mean	1520	1200	840	1200
A	Antimony, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	-0.000536	0.010	0.0043	0.01

R001935

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Barium, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.12	2.0	0.18	2
A	Beryllium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.077	2.0	0.022	2
A	Cadmium,total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	304	200	75	200
A	Chromium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.004	0.10	0.011	0.1
A	Cobalt, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	0.00188	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.25	4.0	0.49	4
A	Lead, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.020	0.040	0.013	0.04
A	Mercury, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.10	0.0015	0.1
A	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.2	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	10/14/2020 - 08/17/2021	CI around mean	-0.742	5.0	2.0	5
A	Selenium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	30	400	370	400
A	Thallium, total	mg/L	10/14/2020 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/14/2020 - 08/17/2021	CI around mean	502	1200	840	1200
A	Antimony, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.003	0.006	0.003	0.006
A	Arsenic, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.010	0.0043	0.01
A	Barium, total	mg/L	10/13/2020 - 08/17/2021	CI around mean	0.022	2.0	0.18	2
A	Beryllium, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.004	0.001	0.004
A	Boron, total	mg/L	10/13/2020 - 08/17/2021	CI around mean	0.00782	2.0	0.022	2
A	Cadmium,total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.005	0.001	0.005
A	Chloride, total	mg/L	10/13/2020 - 08/17/2021	CI around mean	2.4	200	75	200
A	Chromium, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.004	0.10	0.011	0.1

SU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standar
A	Cobalt, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.002	0.006	0.0056	0.006
A	Fluoride, total	mg/L	10/13/2020 - 08/17/2021	CI around mean	0.56	4.0	0.49	4
A	Lead, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.0075	0.0063	0.0075
A	Lithium, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.020	0.040	0.013	0.04
A	Mercury, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.0002	0.002	0.0002	0.002
A	Molybdenum, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.10	0.0015	0.1
A	pH (field)	SU	10/13/2020 - 08/17/2021	CI around mean	6.8	6.5/9.0	6.7/7.3	6.5/9
A	Radium-226 + Radium 228, tot	pCi/L	10/13/2020 - 08/17/2021	CI around mean	-0.774	5.0	2.0	5
A	Selenium, total	mg/L	10/13/2020 - 08/17/2021	CI around median	0	0.050	0.0012	0.05
A	Sulfate, total	mg/L	10/13/2020 - 08/17/2021	CI around mean	141	400	370	400
A	Thallium, total	mg/L	10/13/2020 - 08/17/2021	All ND - Last	0.001	0.002	0.001	0.002
A	Total Dissolved Solids	mg/L	10/13/2020 - 08/17/2021	CI around mean	567	1200	840	1200

R001937

l used to calculate the statistical result:
e below the reporting limit, and the last determined reporting limit is shown
lence band around linear regression
nce band around Thiel-Sen line
ence interval around the geometric mean
: interval around the mean
ce interval around the median
for the most recently collected sample used due to insufficient data
n accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
e the lower / upper limits
n Standard

l in 35 I.A.C. § 845.600(a)(1)
ncentration (see cover page for additional information)

S

HSU	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	
UA	Boron, total	mg/L	11/21/2015 - 08/17/2021	CI around median	3.5	2.0	0.022	2	
UA	Cobalt, total	mg/L	11/21/2015 - 08/17/2021	CI around mean	0.22	0.006	0.0056	0.006	
UA	pH (field)	SU	11/21/2015 - 08/17/2021	CI around mean	6.0	6.5/9.0	6.7/7.3	6.5/9	S
UA	Sulfate, total	mg/L	11/21/2015 - 08/17/2021	CI around median	2000	400	370	400	
UA	Total Dissolved Solids	mg/L	11/21/2015 - 08/17/2021	CI around median	2800	1200	840	1200	
UA	Boron, total	mg/L	11/21/2015 - 08/17/2021	CI around mean	5.5	2.0	0.022	2	
UA	Sulfate, total	mg/L	11/21/2015 - 08/17/2021	CB around T-S line	421	400	370	400	
UA	Total Dissolved Solids	mg/L	11/21/2015 - 08/17/2021	CI around mean	1600	1200	840	1200	
UA	Boron, total	mg/L	10/07/2015 - 08/17/2021	CI around mean	2.6	2.0	0.022	2	
UA	Boron, total	mg/L	10/07/2015 - 08/17/2021	CB around linear reg	3.2	2.0	0.022	2	
UA	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.2	6.5/9.0	6.7/7.3	6.5/9	S
UA	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.4	6.5/9.0	6.7/7.3	6.5/9	S
UA	Total Dissolved Solids	mg/L	10/14/2020 - 08/17/2021	CI around mean	1520	1200	840	1200	
UA	Chloride, total	mg/L	10/14/2020 - 08/17/2021	CI around mean	304	200	75	200	
UA	pH (field)	SU	10/14/2020 - 08/17/2021	CI around mean	6.2	6.5/9.0	6.7/7.3	6.5/9	S

R001938

graphic unit:
aquifer
per liter
per liter
:s
on = method used to calculate the statistical result:
reg = Confidence band around linear regression
ne = Confidence band around Thiel-Sen line
= Confidence interval around the mean
n = Confidence interval around the median
calculated in accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
presented are the lower / upper limits
ater Protection Standard

dard specified in 35 I.A.C. § 845.600(a)(1)
ackground concentration (see cover page for additional information)

ATTACHMENT N

Certification of Financial Assurance Requirements

On June 17, 2021, Illinois Power Generating Company provided financial assurance in the form of performance bonds to the Illinois Environmental Protection Agency in the amount of $27,884,983 for Ash Pond 1, Ash Pond 2, and the GMF Pond System at the Coffeen Power Plant.[1]

I, Matthew A. Goering, Senior Vice President of Illinois Power Generating Company, do hereby certify to the best of my knowledge for the above referenced CCR Units that the financial assurance instruments satisfy the requirements of 35 I.A.C. Part 845, Subpart I.



Matthew A. Goering
Senior Vice President
Illinois Power Generating Company

[1]In the operating permit applications, the GMF Pond System is referred to as the GMF Gypsum Stack Pond and GMF Recycle Pond.

October

DOCUMENT 12

Rees, Jeromy

From: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Sent: Monday, December 11, 2023 1:24 PM
To: Terranova, Sara; Diers, Stefanie; Sofat, Sanjay; Logan-Pugh, Joey L.; Dunaway, Lynn; Summers, Michael
Cc: Hunt, Lauren; Rompot, Derek
Subject: RE: CCR meeting with NGO
Attachments: Enviro initial questions for IEPA for 12.2023 meeting.pdf

Attached is what they sent me late last week.

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

From: Terranova, Sara <Sara.Terranova@Illinois.gov>
Sent: Monday, December 11, 2023 10:10 AM
To: Diers, Stefanie <Stefanie.Diers@Illinois.gov>; LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Subject: CCR meeting with NGO

Is there an agenda for that meeting?

State of Illinois - CONFIDENTIALITY NOTICE: The information contained in this communication is confidential, may be attorney-client privileged or attorney work product, may constitute inside information or internal deliberative staff communication, and is intended only for the use of the addressee. Unauthorized use, disclosure or copying of this communication or any part thereof is strictly prohibited and may be unlawful. If you have received this communication in error, please notify the sender immediately by return e-mail and destroy this communication and all copies thereof, including all attachments. Receipt by an unintended recipient does not waive attorney-client privilege, attorney work product privilege, or any other exemption from disclosure.

Environmental Groups' questions for IEPA in advance of meeting on CCR

1) **Status of applications for operating and closure permits**, including particularly sites classified in Categories 1-4 of the prioritization categories under Part 845. Specific sites we would like to focus on include: Lincoln Stone Quarry, Wood River, CWLP, Edwards, and Vermilion.

    a. How is IEPA determining the order in which it evaluates permit applications? Is it taking into consideration those prioritization categories in determining which to evaluate?

    b. In addition to sites where adjusted standard petitions remain pending, are there other categories of sites that IEPA is choosing not to focus on in permitting? If so, what are those categories of sites and why is IEPA not moving forward on them for the moment?

    c. What other factors are slowing/hindering IEPA review of permit applications?

2) Deficiency letters:

    a. Can you describe your process for reviewing these applications and how these letters fit into the process?

    b. Do those letters reflect a full review of the applications, or are they more of a "completeness" review with further in-depth review to follow?

    c. Can IEPA remind companies to ensure that follow-up submissions are posted on their website as part of their permit application?

    d. What actions will IEPA take if a permit applicant does not respond to a review letter, takes too long to respond, or their response is insufficient?

    e. Would IEPA consider including a deadline for companies to respond, understanding that those deadlines will vary by the severity of the deficiency and how long it would take to provide the necessary information?

3) **Engagement with USEPA:**

    a. "Primary" or "delegation" application:

        i. Regarding the primacy application, you mentioned in the October meeting that some of us were in that some documents or questions had been shared with USEPA, but IEPA was waiting to hear back from USEPA. Have you heard back?

        ii. Is IEPA continuing the conversation with USEPA about the application?

        iii. Do you have any sense of the timeline for submission of the full "primacy" application to USEPA?

    b. USEPA decisions and guidance:

        i. Is IEPA in communication with USEPA considering individual permit decisions?

ii. Is IEPA reviewing or considering USEPA's implementation of the federal CCR rule (e.g. proposed and final "Part A" decisions, letters to operators and states, rule preambles) in evaluating permit applications and/or determining scope of regulated impoundments? If so, in what ways?

4) **Questions concerning specific sites**:

a. Wood River
   i. What is the status of CTI's operating permit application? As discussed before, the application CTI submitted on 11/1/2022 is deficient (incomplete, frequently refers to a different site, etc). In March 2022, and again in June 2022, IEPA said it was working with CTI on this issue. What has happened since then?

   ii. What is the status of CTI's closure permit application? IEPA issued a Violation Notice to CTI for failure to submit a closure permit application on July 26, 2022. The only related document we have seen so far is a 12/2022 closure alternatives analysis for the East Ash Pond. We have seen no other filings re: closure of the East Ash Pond, and no filings at all re: closure of the West Ash Pond Complex.

   iii. We wanted to make sure you're aware that CTI's CCR reporting website has **zero** documents from 2023 and **one** document (closure alt. analysis for East Pond) in all of 2022. Has IEPA discussed this lack of documentation with CTI? If not, what does IEPA plan to do about it?

b. Lincoln Stone Quarry
   i. What is the status of IEPA review of the applications for this site? Have you had discussions with the applicant or USEPA concerning this site?

   ii. Have you reviewed the analyses we sent regarding concerns with the application?

c. Edwards:
   i. *Note: We will plan to share analysis discussing multiple significant concerns with the closure and operating permit applications in advance of this meeting.

   ii. Have you discussed, with the applicant or USEPA, any additional deficiencies in the application beyond those noted in the 10/2023 letter? If so, what are those?

5) **NPDES permits**:

a. Is IEPA considering the relationship between NPDES permits re dewatering (ponded and subsurface waters) and CCR closure permits? How so, and how does that affect IEPA's timeline in issuing one before the other? IEPA seems to be issuing NPDES permits for dewatering (that is, removing both ponded and subsurface water) before approval of closure plans (e.g. Vermilion, Coffeen). Does closure method have no bearing on dewatering? For example, at Coffeen, the dewatering plan is to put the reject water back into the impoundment. This would seem to rule out closure by removal.

6) **Alternate Source Determinations**: How is IEPA addressing ASDs when it hasn't yet evaluated the groundwater monitoring system to determine if monitoring program meets regulatory requirements?

DOCUMENT 13

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Tuesday, December 12, 2023 7:54 AM
To: LeCrone, Darin; Terranova, Sara; Diers, Stefanie; Sofat, Sanjay; Logan-Pugh, Joey L.; Summers, Michael
Cc: Hunt, Lauren; Rompot, Derek
Subject: RE: CCR meeting with NGO
Attachments: Enviro initial questions for IEPA for 12.2023 meeting.pdf

I forwarded the attached document to Gabe, since the NGOs have enforcement related questions, and I didn't see his name in the contacts.

From: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Sent: Monday, December 11, 2023 1:24 PM
To: Terranova, Sara <Sara.Terranova@Illinois.gov>; Diers, Stefanie <Stefanie.Diers@Illinois.gov>; Sofat, Sanjay <Sanjay.Sofat@Illinois.gov>; Logan-Pugh, Joey L. <Joey.L.Logan-Pugh@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Rompot, Derek <Derek.Rompot@Illinois.gov>
Subject: RE: CCR meeting with NGO

Attached is what they sent me late last week.

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

From: Terranova, Sara <Sara.Terranova@Illinois.gov>
Sent: Monday, December 11, 2023 10:10 AM
To: Diers, Stefanie <Stefanie.Diers@Illinois.gov>; LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Subject: CCR meeting with NGO

Is there an agenda for that meeting?

State of Illinois - CONFIDENTIALITY NOTICE: The information contained in this communication is confidential, may be attorney-client privileged or attorney work product, may constitute inside information or internal deliberative staff communication, and is intended only for the use of the addressee. Unauthorized use, disclosure or copying of this communication or any part thereof is strictly prohibited and may be unlawful. If you have received this communication in error, please notify the sender immediately by return e-mail and destroy this communication and all copies thereof, including all attachments. Receipt by an unintended recipient does not waive attorney-client privilege, attorney work product privilege, or any other exemption from disclosure.

Environmental Groups' questions for IEPA in advance of meeting on CCR

1) **Status of applications for operating and closure permits**, including particularly sites classified in Categories 1-4 of the prioritization categories under Part 845. Specific sites we would like to focus on include: Lincoln Stone Quarry, Wood River, CWLP, Edwards, and Vermilion.

    a. How is IEPA determining the order in which it evaluates permit applications? Is it taking into consideration those prioritization categories in determining which to evaluate?

    b. In addition to sites where adjusted standard petitions remain pending, are there other categories of sites that IEPA is choosing not to focus on in permitting? If so, what are those categories of sites and why is IEPA not moving forward on them for the moment?

    c. What other factors are slowing/hindering IEPA review of permit applications?

2) Deficiency letters:

    a. Can you describe your process for reviewing these applications and how these letters fit into the process?

    b. Do those letters reflect a full review of the applications, or are they more of a "completeness" review with further in-depth review to follow?

    c. Can IEPA remind companies to ensure that follow-up submissions are posted on their website as part of their permit application?

    d. What actions will IEPA take if a permit applicant does not respond to a review letter, takes too long to respond, or their response is insufficient?

    e. Would IEPA consider including a deadline for companies to respond, understanding that those deadlines will vary by the severity of the deficiency and how long it would take to provide the necessary information?

3) **Engagement with USEPA:**

    a. "Primary" or "delegation" application:

        i. Regarding the primacy application, you mentioned in the October meeting that some of us were in that some documents or questions had been shared with USEPA, but IEPA was waiting to hear back from USEPA. Have you heard back?

        ii. Is IEPA continuing the conversation with USEPA about the application?

        iii. Do you have any sense of the timeline for submission of the full "primacy" application to USEPA?

    b. USEPA decisions and guidance:

        i. Is IEPA in communication with USEPA considering individual permit decisions?

ii. Is IEPA reviewing or considering USEPA's implementation of the federal CCR rule (e.g. proposed and final "Part A" decisions, letters to operators and states, rule preambles) in evaluating permit applications and/or determining scope of regulated impoundments? If so, in what ways?

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   i. What is the status of CTI's operating permit application? As discussed before, the application CTI submitted on 11/1/2022 is deficient (incomplete, frequently refers to a different site, etc). In March 2022, and again in June 2022, IEPA said it was working with CTI on this issue. What has happened since then?

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   iii. We wanted to make sure you're aware that CTI's CCR reporting website has **zero** documents from 2023 and **one** document (closure alt. analysis for East Pond) in all of 2022. Has IEPA discussed this lack of documentation with CTI? If not, what does IEPA plan to do about it?

b. Lincoln Stone Quarry
   i. What is the status of IEPA review of the applications for this site? Have you had discussions with the applicant or USEPA concerning this site?

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c. Edwards:
   i. *Note: We will plan to share analysis discussing multiple significant concerns with the closure and operating permit applications in advance of this meeting.

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5) **NPDES permits**:

a. Is IEPA considering the relationship between NPDES permits re dewatering (ponded and subsurface waters) and CCR closure permits? How so, and how does that affect IEPA's timeline in issuing one before the other? IEPA seems to be issuing NPDES permits for dewatering (that is, removing both ponded and subsurface water) before approval of closure plans (e.g. Vermilion, Coffeen). Does closure method have no bearing on dewatering? For example, at Coffeen, the dewatering plan is to put the reject water back into the impoundment. This would seem to rule out closure by removal.

6) **Alternate Source Determinations**: How is IEPA addressing ASDs when it hasn't yet evaluated the groundwater monitoring system to determine if monitoring program meets regulatory requirements?

DOCUMENT 14

From: Hunt, Lauren
To: Bierwagen, Justin; Mullenax, Heather
Subject: FW: CCR meeting with NGO
Date: Tuesday, December 12, 2023 8:33:58 AM
Attachments: Enviro initial questions for IEPA for 12.2023 meeting.pdf

FYI….if you could provide an update on your sites regarding their questions on this agenda. We have a meeting with the NGOs next Thursday (21st). I have answers regarding LSQ and Wood River. Our enforcement lawyers will need to answer for wood River as well. however, I do not have answers regarding Edwards and Vermillion (Gabe should have answers for Vermillion). This meeting will include management all the way to the Bureau Chief. I would like to discuss in person the intricacies.

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
Illinois Environmental Protection Agency
Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
Lauren.hunt@illinois.gov
Hours: 8:30 am to 5:30 pm Tuesday through Friday
8:30 am to 4 pm Mondays and alternating Mondays off
Working remotely Mondays and Fridays.

From: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Sent: Monday, December 11, 2023 1:24 PM
To: Terranova, Sara <Sara.Terranova@Illinois.gov>; Diers, Stefanie <Stefanie.Diers@Illinois.gov>; Sofat, Sanjay <Sanjay.Sofat@Illinois.gov>; Logan-Pugh, Joey L. <Joey.L.Logan-Pugh@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Rompot, Derek <Derek.Rompot@Illinois.gov>
Subject: RE: CCR meeting with NGO

Attached is what they sent me late last week.

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6) **Alternate Source Determinations**: How is IEPA addressing ASDs when it hasn't yet evaluated the groundwater monitoring system to determine if monitoring program meets regulatory requirements?

DOCUMENT 15

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Tuesday, December 12, 2023 7:51 AM
To: Neibergall, Gabriel
Subject: FW: CCR meeting with NGO
Attachments: Enviro initial questions for IEPA for 12.2023 meeting.pdf

Gabe,
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Lynn

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DOCUMENT 16

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From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 8:12 AM
To: Hunt, Lauren; Bierwagen, Justin; Mullenax, Heather; Garee, Matthew J.
Cc: Summers, Michael
Subject: FW: Vistra 845 Review Letter Meeting

Will Tuesday 12/19 at 1 PM work for all of you? If not, we can ask about Thursday 12/21.
Please let me know.

From: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Sent: Wednesday, December 13, 2023 7:53 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Subject: [External] Vistra 845 Review Letter Meeting

Lynn,

Tuesday 12/19 at 1PM at your office works for our team (5 Vistra folks from the technical team and 1 groundwater consultant). Will that work for you all?

We'd like to get a better understanding of what you all are looking for regarding the following topics:

1) Waste characterization
2) Groundwater modeling
3) Groundwater data (lab reports, field records)
4) Issues identified with MDL's, stats, and background values (would be helpful if you all could walk through some specific examples on this topic)

Thanks,

Rhys Fuller
Vistra Corp
618-975-1799

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DOCUMENT 17

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 8:35 AM
To: LeCrone, Darin
Cc: Summers, Michael
Subject: FW: Vistra 845 Review Letter Meeting

Darin,
Dynegy has asked for a meeting to discuss the items below. These are focused on groundwater issues, so I don't know that anyone from permits is required, but I wanted you to be aware of the meeting.

Lynn

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DOCUMENT 18

Rees, Jeromy

From: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Sent: Wednesday, December 13, 2023 8:51 AM
To: Dunaway, Lynn
Cc: Summers, Michael
Subject: RE: Vistra 845 Review Letter Meeting

Go ahead and let whoever from permits it is assigned to know, and see if they want to sit in. it doesn't sound like I need to be there, but it might not be a bad idea for the permit engineer to sit in, just so they can keep up with what's going on with the site.

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DOCUMENT 19

Rees, Jeromy

From: Garee, Matthew J. <Matthew.Garee@Illinois.gov>
Sent: Wednesday, December 13, 2023 9:30 AM
To: Hunt, Lauren; Dunaway, Lynn; Bierwagen, Justin; Mullenax, Heather
Cc: Summers, Michael
Subject: RE: Vistra 845 Review Letter Meeting

1 PM on the 19th work for me.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 13, 2023 8:45 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: RE: Vistra 845 Review Letter Meeting

Yep. My calendar is up to date.

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
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Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
Lauren.hunt@illinois.gov
Hours: 8:30 am to 5:30 pm Tuesday through Friday
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Subject: RE: Vistra 845 Review Letter Meeting

I'll let the permit writers know

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From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 8:35 AM
To: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: FW: Vistra 845 Review Letter Meeting

Darin,
Dynegy has asked for a meeting to discuss the items below. These are focused on groundwater issues, so I don't know that anyone from permits is required, but I wanted you to be aware of the meeting.

Lynn

From: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Sent: Wednesday, December 13, 2023 7:53 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Subject: [External] Vistra 845 Review Letter Meeting

Lynn,

Tuesday 12/19 at 1PM at your office works for our team (5 Vistra folks from the technical team and 1 groundwater consultant). Will that work for you all?

We'd like to get a better understanding of what you all are looking for regarding the following topics:

1) Waste characterization
2) Groundwater modeling
3) Groundwater data (lab reports, field records)
4) Issues identified with MDL's, stats, and background values (would be helpful if you all could walk through some specific examples on this topic)

Thanks,

Rhys Fuller
Vistra Corp
618-975-1799

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DOCUMENT 21

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 10:08 AM
To: Fuller, Rhys
Subject: RE: Vistra 845 Review Letter Meeting

Rhys,
Can you tell me which facilities you're most interested in? I want to invite the permit writer, even if these are groundwater focused questions.
Thanks,
Lynn

From: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Sent: Wednesday, December 13, 2023 7:53 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Subject: [External] Vistra 845 Review Letter Meeting

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DOCUMENT 22

From: Fuller, Rhys
To: Dunaway, Lynn
Subject: [External] RE: Vistra 845 Review Letter Meeting
Date: Wednesday, December 13, 2023 11:46:57 AM

Got it, thank you for setting this up.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 11:12 AM
To: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Subject: RE: Vistra 845 Review Letter Meeting

EXTERNAL EMAIL

When the invite arrives please note I shifted the time from 1:00 to 1:30 so we could be in the larger room.

From: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Sent: Wednesday, December 13, 2023 10:15 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Subject: [External] RE: Vistra 845 Review Letter Meeting

Lynn,

The topics relate to comments that were generally made in all of the initial review letters which include Edwards, Newton, Duck Creek, Hennepin, and Coffeen. We could certainly focus on one site's specific comments if that helps – Coffeen and Hennepin might be good cases given they have multiple units both closed and open.

Will you send out a calendar invite or would you like me to do that?

Thanks,

Rhys

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, December 13, 2023 10:08 AM
To: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Subject: RE: Vistra 845 Review Letter Meeting

EXTERNAL EMAIL

Rhys,
Can you tell me which facilities you're most interested in? I want to invite the permit writer, even if these are groundwater focused questions.

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From: Fuller, Rhys <Rhys.Fuller@vistracorp.com>
Sent: Wednesday, December 13, 2023 7:53 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Subject: [External] Vistra 845 Review Letter Meeting

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4. Issues identified with MDL's, stats, and background values (would be helpful if you all could walk through some specific examples on this topic)

Thanks,

Rhys Fuller
Vistra Corp
618-975-1799

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DOCUMENT 23

Luminant

Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234

December 15, 2023
Illinois Environmental Protection Agency
DWPC – Permits MC#15
Attn: 35 I.A.C. § 845.650(e) Alternative Source Demonstration Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Re: Coffen Power Plant Ash Pond No 2; IEPA ID # W1350150004-02

Dear Mr. LeCrone:

In accordance with Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.650(e), Illinois Power Generating Company (IPGC) is submitting this Alternative Source Demonstration (ASD) for the sulfate and TDS exceedance observed at well G407 from the Quarter 2 2023 sampling event at the Coffeen Power Plant Ash Pond No. 2, identified by Illinois Environmental Protection Agency (IEPA) ID No. W1350150004-02.

This ASD is being submitted within 60 days from the date of determination of an exceedance of a groundwater protection standard (GWPS) for constituents listed in 35 I.A.C. § 845.600. As required by 35 I.A.C. § 845.650 (e)(1), the ASD was placed on the facility's website within 24 hours of submittal to the agency.

One hard copy is provided with this submittal.

Sincerely,

Dianna Tickner

Dianna Tickner
Sr. Director – Decommission and Demolition

Enclosures
Alternate Source Demonstration, Quarter 2 2023, Ash Pond No.2 Coffeen Power Plant, Coffeen Illinois

Geosyntec consultants

engineers | scientists | innovators

Alternative Source Demonstration - G407 Sulfate and Total Dissolved Solids

Coffeen Power Plant Ash Pond No. 2
(Unit ID #102)
IEPA ID: W1350150004-02
35 I.A.C. 845.650

Prepared for

Illinois Power Generating Company
134 Cips Lane
Coffeen, Ilinois 62017

Prepared by

Geosyntec Consultants, Inc.
500 W. Wilson Bridge Rd., Suite 250
Worthington, OH 43085

Project Number: GLP8029

December 2023

Geosyntec consultants

Alternative Source Demonstration - G407 Sulfate and Total Dissolved Solids

Coffeen Power Plant Ash Pond No. 2
(Unit ID #102)
IEPA ID: W1350150004-02
35 I.A.C. § 845.650

Prepared for

Illinois Power Generating Company
134 Cips Lane
Coffeen, Illinois 62017

Prepared by

Geosyntec Consultants, Inc.
500 W. Wilson Bridge Rd., Suite 250
Worthington, OH 43085

License No.: 062.040562
Expires: 11/30/2025



John Seymour, P.E.
Senior Principal

Project Number: GLP8029

December 2023

Geosyntec consultants

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Attachment 2: G407 Boring Log and Well Construction Diagram

Attachment 3: Compiled Potentiometric Surface Maps

Attachment 4: Groundwater Model Output

Geosyntec consultants

ACRONYMS AND ABBREVIATIONS

ASD	Alternative source demonstration
AP2	Ash Pond No. 2
CCR	Coal combustion residuals
CPP	Coffeen Power Plant
DA	Deep aquifer
EPRI	Electric Power Research Institute
GWPS	Groundwater protection standard
HCR	Hydrogeologic site characterization report
IAC	Illinois Administrative Code
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
LCU	Lower confining unit
LOE	Line of evidence
mg/L	milligrams per liter
NID	National Inventory of Dams
TDS	Total dissolved solids
UA	Uppermost aquifer
UCU	Upper confining unit
USEPA	United States Environmental Protection Agency

Geosyntec consultants

1. INTRODUCTION

Geosyntec Consultants, Inc. has prepared this alternative source demonstration (ASD) on behalf of Illinois Power Generating Company (IPGC) regarding the Ash Pond No. 2 coal combustion residuals (CCR) unit at the Coffeen Power Plant (CPP) near Coffeen, Illinois. The ASD is completed pursuant to Illinois Administrative Code (IAC) Title 35, Part 845 ("Standards for the Disposal of CCR in Surface Impoundments") and was completed by December 15, 2023, within 60 days of determination of the exceedances (October 16, 2023), as required by 35 I.A.C.§ 845.650(e). This report applies specifically to the CCR Unit referred to as Ash Pond No. 2 (AP2), identification (ID) number (No.) 102, IEPA ID No. W1350150004-02, and National Inventory of Dams (NID) ID No. IL50723 and was prepared in conformance with guidance provided in the Electric Power Research Institute (EPRI) guidance for development of ASDs at CCR sites (EPRI 2017), and the United States Environmental Protection Agency (USEPA)'s Solid Waste Disposal Facility Criteria: Technical Manual (USEPA 1993).

An exceedance of sulfate was identified above the site-specific groundwater protection standard (GWPS) of 400 milligrams per liter (mg/L) at monitoring well G407 following the Second Quarter 2023 sampling event. An exceedance of total dissolved solids (TDS) was identified above the site-specific GWPS of 1,200 mg/L at monitoring well G407 following the Second Quarter 2023 sampling event. TDS represents the mass of dissolved material in the water rather than a specific chemical constituent. The TDS exceedance at G407 is controlled by the elevated concentrations of sulfate.

Under 35 IAC 845.650(e), the owner or operator of a CCR surface impoundment may submit a demonstration that a source other than the CCR surface impoundment caused the contamination and the CCR surface impoundment did not contribute to the contamination, or that the exceedance of the groundwater protection standard resulted from error in sampling, analysis, or statistical evaluation, natural variation in groundwater quality, or a change in the potentiometric surface and groundwater flow direction.

Pursuant to 35 IAC 845.650(e), the lines of evidence (LOEs) documented in this ASD demonstrate that a source other than the CPP AP2 CCR unit was the cause of the GWPS exceedances for sulfate and TDS at downgradient monitoring well G407 and that AP2 did not contribute to the exceedance. Anthropogenic impacts associated with CPP operations was identified as the alternative source for elevated sulfate and TDS concentrations at G407.

2. BACKGROUND

2.1 Site Location and Description

The CPP, operated by the IPGC is located in Montgomery County, Illinois approximately two miles south of the City of Coffeen in Section 11, Township 7 North, and Range 7 East. The CPP is located between the two lobes of Coffeen Lake to the west, east, and south, and is bordered by agricultural land to the north. The CPP operated as a coal-fired power plant from 1964 to November 2019 and has five CCR management units. The approximately 1,100-acre Coffeen Lake was built by damming the McDavid Branch of the East Fork of Shoal Creek in 1963 for use as an artificial cooling lake for the CPP. The CPP and vicinity, including G407 and AP2, are located on a peninsula of land between two lobes of Coffeen Lake. Historically, coal mines were operated at depth in the vicinity of the CPP and a US Minerals processing facility is located to the north. An aerial view of the site is shown in shown in **Attachment 1**.

2.2 Description of the CCR Unit

Coffeen AP2 is an unlined surface impoundment with a surface area of approximately 60 acres, with berms up to 47 feet above the surrounding land surface. AP2 was removed from service and capped in the mid-1980s using a two-foot compacted clay and soil cap (Ramboll 2019).

AP2 was recapped starting in 2019 using a geomembrane cover system in accordance with a closure plan submitted to the Illinois Environmental Protection Agency (IEPA; AECOM, 2017). The cover system installation was completed on November 17, 2020. The geomembrane cap design addresses the potential for slope failure and water infiltration into the closed CCR unit by directing the drainage of surface water (i.e., precipitation) off the cover system.

2.3 Geology and Hydrogeology

Significant site investigation has been completed to fully characterize the geology, hydrogeology, and groundwater quality as provided in the AP2 Initial Operating Permit Application (Burns & McDonnell 2021) and the Hydrogeologic Site Characterization Report (HCR) for AP2 (NRT 2017). These materials are incorporated herein.

There are multiple layers of unlithified material present beneath AP2 and above bedrock which are categorized into hydrostratigraphic units listed below (from the surface downward) based on stratigraphic relationships and hydrogeologic characteristics:

- **Upper Confining Unit (UCU):** Composed of the Roxana and Peoria Silts (Loess Unit) and the upper clayey portion of the Hagarstown member which are classified as silts-clayey silts and gravelly clay below the surficial soil.

- **Uppermost Aquifer (UA):** Composed of the Hagarstown Member which is classified as primarily sandy-gravelly silts and clays with beds of sedimentary deposits. Beds consist of thin

(generally less than three feet in thickness), moderate to high permeability sand, silty sand, and sandy silt/clay units.

- **Lower Confining Unit (LCU):** Comprised of the Vandalia Member, Mulberry Grove Member, and Smithboro Member. The LCU in the vicinity of AP2 consists of thick (generally greater than 15 feet), very low permeability sandy to silty till or clay till.

- **Deep Aquifer (DA):** Comprised of sand and sandy silt/clay units of the Yarmouth Soil, which include accretionary deposits of fine sediment and organic materials, typically less than five feet thick and discontinuous across the CPP.

Bedrock is comprised of the Pennsylvanian-age Bond Formation, which consists of limestone and calcareous clays and shale. Geologic cross-sections modified from versions provided in the Hydrogeologic Characterization Report are provided as **Figure 1**. CCR within AP2 is underlain by the UCU in the majority of the footprint.

G407 is screened from 13.8 to 18.6 ft. bgs (604.6 to 600.0 ft elevation [North American Vertical Datum of 1988, NAVD88]). The boring log for G407, provided in **Attachment 2**, indicates that the lithology of the screened interval is a yellowish brown silt with little fine-to coarse-grained sand.

The potentiometric groundwater contours and generalized groundwater flow directions at the site are shown in **Attachment 3**. Groundwater flow in the vicinity of AP2 is generally to the south and east. The groundwater to the west of AP2 is separated from the groundwater flow regime under AP2 by a groundwater divide. More information regarding this groundwater divide is provided in Section 3.1.

The groundwater monitoring well network for AP2 consists of 11 monitoring wells: three background monitoring wells (G270, G280, G281) and eight compliance monitoring locations (G1001, G401, G402, G403, G404, G405, G406, G407) (**Attachment 1**). Monitoring wells within the network are screened in the UA from approximately elevations 600 to 610 ft.

Monitoring well G407 was originally included in the IEPA-approved Closure Plan monitoring well network, which consisted of fourteen groundwater monitoring wells used to monitor the UA, including three background wells (G270, G280, and G281) and eleven compliance wells (G154, G279, G401, G402, G403, G404, G405, G406, G407, G410, and G411) (NRT 2017). Monitoring wells G154, G279, G407, G410, and G411 were included in the IEPA groundwater monitoring plan to monitor sulfate in groundwater that could potentially be attributed to AP2. These wells were monitored in accordance with Water Pollution Control Permit 2020-EA-65027-1 Special Condition No. 6. An Addendum to the Groundwater Monitoring Plan (Ramboll 2021a) submitted with the Operating Permit (Burns & McDonnell 2021) noted that while G407 is on the opposite side of the groundwater divide from AP2, it would continue to be monitored due to the elevated concentrations of sulfate at that location.

3. G407 ASD LINES OF EVIDENCE

Monitoring well G407 and AP2 are located on opposite sides of a groundwater flow divide which presents a barrier to flow from AP2 toward G407. This groundwater divide is evidenced through groundwater potentiometric surface mapping and modeling, site topography, and groundwater chemistry at the site. This groundwater divide prevents groundwater underlying AP2 from migrating to G407; therefore, the sulfate and TDS exceedances are not attributed to AP2, as discussed below.

3.1 LOE #1 Groundwater Does Not Flow from AP2 to G407 due to the Presence of a Groundwater Divide

Compliance well G407 is located directly west of AP2 (**Attachment 1**). Groundwater flow from beneath AP2 has consistently been southeast. Potentiometric surface maps constructed by Ramboll since November 2016 (**Attachment 3**) indicate that groundwater flow from AP2 towards G407 has never been observed, regardless of season (Ramboll 2021b). Groundwater flow at G407 is predominantly southwest and is separated from groundwater flow beneath AP2 by a groundwater divide located near the western edge of AP2 and occasionally centered around G403. This groundwater divide is present in all potentiometric surface maps generated for the monitoring network between 2016 and 2023 (**Attachment 3**) and is likely related to thinning of the Hagarstown Beds under the western portions of AP2 (NRT 2017). The presence of the known groundwater divide indicates that the observed sulfate and TDS exceedances at G407 cannot be contributed to AP2, as G407 is not hydrologically downgradient of AP2.

The most recent groundwater modeling for AP1 and the historical modeling for AP2 completed by Ramboll indicate that at steady state the groundwater divide separates G407 and AP2 in alignment with the observed flow directions from groundwater measurements. CPP and the areas monitored by the well networks are located on a peninsula between two lobes of Coffeen Lake; groundwater naturally flows from the central portions of the peninsula toward the eastern and western lobes of Coffeen Lake. Groundwater potentiometric surface maps (**Attachment 3**) which include monitoring wells present throughout the peninsula clearly illustrate this flow pattern since monitoring under the 40 C.F.R. 257 regulations began in 2015. Calibration of the groundwater flow model also supports the presence of this flow pattern and the groundwater divide located between AP2 and G407 (**Attachment 4**).

Given the presence of this groundwater divide between AP2 and monitoring well G407, impacts from AP2 would not be observed at G407 and the sulfate and TDS exceedances should be attributed to an alternative source.

3.2 LOE #2 The Presence of a Surface Water Divide Further Supports the Presence of a Groundwater Divide

A surface water divide has also been noted in the vicinity of AP2. The CPP and vicinity, including G407 and AP2, are located on a peninsula of land between two lobes of Coffeen Lake. Topography of the land surface determines which direction precipitation (surface water) will drain towards lower elevations (Coffeen Lake). Connecting the high topographic areas within the peninsula defines the location of a surface water divide (**Figure 3**). Surface water present on the west side of

the divide drains toward the west lobe of Coffeen Lake and water that falls on the east side of the divide flows toward the east lobe of Coffeen Lake. As illustrated on **Figure 3**, G407 is located on the west side of the divide and AP2 is located on the east side of the divide; therefore, surface water from AP2 will not flow west in the direction of G407.

Shallow unconfined groundwater flow typically follows topography (flowing from high head to low head) and the attached groundwater potentiometric surface maps confirm that groundwater flows in the same direction as surface water (**Attachment 3**).

3.3 LOE #3 G407 Does Not Contain Elevated Levels of Boron, which is Indicative of AP2 Leachate

The co-located detection of elevated boron and sulfate concentrations has been noted as a key indicator of the presence of CCR constituents related to AP2 (NRT 2017). Boron concentrations at G407 are consistent with background, with reported values ranging between 0.06 and 0.15 mg/L for groundwater sampling events completed between March 2018 and May 2023 (**Figure 2**). This concentration range is substantially lower than concentrations observed at wells which are known to be impacted by AP2, such as G404, which exhibited boron concentrations two orders of magnitude greater than G407 (up to 15.0 mg/L) over the same time interval.

As shown in **Figure 4,** boron concentrations at G407 are comparable to other unimpacted wells within the monitoring network, including the background wells (G270, G280, and G281) and compliance well G403, which is located cross-gradient of AP2 near the center of the groundwater flow divide. Monitoring locations which are located on the same side of the flow divide as AP2 and downgradient of the unit, such as G404 and G405, tend to exhibit much higher boron concentrations which are indicative of impacts from AP2. These results support the presence of the groundwater divide between AP2 and G407.

The lack of elevated boron concentrations at G407 on the west side of the groundwater divide suggests that the sulfate and associated TDS exceedances observed in groundwater at G407 are not attributable to impacts from AP2. Instead, the presence of elevated sulfate may be attributed to a host of anthropogenic sources at the site, such as the historical mining activities, coal storage activities, construction of engineered features such as railroad beds or parking lots, material handling, or similar.

4. CONCLUSIONS

It has been demonstrated that the sulfate and TDS exceedances at G407 are not due to a release from the AP2 CCR unit and that the unit has not contributed to the exceedance, but instead the exceedance is attributed to a source other than AP2. The following summarizes the three LOEs used to support the sulfate and TDS demonstration:

1. Groundwater beneath AP2 does not flow to G407, as demonstrated by temporally consistent potentiometric surface maps of groundwater elevation across the site and groundwater flow modeling showing a groundwater divide between AP2 and the well of concern.

2. The presence of a surface water divide between AP2 and G407 provides further support for the presence of the groundwater divide which prevents potential migration of groundwater from underneath AP2 to the well of concern. Therefore, G407 is not impacted by the AP2 unit.

3. Groundwater at G407 does not contain elevated boron that would indicate impacts from AP2 leachate. The lack of elevated boron at G407 compared to wells in the immediate vicinity of G407 provides further evidence in support of the presence of the groundwater divide between the unit and G407.

The GWPS exceedances of sulfate and TDS at G407 are not attributable CPP AP2, as the groundwater divide at the CPP prevents migration of groundwater along that flow path. Instead, the exceedances are attributed to impacts from anthropogenic industrial activities that have historically occurred at the CPP. This demonstration fulfills the requirements of both 35 IAC 845.650(e) and the technical manual for the Municipal Solid Waste Landfill federal regulatory program (Code of Federal Regulations, Title 40, Section 258).

Geosyntec consultants

5. REFERENCES

AECOM. 2017. *Closure and Post-Closure Care Plan for the Coffeen Ash Pond No. 2 at Illinois Power Generating Company Coffeen Power Station*. January.

Burns & McDonnell. 2021. *Initial Operating Permit, Coffeen Ash Pond 2*. October.

Illinois Environmental Protection Agency (IEPA). 2016. *Dynegy Midwest Generation, Inc. – Baldwin Energy Complex: Baldwin Fly Ash Pond System Closure – NPDES Permit No. IL000043*, letter from William Buscher (IEPA) to Rick Diericx (Dynegy Operating Company), dated August 16, 2016.

Natural Resource Technology, Inc. (NRT). 2017. *Hydrogeologic Site Characterization Report, Ash Pond 2, Coffeen Power Station, Coffeen, Illinois*. January.

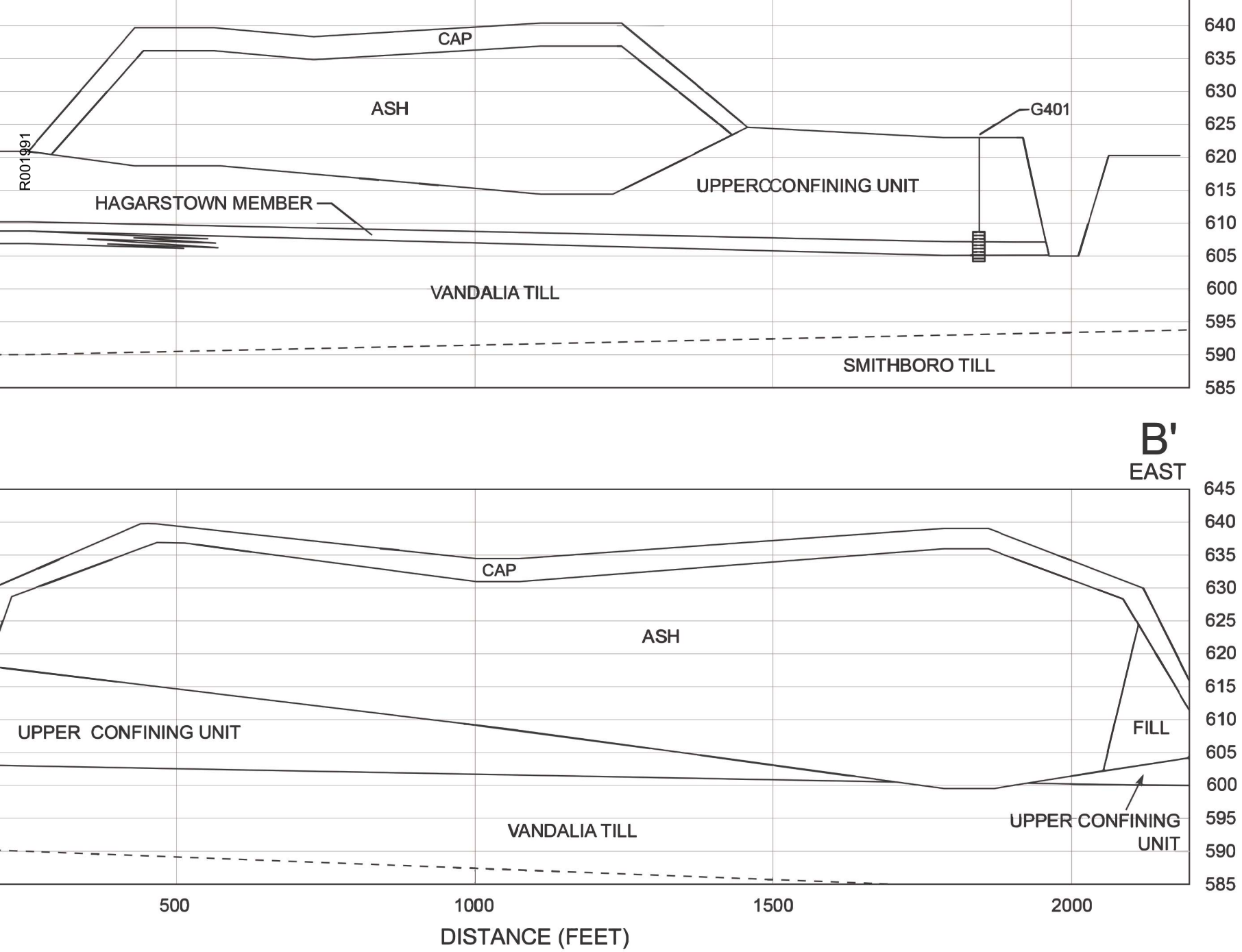
Ramboll. 2021a. *Groundwater Monitoring Plan Addendum for Ash Pond No. 2. Coffeen Power Plant, Coffeen, IL*. Ramboll Americas Engineering Solutions, Inc. October.

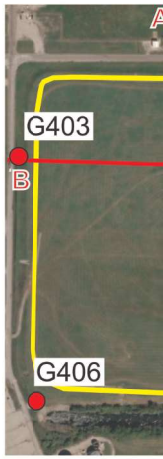
Ramboll. 2021b. *Hydrogeologic Site Characterization Report, Ash Pond No. 1, Coffeen Power Plant, Coffeen, Illinois*. Ramboll Americas Engineering Solutions, Inc. October.

Ramboll. 2023. *35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances – Quarter 2, 2023. Ash Pond No. 2, Coffeen Power Plant, Coffeen, Illinois.* Ramboll Americas Engineering Solutions, Inc. October.

United States Environmental Protection Agency (USEPA). 1993. *Criteria for Solid Waste Disposal Facilities: A Guide for Owners/Operators*. March.

FIGURES





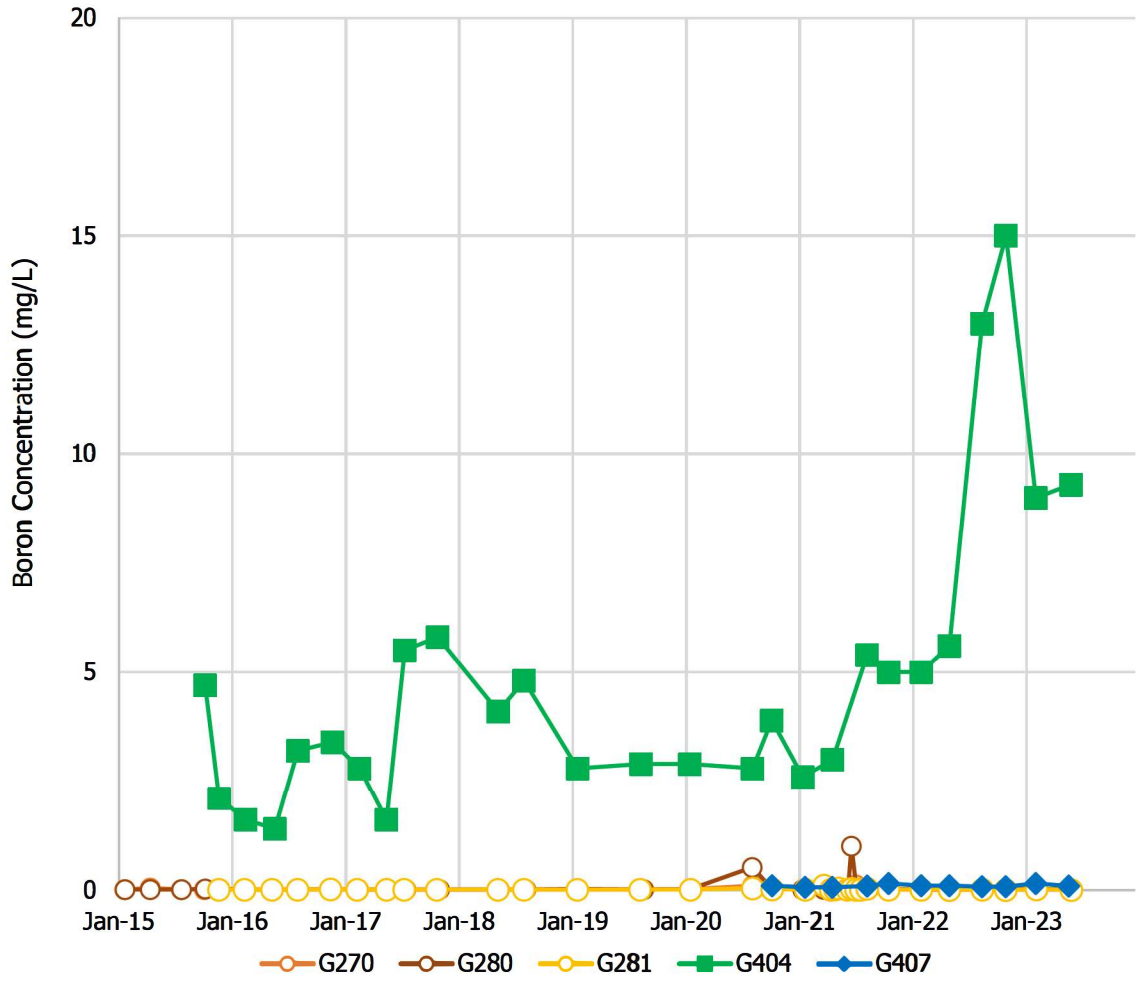
VERTICAL SCALE IN FEET

VERT

Notes

- Well locations are approximate
- Geologic cross-sections modified from Hydrogeologic Monitoring Plan (Natural Resource Technology, 2017)
- Cap thickness is approximate

Ash Pond



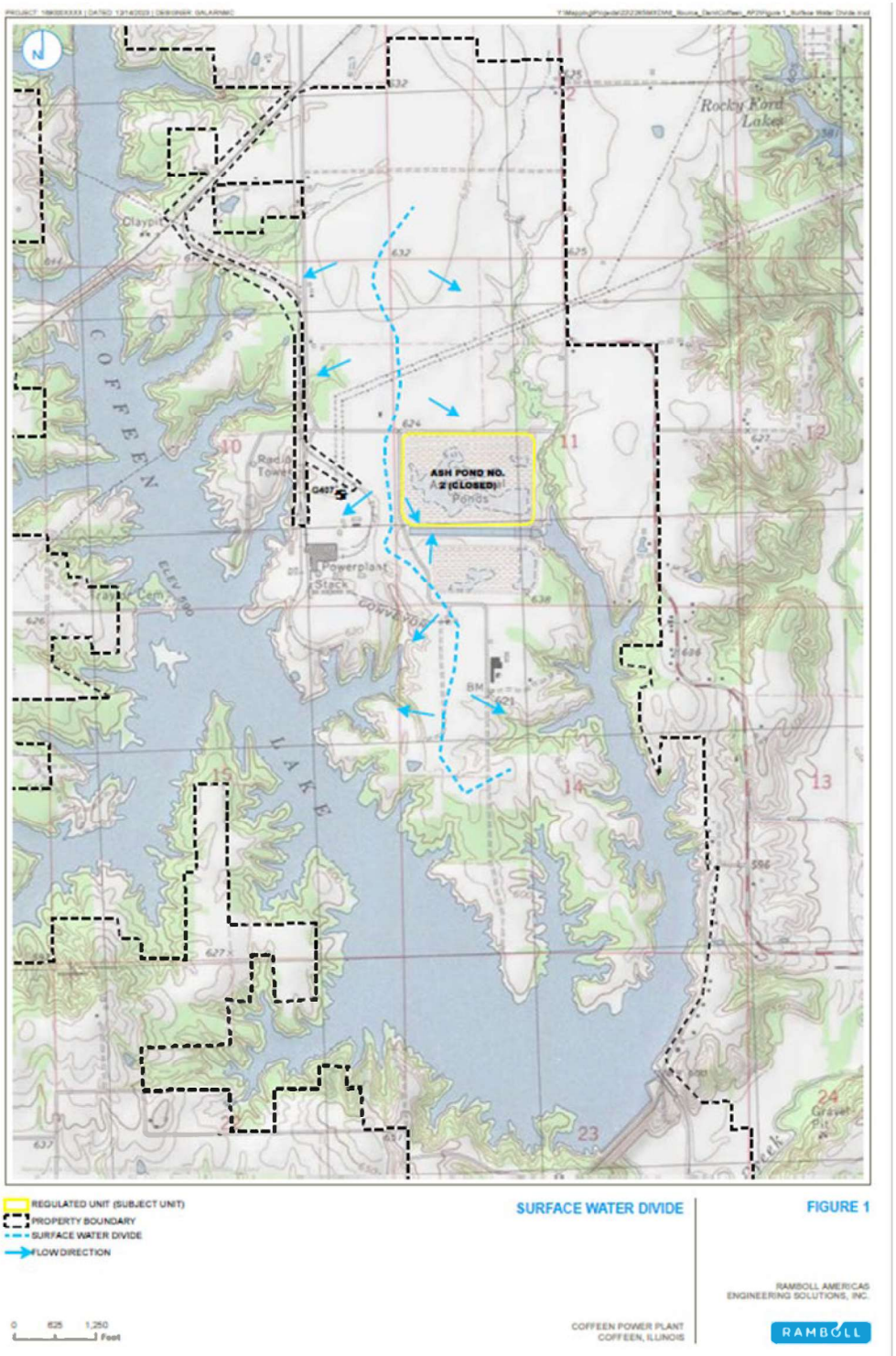
Notes: Total boron results are shown for unfiltered samples in units of milligrams per liter (mg/L). Monitoring wells G270, G280, and G281 are background wells, denoted on the graph by hollow symbology. Monitoring well G404 has been identified as previously impacted by Ash Pond 2.

AP2 Monitoring Well Network Boron Time Series

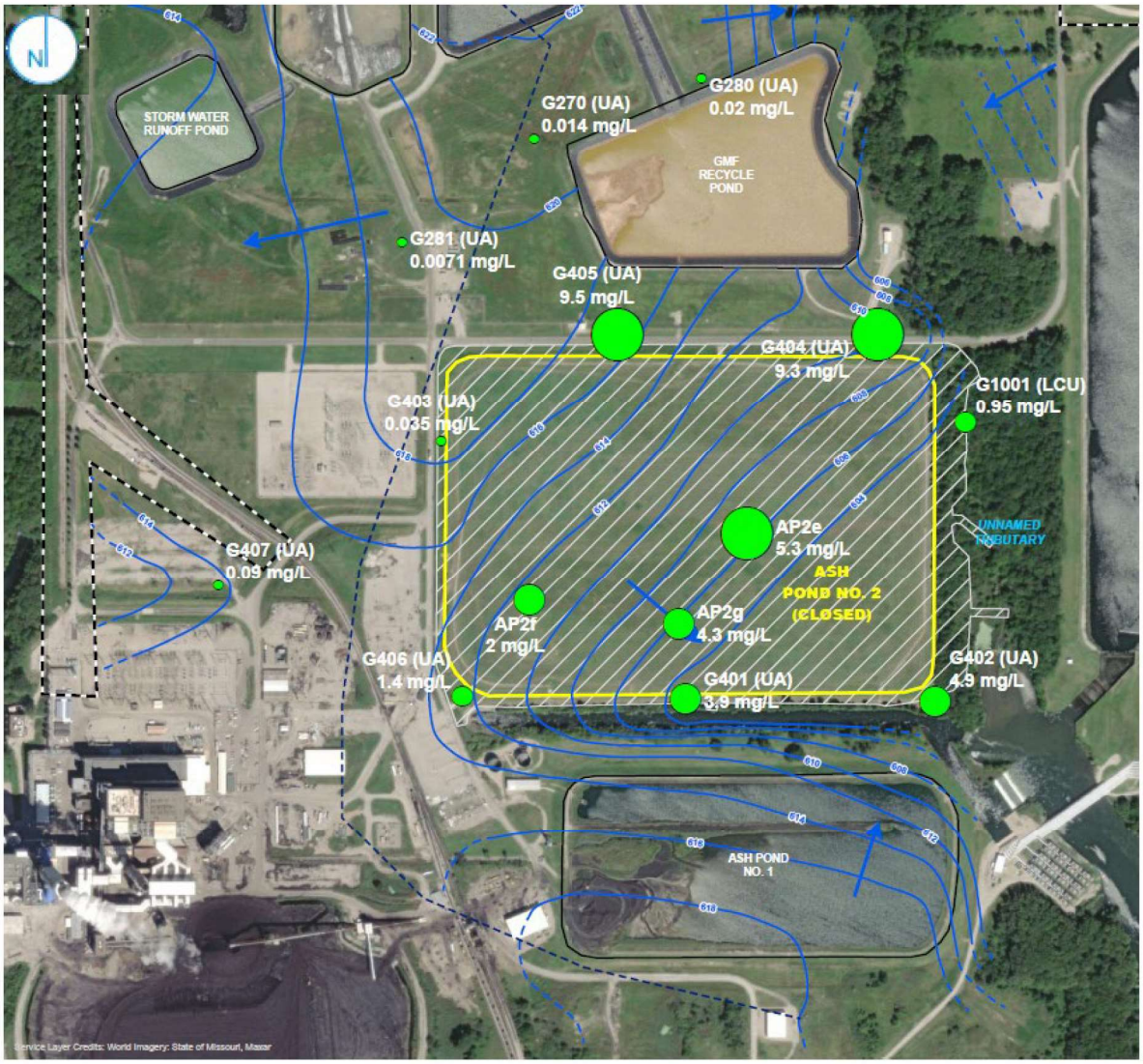
Geosyntec consultants

Columbus, OH | December 2023

Figure 2



	Surface Water Divide	
	Geosyntec consultants	Figure **3**
	Columbus, OH | December 2023	



GROUNDWATER DIVIDE
GROUNDWATER ELEVATION CONTOUR (2-FT CONTOUR INTERVAL, NAVD88)
INFERRED GROUNDWATER ELEVATION CONTOUR
GROUNDWATER FLOW DIRECTION

REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE
LIMITS OF FINAL COVER
PROPERTY BOUNDARY

POTENTIOMETRIC SURFACE MAP
MAY 30, 2023

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

Notes:
1: Boron concentrations from AP2 porewater samples and the Q2 2023 sampling event correspond with the radius of green circles on the figure. Boron concentration values are provided beneath location names.
2: AP2 porewater samples were collected in 2016.
3: Elevations in parentheses were not used for contouring.
4: Elevation contours shown in feet, North American Vertical Datum of 1988 (NAVD88).

Boron Distribution Relative to Groundwater Flow Direction

Geosyntec consultants

Columbus, OH | December 2023

Figure 4

ATTACHMENT 1
Proposed 845 Groundwater Monitoring Network

R001996



Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\CoffeenAP2_GMP\Figure 2-1_Proposed Monitoring Well Network.mxd

PROJECT: 169000XXXX | DATED: 10/6/2021 | DESIGNER: STOLZSD

COMPLIANCE WELL
BACKGROUND WELL
MONITORING WELL
STAFF GAGE
PART 845 REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE
LIMITS OF FINAL COVER
PROPERTY BOUNDARY

0 200 400 Feet

PROPOSED 845 GROUNDWATER MONITORING WELL NETWORK

ADDENDUM TO THE GROUNDWATER MONITORING PLAN
ASH POND NO. 2
COFFEEN POWER PLANT
COFFEEN, ILLINOIS

FIGURE 2-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

ATTACHMENT 2
G407 Boring Log and Well Construction Diagram

FIELD BORING LOG

HANSON

CLIENT: Natural Resources Technology, Inc.
Site: Coffeen Power Station - Ash Pond 2
Location: 134 CIPS Lane, Coffeen, IL 62017
Project: 16E0080
DATES: **Start:** 8/16/2016
Finish: 8/16/2016
WEATHER: Rain, (mid-70s)

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4 1/4" Hollow Stem Auger
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: K. Theesfeld

BOREHOLE ID: G407
Well ID: G407
Surface Elev: 618.35 ft. MSL
Completion: 20.00 ft. BGS
Station: 2,513,705.87N
2,513,705.87E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Coffeen
Township: East Fork
Section 10, **Tier** 7 N.; **Range** 3 W.

WATER LEVEL INFORMATION:
▼ = 16.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type
1A	12/24 50%	ss	4-3 3-3 N=6	14		3.50
2A	20/24 83%	ss	2-2 4-4 N=6	18		1.50
3A	23/24 96%	ss	1-2 3-4 N=5	19		1.75
4A	24/24 100%	ss	1-3 3-5 N=6	19		1.50
5A	21/24 88%	ss	1-2 4-4 N=6	19		0.50
6A	22/24 92%	ss	1-2 2-1 N=4	17		
7A	24/24 100%	ss	7-29 33-17 N=62	8		
8A	24/24 100%	ss	3-7 12-17 N=19	12		4.50
9A	24/24 100%	ss	4-9 14-20 N=23	13		4.00
10A	24/24 100%	ss	2-8 14-19 N=22	14		4.50

Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	Very dark gray (10YR3/1), wet, medium, SILT with some organics. [Fill]		618	
2	Gray (10YR6/1), wet, loose, SAND with some gravel and little clay. [Fill]		616	
4	Yellowish brown (10YR5/6) with 5% dark yellowish brown (10YR3/6) mottles, moist, very stiff, SILT with some clay and trace very fine- to fine-grained sand. Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with some clay, little fine- to coarse-grained sand, and trace small gravel.		614	
6	Brown (10YR5/3) with 25% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, trace fine-grained sand and trace small gravel.		612	
8	Brown (10YR5/3) with 10% yellowish brown (10YR5/6) mottles, moist, stiff, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.		610	
10	Yellowish brown (10YR5/6) with 25% brown (10YR5/3) mottles, moist, medium, CLAY with few silt, few fine-grained sand, and trace small gravel.		608	
12	Yellowish brown (10YR5/8) with 5% gray (10YR5/1) mottles, moist, very loose, fine-grained SAND with some clay and trace small gravel.		606	
14	Gray (10YR5/1) with 25% yellowish brown (10YR5/8) mottles, moist, very dense, fine-grained SAND		604	
▼ 16	Brown (10YR5/3), moist, hard, SILT with some clay and little fine- to coarse-grained sand. Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6) and 5% black (10YR2/1) mottles, SILT with some clay and little fine- to coarse-grained sand.		602	
18	Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, moist, hard, SILT with little fine- to coarse-grained sand and trace small gravel.		600	
20	Yellowish brown (10YR5/4) with 5% yellowish brown (10YR5/6), 5% dark gray (10YR4/1) and 5% black (10YR2/1) mottles, wet, stiff, SILT with little fine- to coarse-grained sand and little small gravel. Dark grayish brown (10YR4/2) with 10% dark yellowish brown (10YR3/6) mottles, moist, hard, CLAY with some silt, little fine- to coarse-grained sand and trace small gravel.			

End of Boring = 20.0 ft. BGS

NOTE(S): G407 installed in boring.

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Montgomery Well #: G407

Site Name: Coffeen Power Station - Ash Pond 2 Borehole #: G407

State Plane Coordinate: X 2,513,705.9 Y 872,973.4 (or) Latitude: 39° 3' 41.665" Longitude: -89° 24' 7.213"

Surveyed By: Gary C. Rogers IL Registration #: 035-002957

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow stem auger Drilling Fluid (Type): none

Logged By: Kristen L. Theesfeld Date Started: 8/16/2016 Date Finished: 8/16/2016

Report Form Completed By: Suzanna L. Keim Date: 8/24/2016

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >24 hours

Type of Bentonite Seal -- [Granular] Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 15 minutes

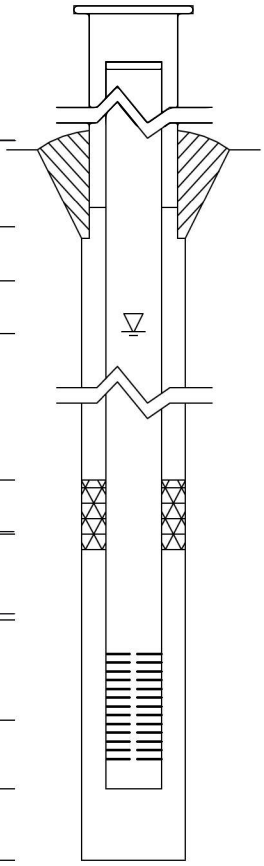
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand (if applicable)

Installation Method: Gravity



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
621.70	-3.35	Top of Protective Casing
621.32	-2.97	Top of Riser Pipe
618.35	0.00	Ground Surface
616.35	2.00	Top of Annular Sealant
		Static Water Level (After Completion)
607.50	10.85	Top of Seal
605.50	12.85	Top of Sand Pack
604.57	13.78	Top of Screen
599.74	18.61	Bottom of Screen
599.31	19.04	Bottom of Well
598.35	20.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

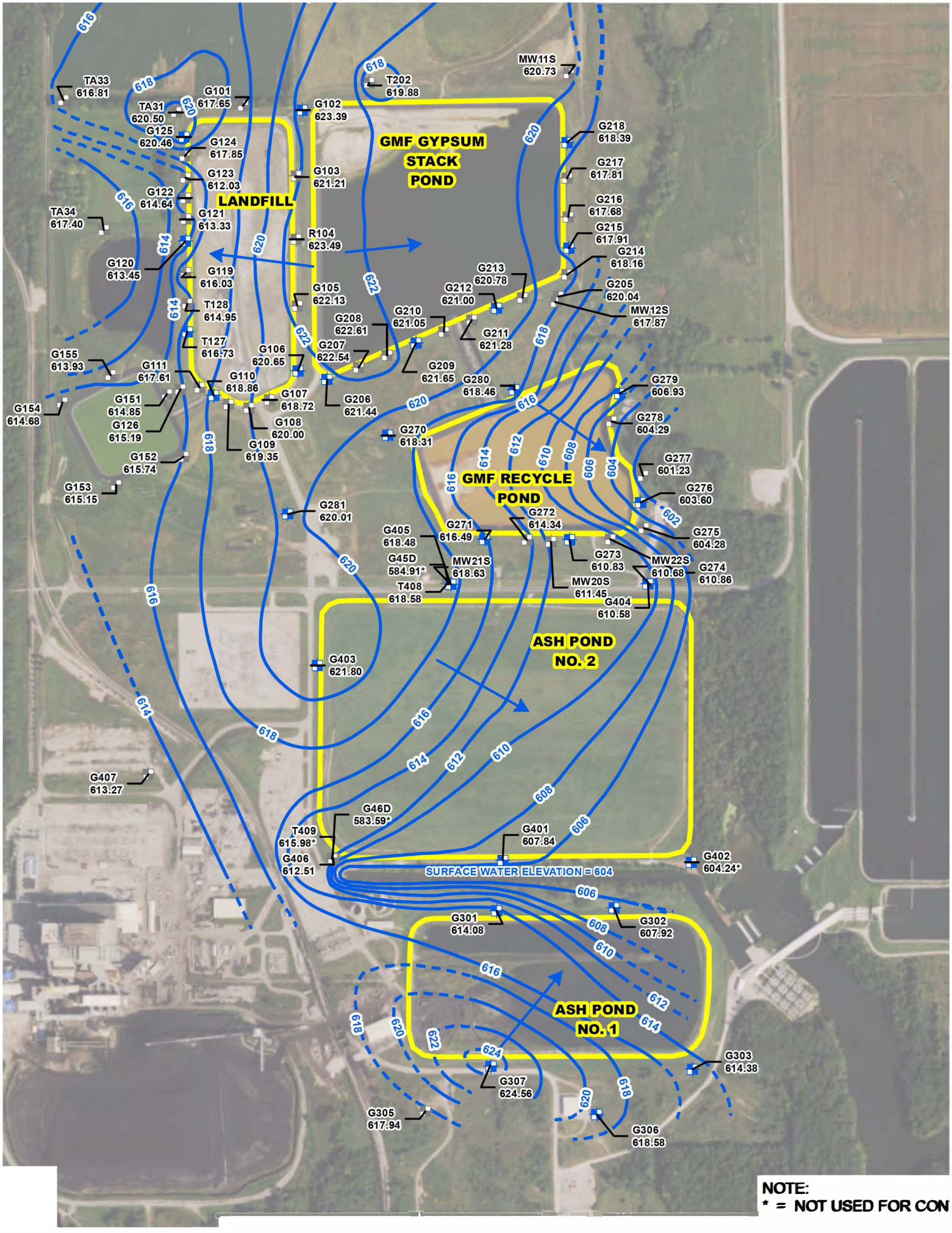
Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	16.75
Bottom of Screen to End Cap	(feet)	0.43
Screen Length (1st slot to last slot)	(feet)	4.83
Total Length of Casing	(feet)	22.01
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

ATTACHMENT 3
Compiled Potentiometric Surface Maps

GROUNDWATER ELEVATION CONTOUR MAPS
MONITORING PERIOD 2016 - 2023

LOCATION: COFFEEN POWER PLANT
UNIT NAME: ASH POND NO. 2


GMF GYPSUM STACK POND
LANDFILL
GMF RECYCLE POND
ASH POND NO. 2
ASH POND NO. 1
SURFACE WATER ELEVATION = 604
TA33 616.81
TA31 620.50
TA34 617.40
G101 617.65
G102 623.39
T202 619.88
MW11S 620.73
G125 620.46
G124 617.85
G123 612.03
G122 614.64
G121 613.33
G120 613.45
G103 621.21
R104 623.49
G218 618.39
G217 617.81
G216 617.68
G215 617.91
G214 618.16
G213 620.78
G212 621.00
G205 620.04
MW12S 617.87
G119 616.03
G105 622.13
T128 614.95
T127 616.73
G208 622.61
G210 621.05
G211 621.28
G207 622.54
G209 621.65
G106 620.65
G110 618.86
G107 618.72
G206 621.44
G280 618.46
G279 606.93
G278 604.29
G277 601.23
G276 603.60
G275 604.28
G274 610.86
G155 613.93
G111 617.61
G151 614.85
G126 615.19
G154 614.68
G108 620.00
G109 619.35
G152 615.74
G153 615.15
G270 618.31
G281 620.01
G271 616.49
G272 614.34
G273 610.83
G405 618.48
G45D 584.91*
T408 618.58
MW21S 618.63
MW20S 611.45
MW22S 610.68
G404 610.58
G403 621.80
G407 613.27
G46D 583.59*
T409 615.98*
G406 612.51
G401 607.84
G402 604.24*
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G307 624.56
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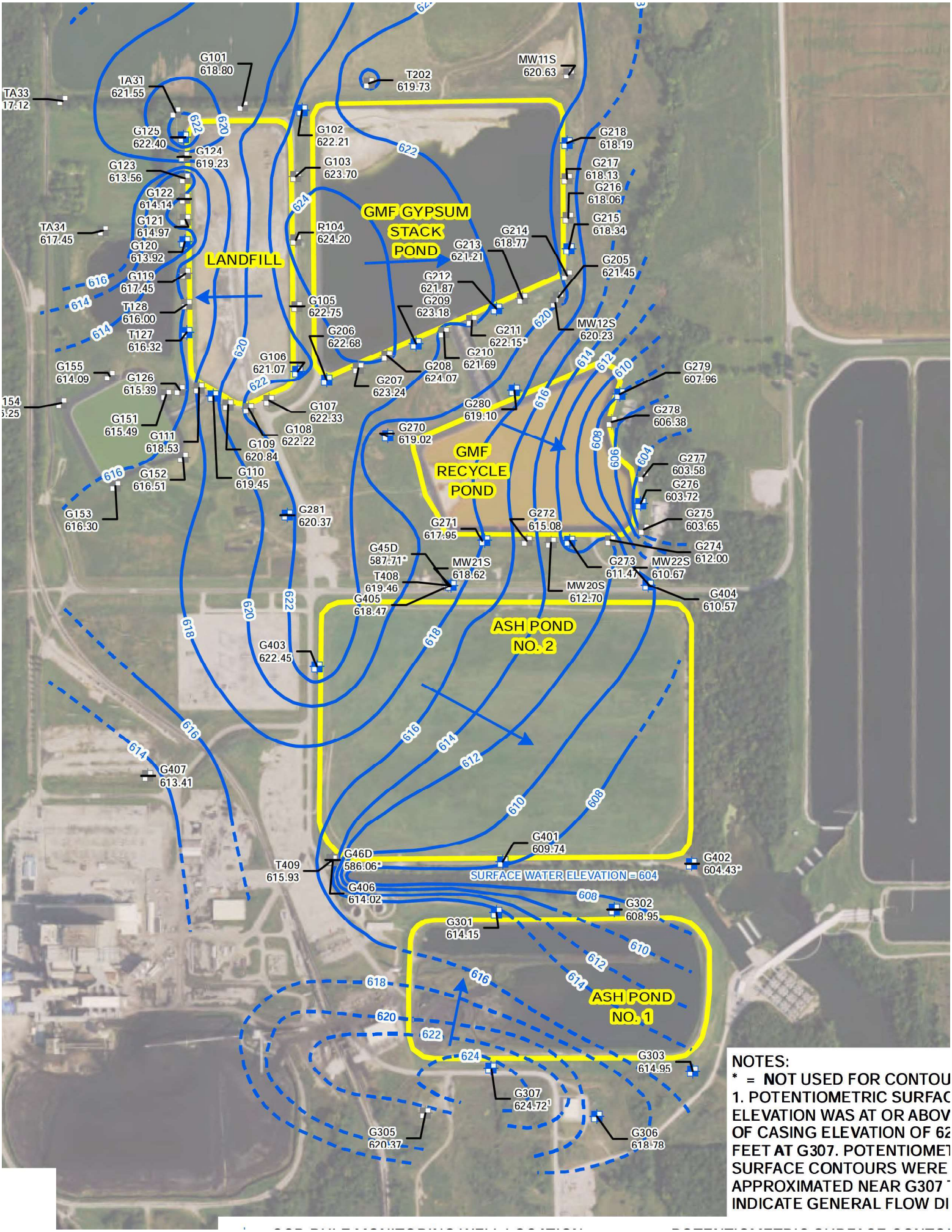
G306 618.58
NOTE:
* = NOT USED FOR CON


GMF GYPSUM STACK POND
LANDFILL
GMF RECYCLE POND
ASH POND NO. 2
ASH POND NO. 1
SURFACE WATER ELEVATION = 604
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TA31 621.55
TA33 17.12
T202 619.73
MW11S 620.63
G125 622.40
G124 619.23
G102 622.21
G103 623.70
G218 618.19
G217 618.13
G216 618.06
G123 613.56
G122 614.14
G121 614.97
G120 613.92
TA34 617.45
R104 624.20
G213 621.21
G214 618.77
G215 618.34
G205 621.45
G119 617.45
G212 621.87
G209 623.18
T128 616.00
G105 622.75
T127 616.32
G206 622.68
G211 622.15*
MW12S 620.23
G106 621.07
G208 624.07
G210 621.69
G155 614.09
G126 615.39
G207 623.24
G279 607.96
G280 619.10
G278 606.38
G107 622.33
G151 615.49
G270 619.02
G108 622.22
G111 618.53
G109 620.84
G277 603.58
G152 616.51
G110 619.45
G276 603.72
G153 616.30
G281 620.37
G271 617.95
G272 615.08
G275 603.65
G45D 587.71*
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G273 611.47
MW22S 610.67
G274 612.00
T408 619.46
MW20S 612.70
G405 618.47
G404 610.57
G403 622.45
G407 613.41
G401 609.74
G46D 586.06*
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G302 608.95
G301 614.15
G303 614.95
G307 624.72
G305 620.37
G306 618.78
NOTES:
* = NOT USED FOR CONTOU
1. POTENTIOMETRIC SURFAC
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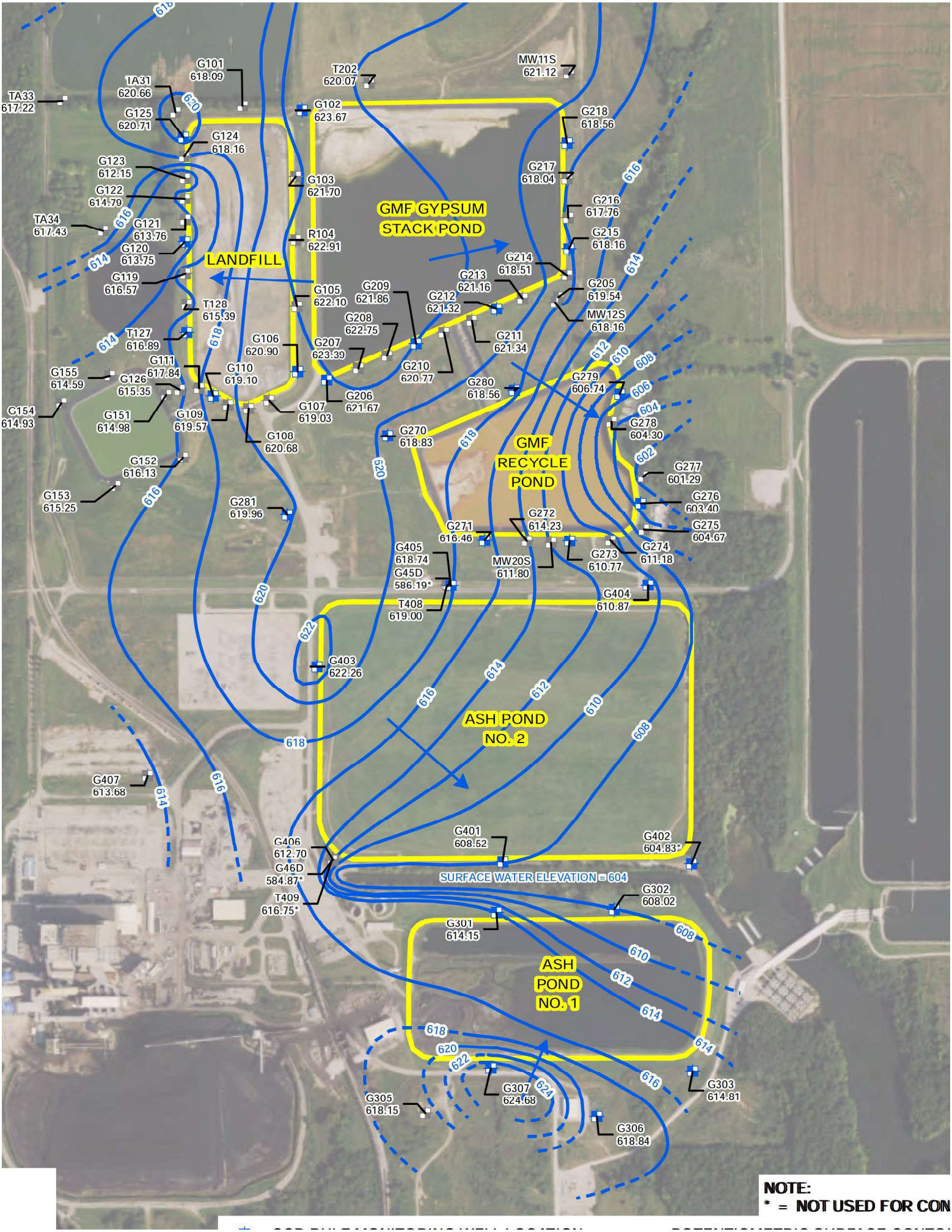
OF CASING ELEVATION OF 62
FEET AT G307. POTENTIOMET
SURFACE CONTOURS WERE
APPROXIMATED NEAR G307
INDICATE GENERAL FLOW DI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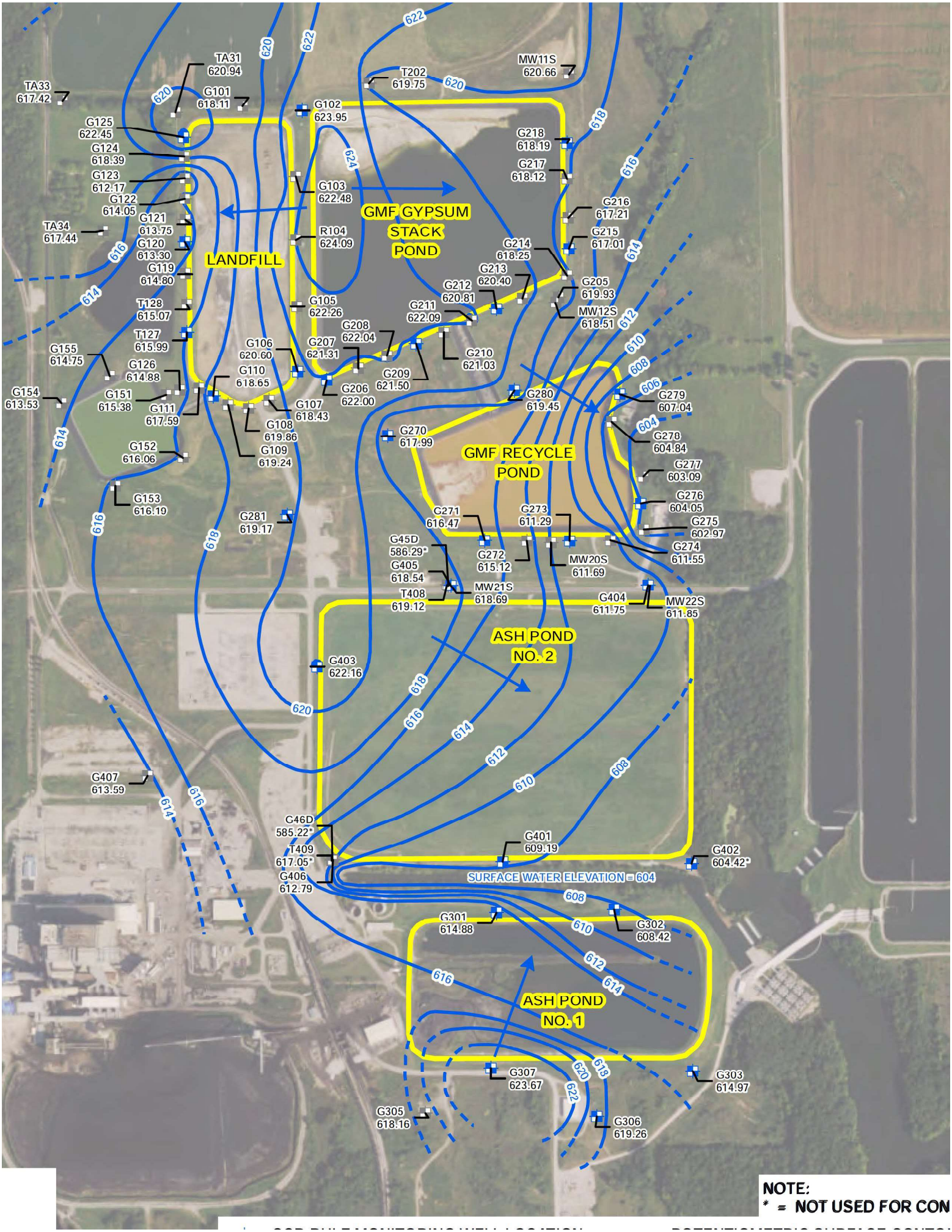
ASH POND NO. 1
SURFACE WATER ELEVATION = 604
NOTE:
* = NOT USED FOR CON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G122 614.05
G121 613.75
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TA34 617.44
R104 624.09
G103 622.48
GMF GYPSUM STACK POND
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G214 618.25
G213 620.40
G212 620.81
G205 619.93
MW12S 618.51
G211 622.09
G105 622.26
T128 615.07
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G155 614.75
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G108 619.86
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G274 611.55
G271 616.47
G273 611.29
G272 615.12
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G45D 586.29*
G405 618.54
T408 619.12
MW21S 618.69
G404 611.75
MW22S 611.85
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G407 613.59
G46D 585.22*
T409 617.05*
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G401 609.19
G402 604.42*
SURFACE WATER ELEVATION = 604
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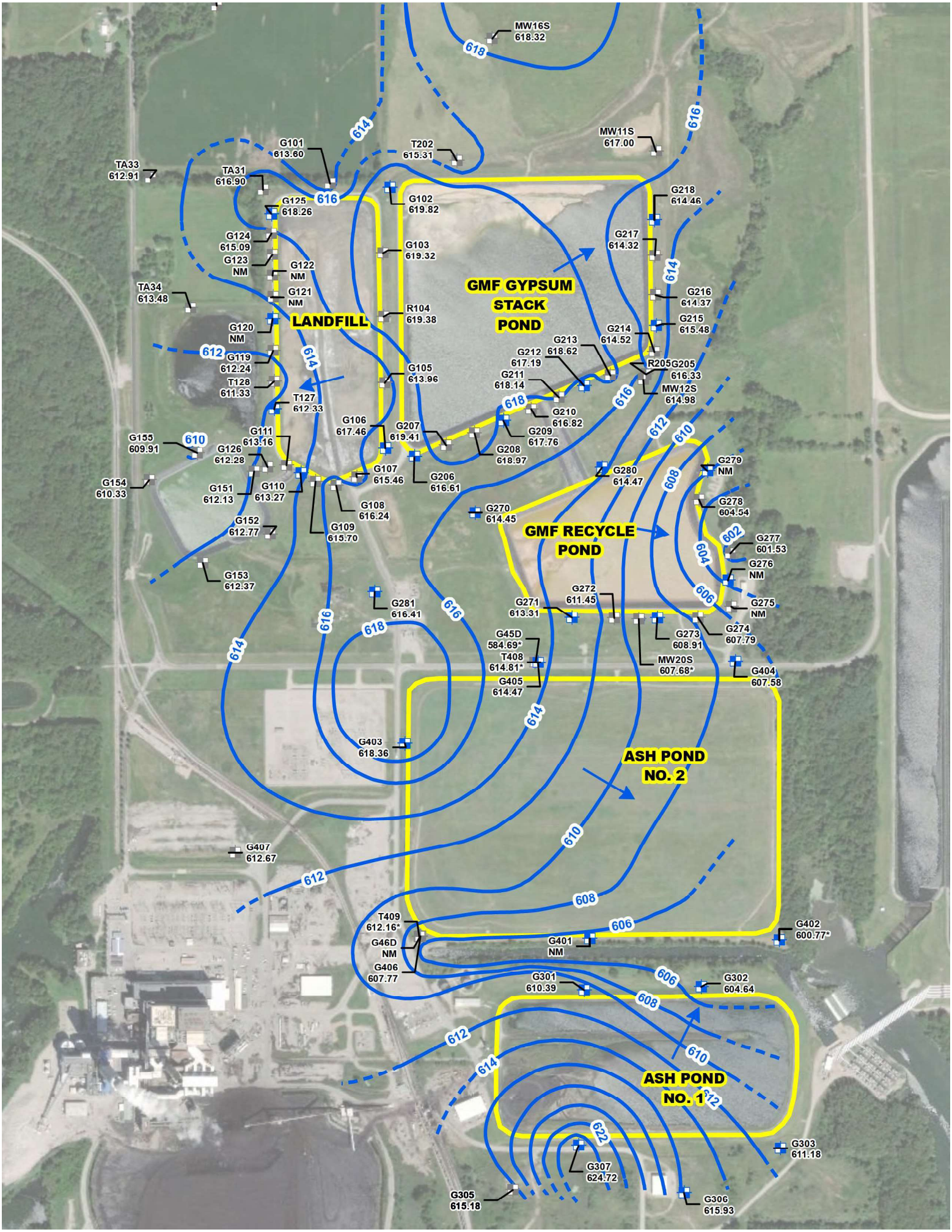
NOTE:
* = NOT USED FOR CON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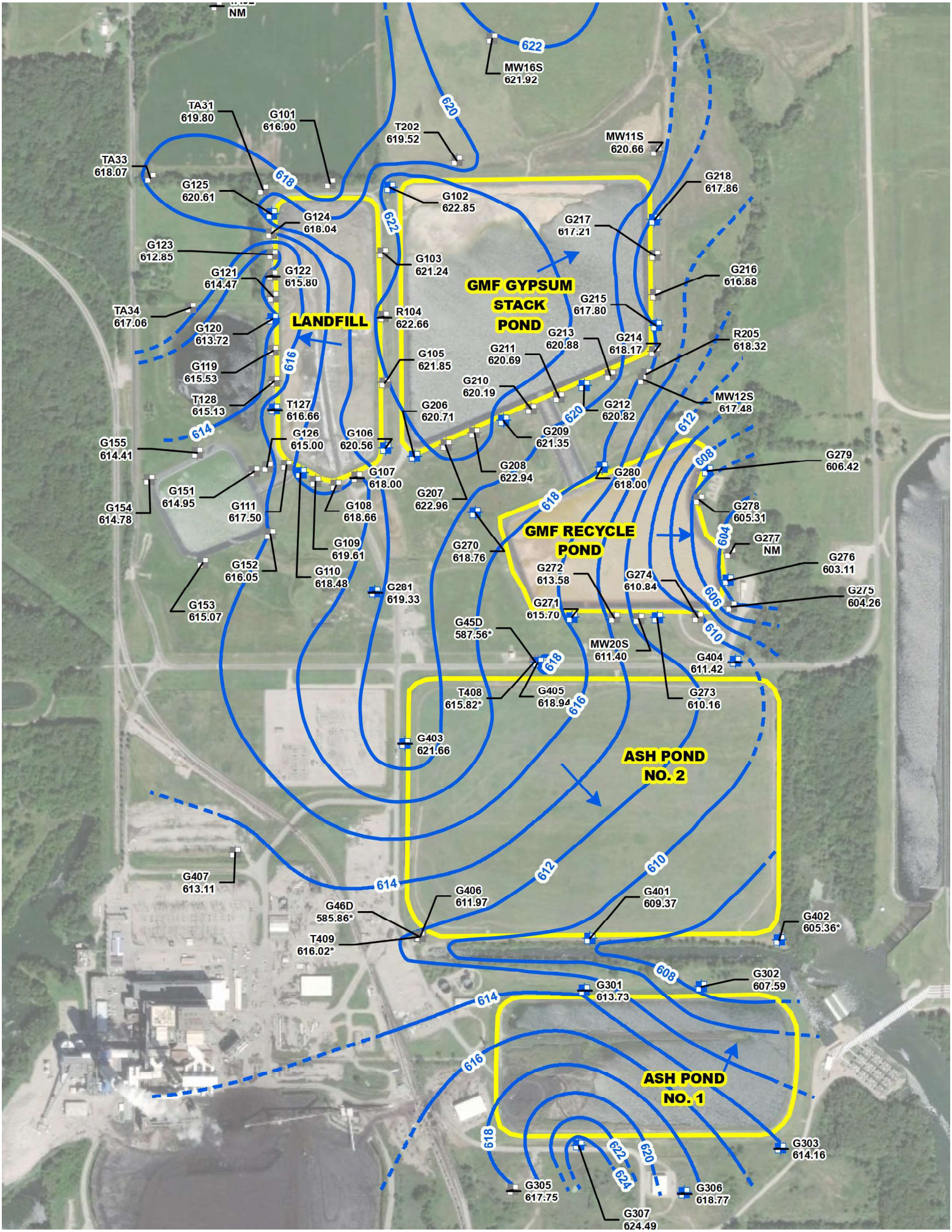
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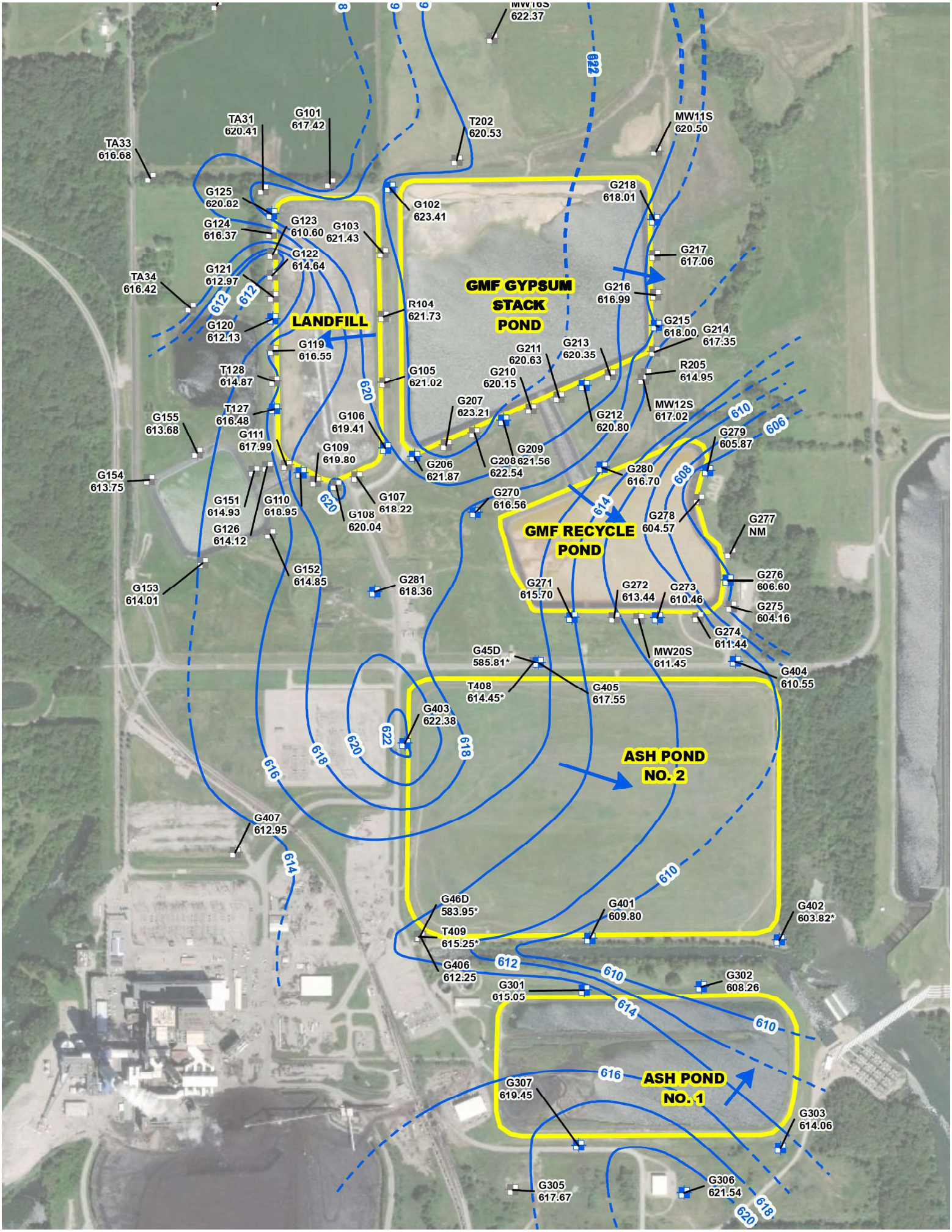
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G46D
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G401
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G402
603.82*
T409
615.25*
G406
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615.05
G302
608.26
G307
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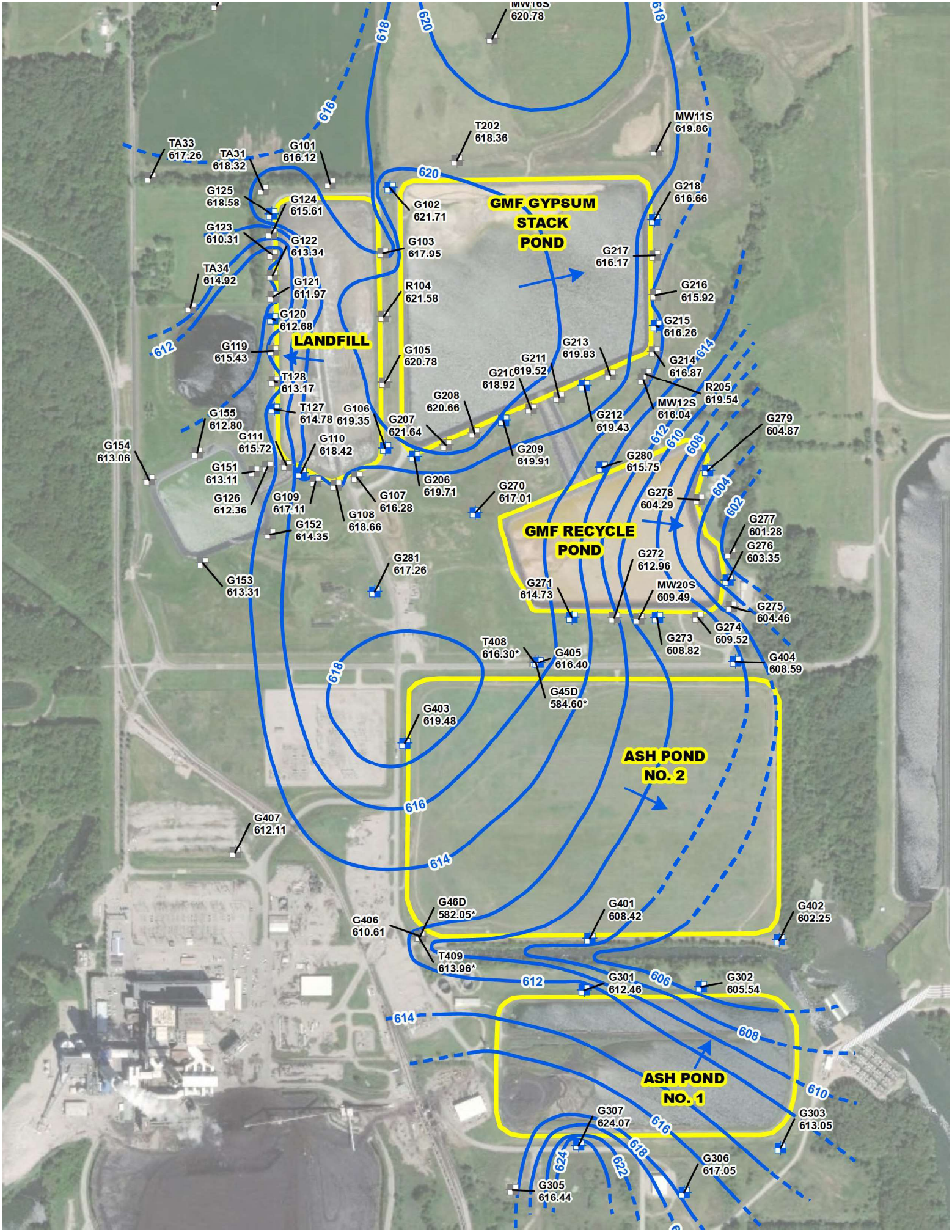
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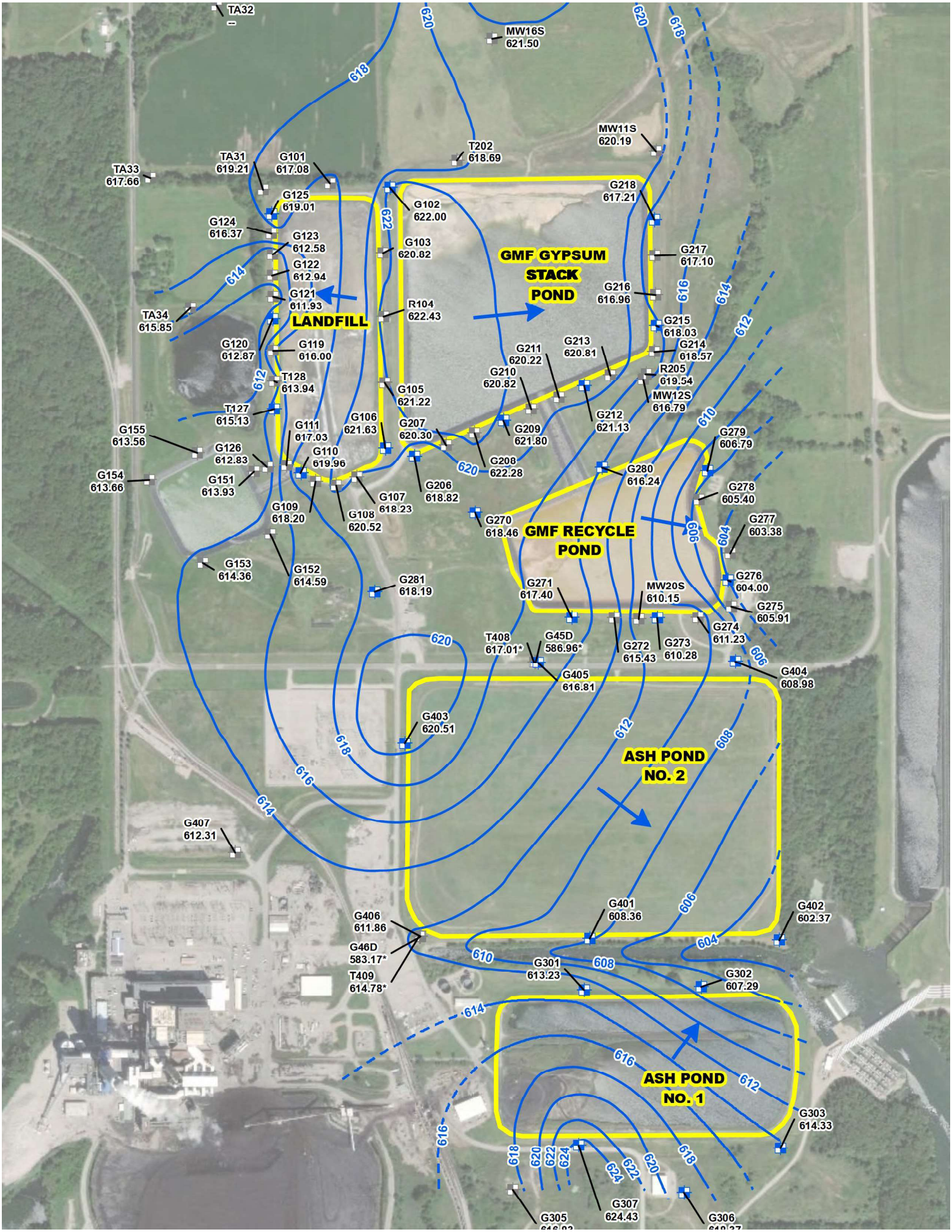
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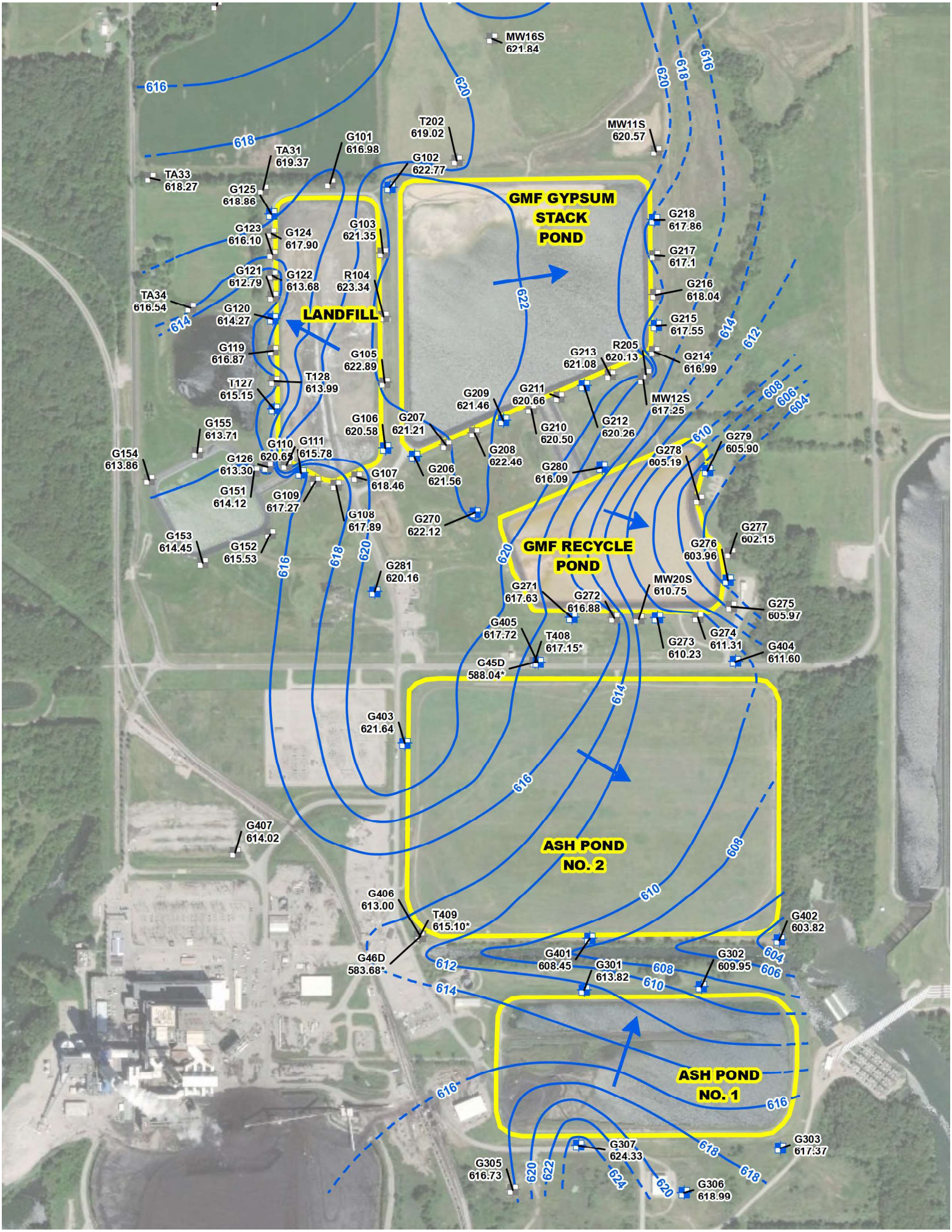
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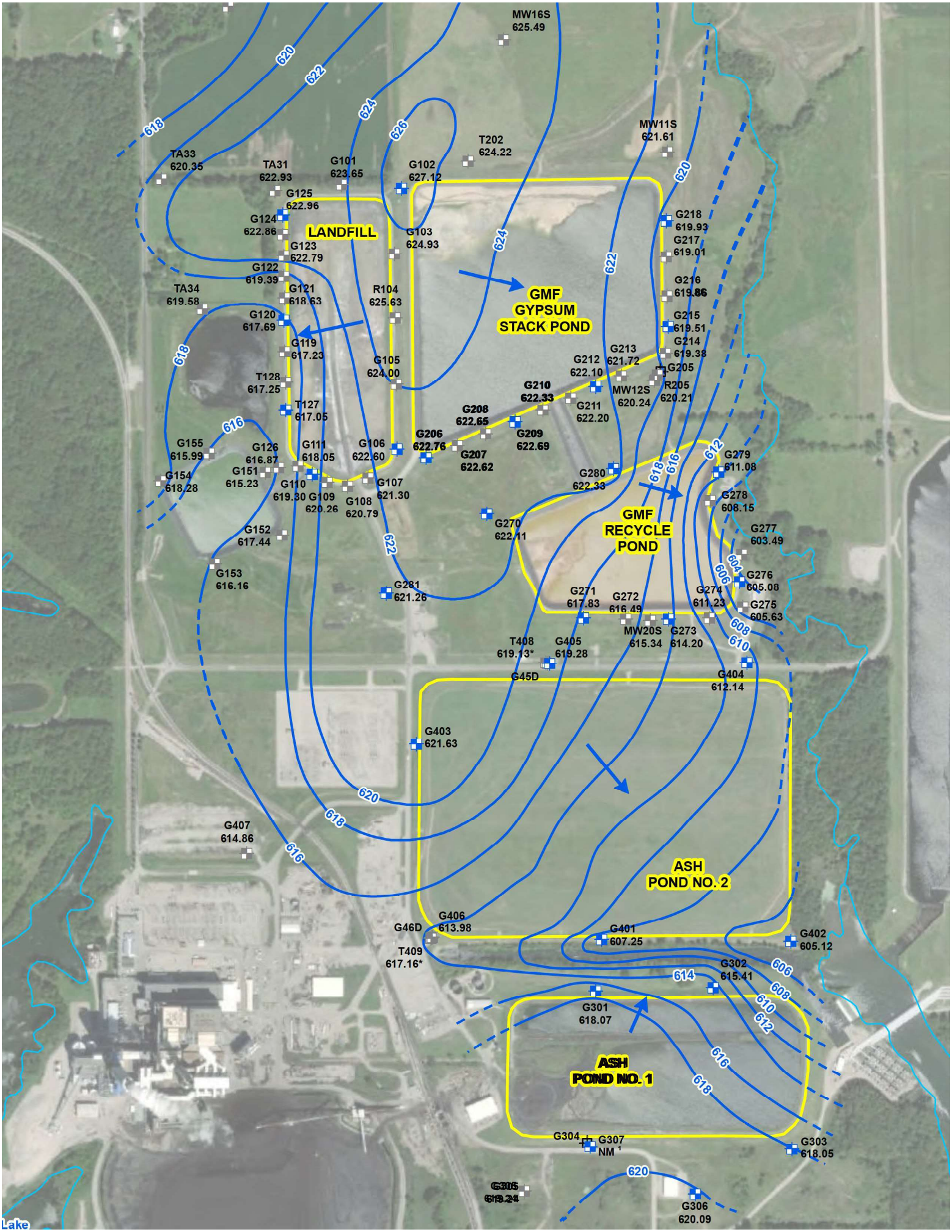
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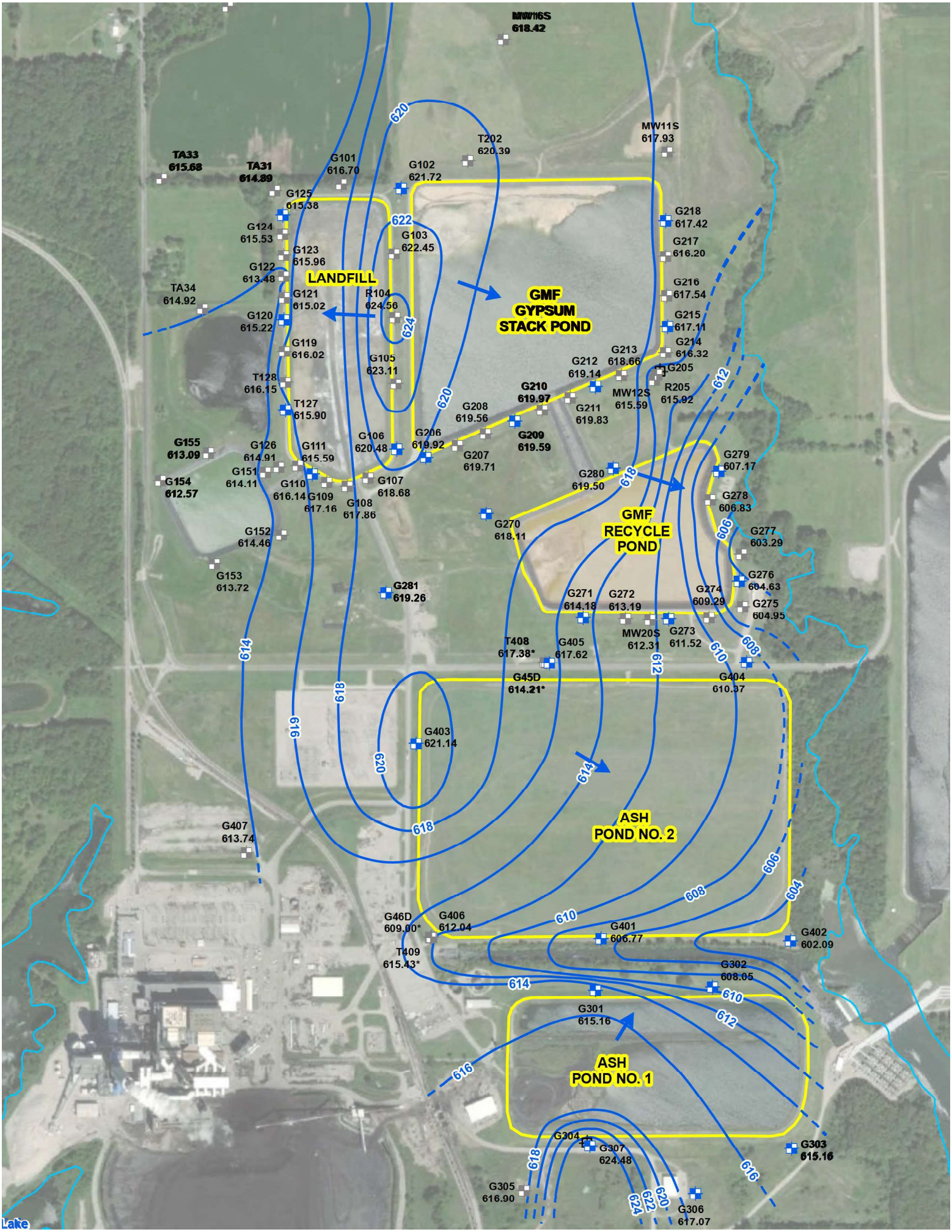
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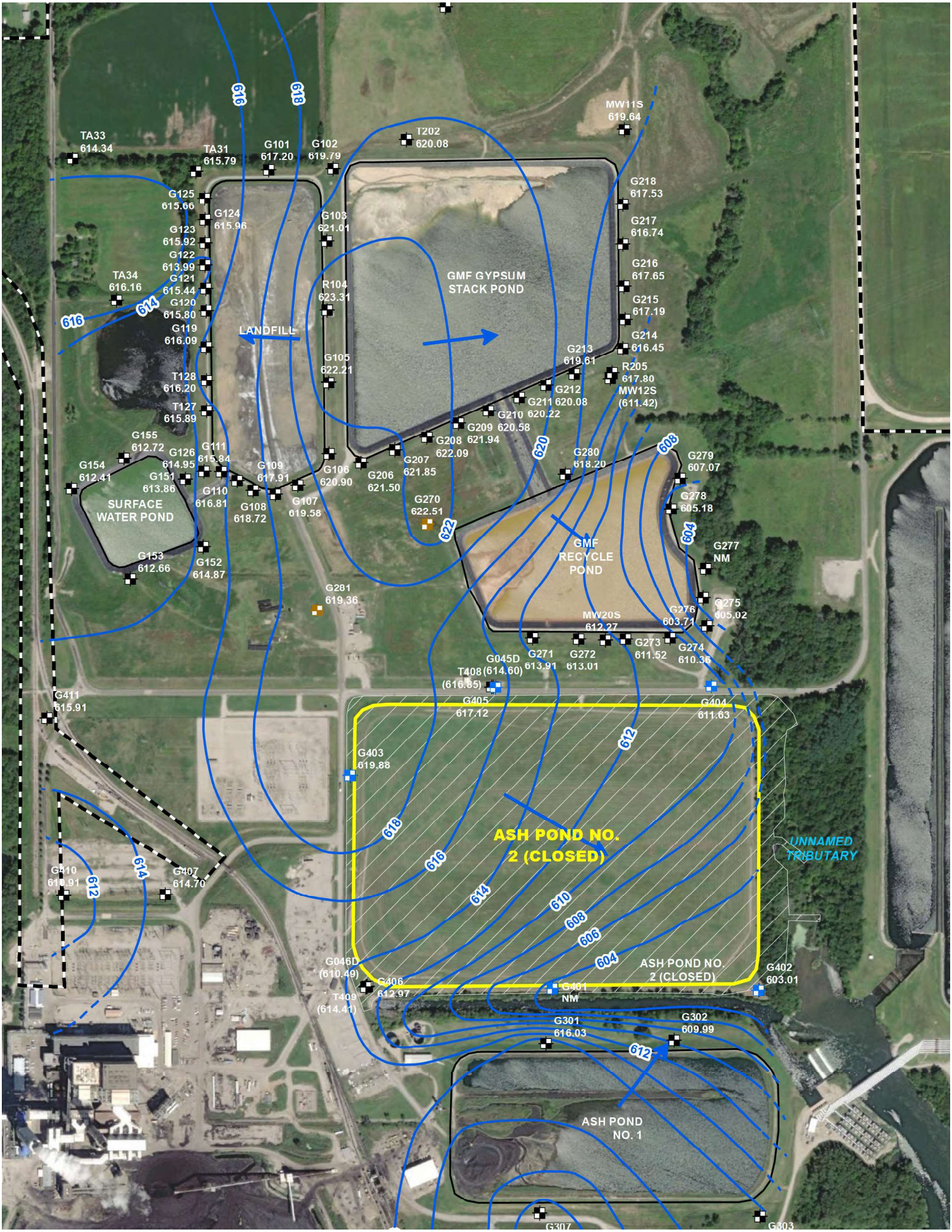
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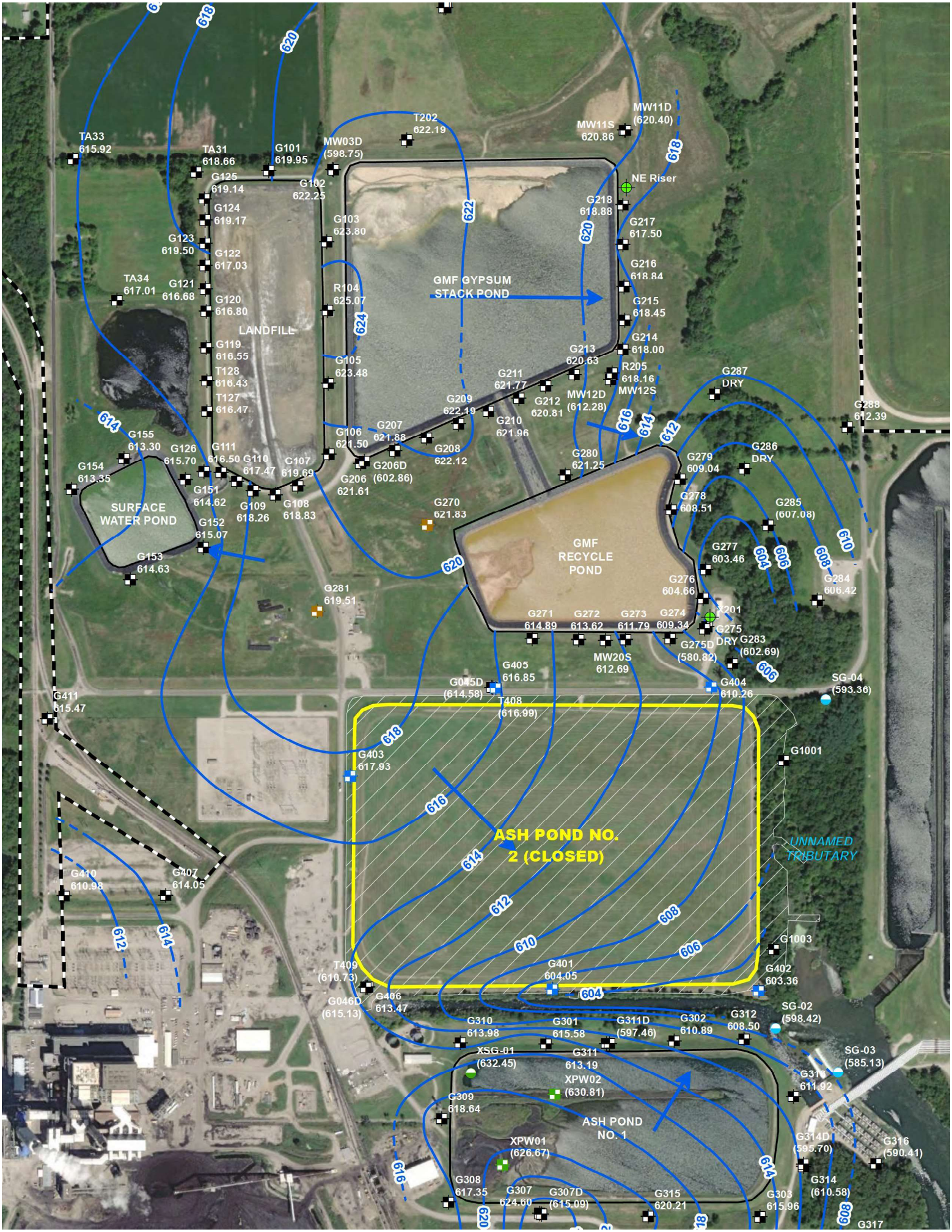
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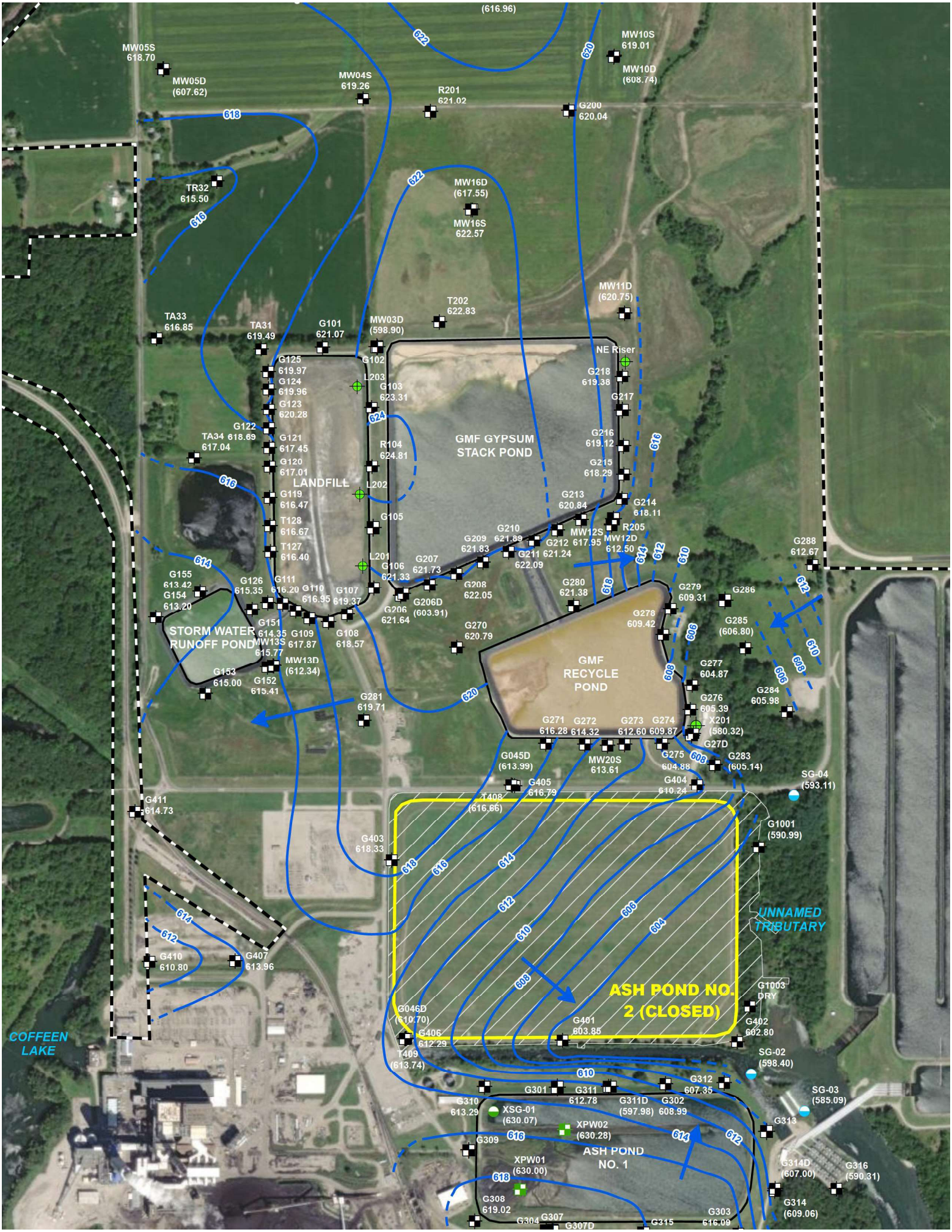
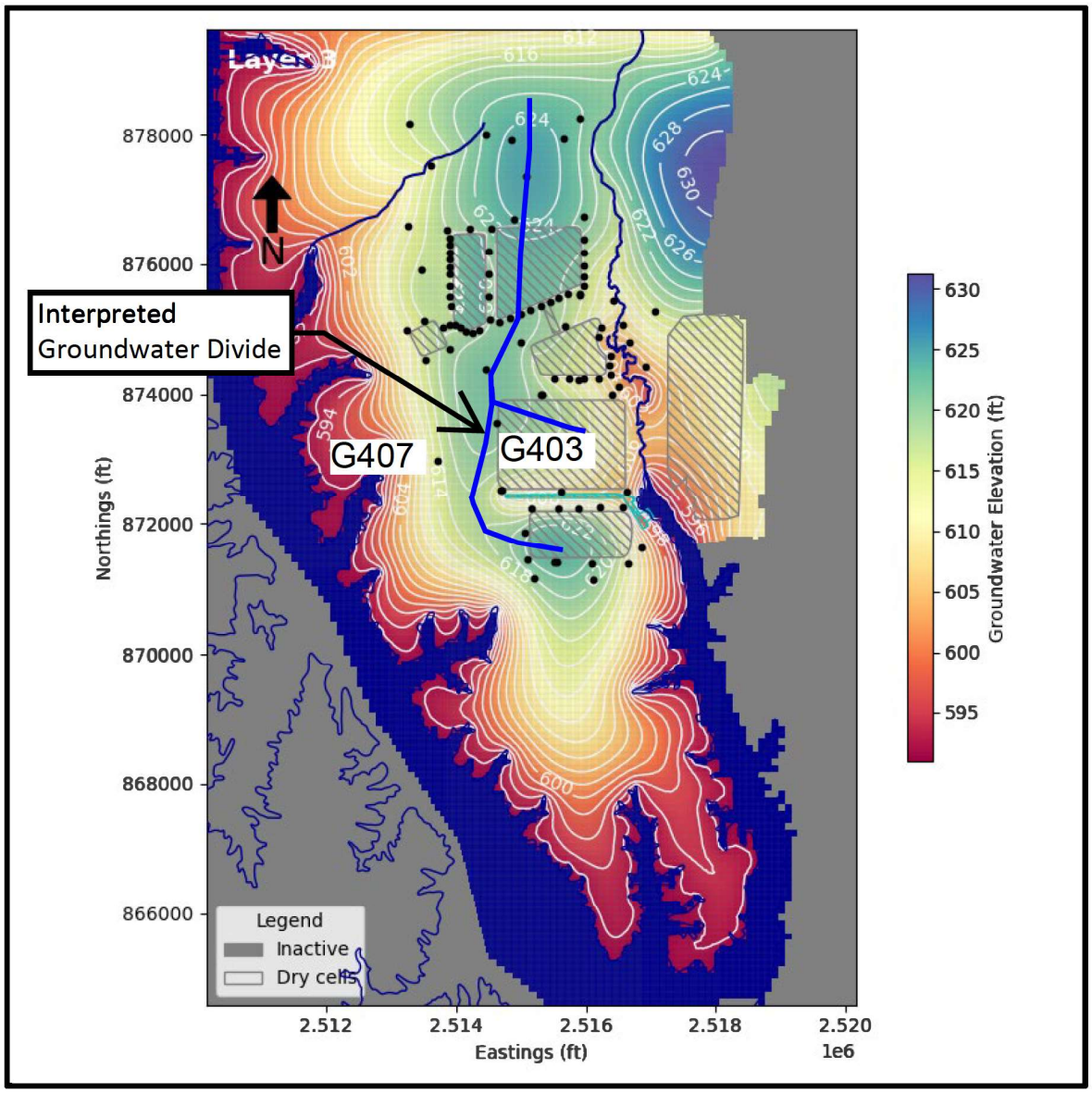
G155
613.30
G207
621.88
G106
621.50
G210
621.96
G154
613.35
G126
615.70
G111
616.50
G110
617.47
G107
619.69
G206D
(602.86)
G208
622.12
G280
621.25
G279
609.04
G286
DRY
G206
621.61
G151
614.62
G109
618.26
G108
618.83
G278
608.51
G285
(607.08)
SURFACE
WATER POND
G270
621.83
G152
615.07
GMF
RECYCLE
POND
G277
603.46
G153
614.63
G276
604.66
G284
606.42
G281
619.51
G271
614.89
G272
613.62
G273
611.79
G274
609.34
T201
G275
DRY
G275D
(580.82)
G283
(602.69)
MW20S
612.69
G405
616.85
G045D
(614.58)
G404
610.26
SG-04
(593.36)
G411
615.47
T408
(616.99)
G1001
G403
617.93
ASH POND NO.
2 (CLOSED)
UNNAMED
TRIBUTARY
G410
610.98
G407
614.05
G1003
T409
(610.73)
G401
604.05
G402
603.36
G046D
(615.13)
G406
613.47
SG-02
(598.42)
G310
613.98
G301
615.58
G311D
(597.46)
G302
610.89
G312
608.50
XSG-01
(632.45)
G311
613.19
SG-03
(585.13)
XPW02
(630.81)
G309
618.64
G313
611.92
ASH POND
NO. 1
XPW01
(626.67)
G314D
(595.70)
G316
(590.41)
G308
617.35
G307
624.60
G307D
(615.09)
G315
620.21
G303
615.96
G314
(610.58)
G317


(616.96)
MW05S 618.70
MW05D (607.62)
MW04S 619.26
R201 621.02
G200 620.04
MW10S 619.01
MW10D (608.74)
TR32 615.50
MW16D (617.55)
MW16S 622.57
MW11D (620.75)
T202 622.83
TA33 616.85
TA31 619.49
G101 621.07
MW03D (598.90)
G125 619.97
G124 619.96
G123 620.28
G122
TA34 618.69 617.04
G121 617.45
G120 617.01
G119 616.47
T128 616.67
T127 616.40
G102
L203
G103 623.31
R104 624.81
L202
G105
L201
G106 621.33
G107 619.37
G206 621.64
G206D (603.91)
G207 621.73
G208 622.05
G209 621.83
G210 621.89
G211 621.24
622.09
G212 617.95
MW12S
MW12D 612.50
R205
G213 620.84
G214 618.11
G215 618.29
G216 619.12
G217
G218 619.38
NE Riser
GMF GYPSUM STACK POND
LANDFILL
STORM WATER RUNOFF POND
GMF RECYCLE POND
G155 613.42
G154 613.20
G126 615.35
G111 616.20
G110 616.95
G151 614.35
MW13S 615.77
MW13D (612.34)
G109 617.87
G108 618.57
G153 615.00
G152 615.41
G270 620.79
G278 609.42
G279 609.31
G280 621.38
G281 619.71
G286
G285 (606.80)
G288 612.67
G277 604.87
G276 605.39
G284 605.98
X201 (580.32)
G271 616.28
G272 614.32
G273 612.60
G274 609.87
G27D
G275 604.88
G283 (605.14)
MW20S 613.61
G045D (613.99)
G405 616.79
G404 610.24
SG-04 (593.11)
G411 614.73
T408 (616.66)
G403 618.33
G1001 (590.99)
UNNAMED TRIBUTARY
ASH POND NO. 2 (CLOSED)
G1003 DRY
G402 602.80
G046D (610.70)
G406 612.29
T409 (613.74)
G401 603.85
SG-02 (598.40)
SG-03 (585.09)
G410 610.80
G407 613.96
COFFEEN LAKE
G301
G311 612.78
G311D (597.98)
G312 607.35
G302 608.99
G310 613.29
XSG-01 (630.07)
XPW02 (630.28)
G313
G309
ASH POND NO. 1
XPW01 (630.00)
G314D (607.00)
G316 (590.31)
G308 619.02
G314 (609.06)
G304
G307
G307D
G315
G303 616.09
618
616
614
612
610
608
606
604
620
622
624

ATTACHMENT 4
Coffeen Power Plant Groundwater Model Output

FIGURE 5-24



SIMULATED STEADY STATE GROUNDWATER LEVEL CONTOURS FROM UA (LAYER 3) FROM THE CALIBRATED MODEL

GROUNDWATER MODELING REPORT
ASH POND NO. 1
COFFEEN POWER PLANT
COFFEEN, ILLINOIS

RAMBOLL

DOCUMENT 24

Rees, Jeromy

From: Voelker, Brian <Brian.Voelker@vistracorp.com>
Sent: Friday, December 15, 2023 1:42 PM
To: EPA.CCR.Part845.Coordinator@Illinois.gov; EPA.CCR.Part845.Notify@Illinois.gov; Hunt, Lauren; EPA.BOW.GWS.CCR@illinois.gov
Cc: Morris, Phil; Fuller, Rhys; Modeer, Victor; Cravens, Stuart; Davies, Sam; Mitchell, David
Subject: [External] Coffeen Power Plant AP2 Sulfate and TDS ASD submittal notice

As a courtesy this email is to provide notice that an ASD for sulfate and TDS at the Coffeen Ash Pond No 2 was submitted/delivered to IEPA via FedEx on December 15, 2023, to the address provided below.

Illinois Environmental Protection Agency
Bureau of Water Permit Section #15
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794

It was also placed on the Luminant CCR public website, and you can access a copy there. The link below will take you to the website.
https://www.luminant.com/ccr/illinois-ccr/?dir=il-ccr%2FCoffeen%2F2023

Please let me know if you have questions or concerns.

Thanks,
Brian

DOCUMENT 25

Rees, Jeromy

From: EPA.CCR.Part845.Coordinator <EPA.CCR.Part845.Coordinator@Illinois.gov>
Sent: Monday, December 18, 2023 10:12 AM
To: EPA.CCR.Part845.Coordinator; EPA.BOW.GWS.CCR
Subject: Coffeen Power Plant Ash Pond No. 2 Alternative Source Demonstration

You are receiving this message because you subscribed to the Illinois EPA Listserv for Part 845, Coal Combustion Residual (CCR) facilities. In accordance with 35 Ill. Adm. Code 845.650(e)(2) let this serve as notification that the Illinois Environmental Protection Agency (Illinois EPA) received an Alternative Source Demonstration (ASD) from **Coffeen Power Plant Ash Pond** on **December 15th 2023**.

For further information regarding this ASD, you may refer to the facility's Coal Combustion Residual (CCR) website. A link to the facility's CCR website can be found via the Illinois EPA CCR website located at:
Coal Combustion Residual Surface Impoundments - Coal Combustion Residual Surface Impoundments (illinois.gov)

Please direct any comments to **GROUNDWATER SECTION** at **EPA.BOW.GWS.CCR@Illinois.gov** within 14 days of the date of this notice for consideration per 35 Ill. Adm. Code 845.650(e)(3).

Please do not reply, this email box is not monitored.

Illinois Environmental Protection Agency
DWPC – Permits MC #15
Attn: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276
217-558-0347

Thank you,

State of Illinois - CONFIDENTIALITY NOTICE: The information contained in this communication is confidential, may be attorney-client privileged or attorney work product, may constitute inside information or internal deliberative staff communication, and is intended only for the use of the addressee. Unauthorized use, disclosure or copying of this communication or any part thereof is strictly prohibited and may be unlawful. If you have received this communication in error, please notify the sender immediately by return e-mail and destroy this communication and all copies thereof, including all attachments. Receipt by an unintended recipient does not waive attorney-client privilege, attorney work product privilege, or any other exemption from disclosure.

DOCUMENT 26

Rees, Jeromy

From: EPA.CCR.Part845.Coordinator <EPA.CCR.Part845.Coordinator@Illinois.gov>
Sent: Monday, December 18, 2023 10:53 AM
Cc: EPA.CCR.Part845.Coordinator; EPA.BOW.GWS.CCR
Subject: Alternative Source Demonstration (ASD) for the sulfate and TDS exceedance observed at well G407, Qtr.2, 2023 from Coffeen Power Plant

You are receiving this message because you subscribed to the Illinois EPA Listserv for Part 845, Coal Combustion Residual (CCR) facilities. In accordance with 35 Ill. Adm. Code 845.650(e)(2) let this serve as notification that the Illinois Environmental Protection Agency (Illinois EPA) received an Alternative Source Demonstration (ASD) for the sulfate and TDS exceedance observed at well G407, Qtr.2, 2023 from **Coffeen Power Plant** on **December 15th 2023**.

For further information regarding this ASD, you may refer to the facility's Coal Combustion Residual (CCR) website. A link to the facility's CCR website can be found via the Illinois EPA CCR website located at:
Coal Combustion Residual Surface Impoundments - Coal Combustion Residual Surface Impoundments (illinois.gov)

Please direct any comments to **GROUNDWATER SECTION** at **EPA.BOW.GWS.CCR@Illinois.gov** within 14 days of the date of this notice for consideration per 35 Ill. Adm. Code 845.650(e)(3).

Please do not reply, this email box is not monitored.

Illinois Environmental Protection Agency
DWPC – Permits MC #15
Attn: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276
217-558-0347

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DOCUMENT 27

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Tuesday, December 19, 2023 5:08 PM
To: Brown, Michael L.
Subject: Statistics follow up

Hi Mike.
Just to recap our conversation. Our team does not have any one with experience in statistics. During my reviews of the statistics for previous projects, I have leaned on Mike Summers because he had statistics experience from working in Land. However, we did find that some of our projects here in BOW were not following the regulations as they are written prior to 845 (845 and other Title 35 gw regs require the use of the USEPA unified code unless the RP is using the basic methods outlined in the regulations specifically). Thus our team did NOT have anyone with any statistical experience prior to Mike Summers and will lose the only statistical reviewer when he leaves.
No one on our team feels comfortable with having the reviewing job for statistics going forward.
Case in Point—today in the meeting with Dynegy: Dynegy asked specific questions about Coffeen statistics review comments and we were not able to answer at the time. We will need to get with Mike Summers and figure out a path forward before he leaves.
Thank you.
Lauren

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
Illinois Environmental Protection Agency
Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
Lauren.hunt@illinois.gov
Hours: 8:30 am to 5:30 pm Tuesday through Friday
8:30 am to 4 pm Mondays and alternating Mondays off
Working remotely Mondays and Fridays.

State of Illinois - CONFIDENTIALITY NOTICE: The information contained in this communication is confidential, may be attorney-client privileged or attorney work product, may constitute inside information or internal deliberative staff communication, and is intended only for the use of the addressee. Unauthorized use, disclosure or copying of this communication or any part thereof is strictly prohibited and may be unlawful. If you have received this communication in error, please notify the sender immediately by return e-mail and destroy this communication and all copies thereof, including all attachments. Receipt by an unintended recipient does not waive attorney-client privilege, attorney work product privilege, or any other exemption from disclosure.

DOCUMENT 28

Rees, Jeromy

From: Jenny Cassel <jcassel@earthjustice.org>
Sent: Tuesday, December 19, 2023 12:00 PM
To: justin.bierwagen@Illinois.gov; EPA.BOW.GWS.CCR
Cc: Thomas Cmar; Mychal Ozaeta; Melissa Legge; arehn
Subject: [External] Prairie Rivers Network comments on ASD for Vermilion NEAP
Attachments: 12.19.23 PRN comments on ASD for Vermilion.pdf

Mr. Bierwagen and others it may concern in the Illinois EPA Groundwater Section,

Please see attached comments, submitted on behalf of Prairie Rivers Network, on Dynegy's "alternate source demonstration" for the Vermilion New East Ash Pond. We appreciate your consideration of these comments, pursuant to 35 IAC 845.650(e)(3), and strongly urge you not to concur with the ASD.

Sincerely,
Jenny Cassel

Jenny Cassel
Senior Attorney, Clean Energy Program
Earthjustice
311 S. Wacker Drive, Suite 1400
Chicago, IL 60606
T: 312-500-2198 (direct)
jcassel@earthjustice.org

December 19, 2023

Groundwater Section staff
Illinois Environmental Protection Agency
EPA.BOW.GWS.CCR@illinois.gov

RE: Public Comments on Alternative Source Demonstration for Vermilion NEAP

Dear Illinois EPA Groundwater Section staff,

Pursuant to 35 I.A.C. § 845.650(e)(3), on behalf of Prairie Rivers Network, Earthjustice respectfully submits these public comments concerning the alternative source demonstration ("ASD") submitted for the New East Ash Pond ("NEAP") at the former Vermilion plant. We urge IEPA not to concur because Dynegy failed to demonstrate that the NEAP did not contribute to the contamination found in groundwater monitoring wells.

Under the Part 845 rules, an alternative source demonstration ("ASD") is a:

> demonstration . . . that a source other than the CCR surface impoundment caused the contamination and the CCR surface impoundment *did not contribute* to the contamination, or that the exceedance . . . resulted from error in sampling, analysis, statistical evaluation, natural variation in groundwater quality, or a change in potentiometric surface and groundwater flow direction.

35 I.A.C. § 845.650(e) (emphasis added).

Dynegy has not met this high bar for avoiding corrective action. First, it inappropriately relies on a geochemical analysis called a "Piper plot" as evidence that the NEAP is not contributing to the pollution at issue. Second, Dynegy has not provided adequate information to substantiate its assertion that comparisons of groundwater concentrations with porewater concentrations demonstrate that the NEAP is not contributing to groundwater exceedances. Third, Dynegy has not shown that shallow groundwater cannot be contributing to high concentrations of CCR pollutants in deeper groundwater. Fourth and finally, Dynegy has not conclusively shown that the NEAP did not contribute to chloride, lithium, sulfate and total dissolved solids ("TDS") contamination in monitoring wells ("MW") 35D and 70D because it lacks a groundwater monitoring program approved by the Agency following public review and comment. Without an approved groundwater monitoring program, the Agency cannot make a supported decision that the purported "demonstration" establishes that the NEAP has not contributed to exceedances.

1. **Comparisons of porewater to groundwater, including those based on the "ionic composition" of the waters, do not suffice to demonstrate that the NEAP did not contribute to contamination in MWs 35D and 70D.**

One "line of evidence" that Dynegy offers in support of its purported demonstration that NEAP did not contribute to the chloride, lithium, sulfate and TDS pollution found in MWs 35D

and 70D involves comparing the chemistry of CCR porewater to that of groundwater.[1] Dynegy relies on a "Piper plot" in claiming that geochemistry at the site shows that CCR leachate from the NEAP is not contributing to the pollution. However, the U.S. Environmental Protection Agency ("USEPA") has *rejected* the use of such "Piper plots" in ASDs. As USEPA explained in its final Part A decision for the Gavin power plant,[2] a Piper plot "does not consider hydrogeology" and reliance on such plots "seeks to set aside the information about site geology and hydrology that has been used to characterize the direction of groundwater flow, and instead to determine where groundwater sampled from compliance wells came from based solely on chemistry." [3] Because relying on a Piper plot analysis would disregard site-specific hydrogeology, USEPA determined that, "in the context of the CCR regulations, it is inappropriate as part of the ASD to use Piper plots to determine from where groundwater at compliance wells is coming."[4]

The Illinois legislature provided that Part 845 is to be "at least as protective and comprehensive" as the federal CCR rule.[5] Accordingly, Illinois EPA should reject "Piper plots" as evidence, both in this instance and where offered as support for other ASDs, that a CCR surface impoundment is not contributing to groundwater pollution.

A second "line of evidence" that Dynegy offers in support of its ASD is the argument that concentrations of chloride in NEAP porewater are less than chloride concentrations in groundwater.[6] IEPA should also reject this line of evidence. Dynegy does not provide adequate information about exactly where in the NEAP the porewater sample was taken, whether more than one sample was taken, the pH of the sampled porewater, or other geochemical information that potentially could allow the Agency to determine that the NEAP is not contributing to chloride exceedances. This same lack of information casts doubt on Dynegy's third "line of evidence," since it also relies, in part, on a distinction between groundwater and porewater.[7]

Given Dynegy's admission that sulfate and TDS exceedances at wells 70S are attributable to the NEAP,[8] claims that the NEAP does not contribute to exceedances of those and other pollutants in a deeper well in the same location (70D) or MW 35D are suspect and must be closely scrutinized. Dynegy has not met its burden with this ASD.

[1] Dynegy ASD for Vermilion at 9-10 of 17.
[2] USEPA, Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals From Electric Utilities; A Holistic Approach to Closure Part A: Final Decision on Request For Extension of Closure Date Submitted by Gavin Power, LLC ("Final Gavin Part A Decision"), Notice of availability of final decision, 87 Fed. Reg. 72,989 (Nov. 28, 2022); Final Gavin Part A Decision, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0590-0100.
[3] Final Gavin Part A Decision at 67-68.
[4] *Id*.
[5] 415 ILCS 5/22.59(g)(1).
[6] Dynegy ASD for Vermilion at 10-11 of 17.
[7] *See* Dynegy ASD for Vermilion at 12 of 17 ("Principal component analysis (PCA) shows that BCU groundwater is distinct from CCR porewater.")
[8] *See id*. at 5 of 17 ("Sulfate and TDS GWPS exceedances at well 70S will be addressed in accordance with 35 I.A.C. § 845.660"); 35 I.A.C. § 845.660 (requiring initiation of an assessment of corrective measures).

2. Dynegy has not shown that there is no connection between deeper groundwater and groundwater potentially affected by the NEAP.

As noted above, Dynegy's obligation is to demonstrate that the NEAP is not contributing to exceedances in groundwater. Dynegy undercuts its own arguments: while claiming that deeper groundwater is separate from shallow groundwater, it acknowledges that analysis has "indicated…that the wells that 'draw water from the bedrock are *either only slightly connected to* or completely isolated from the local groundwater flow system…."[9] If indeed the bedrock groundwater is "slightly connected to" groundwater closer to the surface, then CCR pollutants in the shallower groundwater may be contributing to exceedances in deeper monitoring wells. Dynegy has not met its burden.

3. IEPA has not yet approved a groundwater monitoring program under Part 845 for the NEAP.

IEPA should also reject Dynegy's ASD because Vermilion lacks an approved groundwater monitoring program under Part 845. An approved groundwater monitoring program – which includes appropriate locations, depths, and number of background and downgradient monitoring wells, as well as satisfactory sampling procedures and determinations of which wells accurately represent "background" groundwater quality – is an *essential prerequisite for any ASD.* Without an approved program, owners/operators may be engaging in a variety of erroneous monitoring practices that result in contamination from the CCR surface impoundment not being fully detected or characterized.

Among other flaws, owners or operators may have set up a groundwater monitoring system that is missing contaminant pathways; treating CCR-contaminated wells as "background" wells, resulting in pollution associated with the CCR surface impoundment improperly not being classified as an exceedance; or failing to account for "mounding" or other hydrogeological characteristics that affect groundwater flow direction. In short, without an IEPA-approved program properly revealing what contamination is coming from a CCR surface impoundment, *there is insufficient information for IEPA to determine—or for owners/operators to demonstrate—that pollution is NOT coming from the impoundment.*

Our concerns about serious flaws in groundwater monitoring performed by industry, absent review and approval (after public comment) from the Agency, are far from hypothetical. USEPA has reviewed the groundwater monitoring systems of multiple CCR surface impoundments – including one here in Illinois[10] – and found, or proposed to find, numerous grave errors in how that monitoring is being carried out.

Many of these evaluations have come in the form of USEPA's review of owners/operators' "Part A" applications. To obtain an extension of the deadline to cease receipt of CCR in a CCR surface impoundment that is required to close, owners/operators were required to demonstrate,

[9] Dynegy ASD for Vermilion at 13 of 17 (emphasis added).
[10] *See* https://www.epa.gov/coalash/coal-combustion-residuals-ccr-part-implementation (noting proposed denial of Waukegan "Part A" application, with link to proposed denial).

among other things, full compliance with the CCR rule at the entire facility where the CCR surface impoundment is located.[11] As of this writing, USEPA has issued thirteen proposed decisions on Part A applications, one of which it finalized.[12] It evaluated compliance with the groundwater monitoring mandates of the CCR rule at eight of those facilities.[13]

At *every* site that USEPA reviewed as part of its Part A evaluations, including one in Illinois (Waukegan), it identified serious problems with facilities' groundwater monitoring systems:

- At the Gavin coal-fired power plant, USEPA found that the owner/operator failed to thoroughly characterize groundwater flow direction, failed to properly establish background wells, and lacked adequate downgradient wells, among other flaws.[14]

- At the Waukegan plant, USEPA proposed to find that Midwest Generation did not properly characterize groundwater flow direction, lacked sufficient wells to fully monitor potential contamination, improperly used "intrawell" statistical analysis of monitoring results, and used improper "background" wells that were dug through CCR.[15]

- At the Ottumwa, Clifty Creek, and Spurlock plants, USEPA proposed to find that, among other deficiencies, the groundwater monitoring wells were too far apart or not properly sited, leaving potential contaminant pathways unmonitored.[16]

- At A.B. Brown, USEPA proposed to find, among other concerns, that the groundwater monitoring wells were not placed in sufficient locations to detect all potential contaminant pathways, that groundwater flow characterization was inadequate, and samples were improperly evaluated using "intrawell" statistical analysis.[17]

- At Mountaineer, USEPA proposed to find, among other flaws, that the company did not appropriately locate either background or downgradient wells, and improperly analyzed groundwater monitoring data, including by excluding so-called "outlier" data and by using intrawell analysis.[18]

[11] USEPA, Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals From Electric Utilities; A Holistic Approach to Closure, 85 Fed. Reg. 53,516 (Aug. 28, 2020).
[12] *See* https://www.epa.gov/coalash/coal-combustion-residuals-ccr-part-implementation (listing CCR surface impoundments for which USEPA has issued proposed and final decisions).
[13] *See id*. (noting proposed decisions, including complete and incomplete or ineligible applications).
[14] *See* final Gavin Part A decision at 45-54 and 70-76, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0590-0100.
[15] *See* proposed Waukegan Part A decision at 31-47, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2023-0209-0001.
[16] *See* proposed Ottumwa Part A decision at 43-46, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0593-0002; proposed Clifty Creek Part A decision at 44-45, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0587-0023; and proposed Spurlock Part A decision at 55-56, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0595-0002;
[17] *See* proposed A.B. Brown Part A decision at 31-47, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2022-0335-0001.
[18] *See* proposed Mountaineer Part A decision at 33-48, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0842-0001.

- At the Calaveras plant, USEPA proposed to find, among other flaws, that groundwater monitoring wells are improperly spaced, inadequate in number, and not located at the waste boundary, and the company did not appropriately identify background wells.[19]

USEPA has likewise identified severe deficiencies in the groundwater monitoring programs at multiple CCR facilities in Alabama[20] and at one facility in Kansas to which it sent a letter summarizing conversations regarding compliance concerns.[21]

In effect, *every time* USEPA has taken a close look at the groundwater monitoring program for a CCR surface impoundment or landfill, it has identified deficiencies that could lead to contamination from those CCR units being released undetected. There is no reason to believe those deficiencies are limited to sites outside of Illinois; indeed, as noted, one facility where USEPA found those deficiencies is the Waukegan plant. Until IEPA fulfills the critical oversight role assigned to it by the Coal Ash Pollution Prevention Act and Part 845, namely, it has reviewed and approved the groundwater monitoring program for Vermilion, *all ASDs for the site should be denied.*

4. Conclusion

Dynegy admits that the NEAP is leaking, and its Vermilion ash ponds continue to pose a grave threat to Illinois' only National Scenic River, the Middle Fork of the Vermilion River. Though PRN believes that Dynegy and IEPA have made the proper choice, in a separate proceeding, to excavate the impoundments and move the ash to an onsite landfill, IEPA must move expeditiously to issue a construction permit for closure by removal so that the coal ash can be moved, further contamination halted, and the Middle Fork restored.

Commenters reserve the right to provide additional comment on this or any other ASDs for Vermilion once an approved groundwater monitoring system, set out in IEPA-approved operating permit, is in place.

Thank you for taking these comments into consideration.

Best,

Jennifer Cassel
Thom Cmar
Mychal Ozaeta
Melissa Legge
Earthjustice

[19] *See* proposed Calaveras Part A decision at 47-55, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2022-0333-0001.
[20] Alabama: Denial of State Coal Combustion Residuals Permit Program, 88 Fed. Reg. 55,220, 55,239 - 55,241, 55,249 - 55,253, 55,260 - 55,267, and 55,271 - 55,272 (Aug. 14, 2023).
[21] USEPA, Letter re: Notice of Potential Violations/Opportunity to Confer, Tecumseh Energy Center, Tecumseh, Kansas, Enclosure 1 at 1-4 (Jan. 2021), attached hereto.

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Counsel for Prairie Rivers Network

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 7
11201 Renner Boulevard
Lenexa, Kansas 66219

SENT BY ELECTRONIC MAIL
RECEIPT CONFIRMATION REQUESTED
jared.morrison@evergy.com

Mr. Jared Morrison
Director, Water and Waste Programs
Evergy Kansas Central, Inc.
818 S. Kansas Avenue
P.O. Box 889
Topeka, Kansas 66601

Re: Notice of Potential Violations/Opportunity to Confer
Tecumseh Energy Center, Tecumseh, Kansas

Dear Mr. Morrison:

Thank you for taking the time on January 25, 2021, and March 9, 2021, to discuss disposal of coal combustion residuals (CCR) at the Evergy Tecumseh Energy Center (TEC) located near Tecumseh, Kansas, and the requirements of 40 C.F.R. Part 257, Subpart D (the CCR Rule). After further review of the information posted on your publicly accessible CCR compliance web site (TEC CCR web site), the U.S. Environmental Protection Agency (the EPA or the Agency) continues to be concerned about compliance with the CCR Rule at TEC.

According to the TEC CCR web site, two units at the facility are subject to requirements in the CCR Rule: one surface impoundment (Bottom Ash Settling Area or BASA) and one landfill (322 Landfill). The Agency has reviewed the following documents posted for these units:

- Annual Groundwater Monitoring and Corrective Action (GWMCA) Reports (2017, 2018, 2019 and 2020, revised March 6, 2021)
- Groundwater Monitoring Systems Certification (2017, revised March 9, 2021)
- Statistical Method Certifications (2017, 2018, 2019)
- Closure Plan TEC Industrial Landfill 322 (2016, revised Mar 4, 2021)
- Post-Closure Plan TEC Industrial Landfill 322 (2016, revised March 4, 2021)

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This review identified several missing, erroneous, or incomplete elements, which represent potential violations, described in Enclosure 1. The EPA's priority is to ensure Evergy is operating in compliance with the CCR Rule. While we appreciate Evergy's efforts to date to comply with the CCR Rule, and offers to perform additional work, the EPA has continuing concerns as to whether some requirements are being met. Based on the issues highlighted in the May 13, 2021, letter from Mr. Mark Anstoetter, and the results of the January and March meetings, we believe that further discussions are warranted. The EPA is interested in discussing the issues identified in Mr. Anstoetter's letter and developing an agreed-upon compliance schedule to address areas of noncompliance if possible. A proposed compliance schedule is set forth in Enclosure 2.

The EPA also believes that these potential violations are likely significant enough to warrant the assessment of a civil penalty. The terms of any agreed-upon resolution of areas of noncompliance, a compliance schedule and penalty would be incorporated into a Consent Agreement and Final Order issued pursuant to Section 3008(a) of RCRA, 42 U.S.C. § 6928(a).

Any submittal that TEC prepares to comply with the CCR Rule must be maintained, placed in the operating record, and posted by TEC in accordance with the recordkeeping, notification and publicly accessible CCR web site requirements, pursuant to 40 C.F.R. §§ 257.105, 257.106 and 257.107. Please note that original versions of documents must remain on the CCR web site for 5 years, in accordance with 40 C.F.R. § 257.107(c).

To schedule a call to discuss these issues, please contact Kelley Catlin in the Office of Regional Counsel within 10 calendar days of receipt of this letter at (913) 551-7110 or Bob Aston, at (913) 551-7392. Thank you for your prompt attention to this important matter.

Sincerely,

Wendy Lubbe
Acting Director
Enforcement and Compliance Assurance Division

cc: Mark Anstoetter, Esq.
Shook, Hardy and Bacon
manstoetter@shb.com

Julie Coleman, Director (e-copy)
Bureau of Waste Management
Kansas Department of Health and Environment

ENCLOSURE 1
Potential Violations
Tecumseh Energy Center

1) Reporting monitoring data

- 40 C.F.R. § 257.90(e)(3) – The Annual Groundwater Monitoring and Corrective Action (GWMCA) Reports must include all monitoring data obtained under 40 C.F.R. §§ 257.90 through 257.98. This includes results of laboratory analysis of groundwater or other environmental media samples for the presence of constituents in Appendices III and IV to 40 C.F.R. part 257 (or of other constituents, such as those supporting characterization of site conditions that may ultimately affect a remedy), any required statistical analyses performed on those results, measured groundwater elevations, and calculated groundwater flow rate and direction. The posted Annual GWMCA Reports do not include all the required information.

2) Groundwater monitoring system

- 40 C.F.R. § 257.91 – The performance standards require that a groundwater monitoring system consist of a sufficient number of wells, installed at appropriate locations and depths, to accurately characterize the quality of groundwater upgradient and passing the downgradient boundary of the unit. The following issues with the groundwater monitoring system have been identified:

    - 40 C.F.R. § 257.91(c) – Each groundwater monitoring system is required to have a sufficient number of wells to accurately characterize groundwater quality, including at least three downgradient wells[1]. In December 2019 at the BASA, MW-9 was not monitored due to lack of water in the well. This resulted in failure of the BASA groundwater monitoring system to meet the requirement to have a minimum of 3 downgradient wells in the BASA groundwater monitoring system during this semi-annual period.

    - 40 C.F.R. § 257.91(f) – The certification by a professional engineer (P.E.) that the groundwater monitoring systems have been designed and constructed to meet the requirements of 40 C.F.R. § 257.91 must document the basis supporting the determination for monitoring systems using only one upgradient and three downgradient wells. The groundwater monitoring systems for both the BASA and the 322 Landfill each consist of only one upgradient and three downgradient wells. The P.E. certification for the systems does not include the basis for the certification. This basis must include the criteria specified in 40 C.F.R. § 257.91(b), which is required to

[1] As the EPA explained in the preamble to the CCR Rule (see 80 FR 21400), "As a practical matter, the EPA expects that there will be few cases, if any, where four wells will be sufficient, given that this requirement was originally developed for hazardous waste management units that are typically much smaller than CCR units. As mentioned above, a small unit with simple geology, a flat and constant hydraulic gradient, uniform hydraulic conductivity, low seepage velocity, and high dispersivity potential would be the type of unit for which the minimum number of wells could be sufficient to meet the overall performance standard. Although the EPA is finalizing a requirement for one upgradient and three downgradient wells as a regulatory minimum, the Agency expects large CCR units to have many more wells because most CCR sites have hydrologic settings that are too complex for the regulatory minimum to be adequate."

be considered when determining the appropriate number, spacing and depths of groundwater monitoring wells.

TEC has not provided any of the information required to support the design of the groundwater monitoring systems in the system certifications, except potentiometric maps included in the Annual GWMCA Reports. Some of the potentiometric maps appear to be based on an insufficient number of groundwater elevation data points to support the contours drawn. Moreover, there is evidence that both the BASA and the 322 Landfill groundwater monitoring systems do not meet the performance standard in 40 C.F.R. § 257.91.

With regard to the BASA, the analysis and data included in the BASA Alternate Source Demonstrations (ASDs) indicate background groundwater quality may not be properly characterized. Potentiometric maps included in the revised 2018 Annual GWMCA Report indicate at least a 90-degree shift in groundwater flow direction. This shift in flow direction results in monitoring well MW-11, which is designated as a side gradient well, being downgradient during 2018. This shift in flow direction similarly affects upgradient well MW-7. During 2018, MW-7 is depicted as either side gradient and potentially downgradient of the BASA unit and may not represent true background conditions. This shift in groundwater flow direction is not noted in the revised 2018 GWMCA Report. Additionally, the BASA is located next to a water feature that appears to exert seasonal or temporal influence on groundwater flow direction.

With regard to the 322 Landfill, this unit is too large for one upgradient and three downgradient wells to be spatially adequate to represent groundwater quality. The unit is approximately 56 acres, and its western and eastern boundaries are each approximately 2500 feet long. However, there are no groundwater monitoring wells along the western boundary of the unit and only one downgradient well on the eastern boundary of the unit, approximately 300 feet south of the northeast corner of the unit (see Figure 1 in the 2020 Annual GWMCA Report). Potentiometric flow maps depict groundwater flow toward the north/northeast, and groundwater is depicted as migrating toward the unit in this direction along the entire length of the western boundary and away from it along the entire length of the eastern boundary. 40 C.F.R. § 257.91(a)(2) requires that the downgradient monitoring system be "installed at the waste boundary that ensures detection of groundwater contamination," such that "all potential contaminant pathways must be monitored." Thus, the existence of over 2,000 feet of unmonitored, downgradient waste boundary along the eastern side of the landfill does not ensure detection of groundwater contamination.

The number, spacing, and depths of groundwater monitoring wells needed to sufficiently monitor upgradient groundwater quality and at the downgradient boundary must be determined using site-specific information as required by 40 C.F.R. § 257.91(b), which is currently missing from the reports and certifications available for review. However, simply based on size and available information it appears that neither background groundwater quality nor groundwater quality at the downgradient unit boundary are accurately characterized at either the BASA or the 322 Landfill.

3) Groundwater sampling and analysis requirements

- 40 C.F.R. § 257.93(d) – Background groundwater quality must be established for each constituent in a hydraulically upgradient well, or a background well that meets the requirements of 40 C.F.R. § 257.91(a)(1). 40 C.F.R. § 257.91(a)(1) allows background groundwater quality to be established in a well that has not been affected by leakage from a CCR unit and is not hydraulically upgradient if either of two criteria is met:

- inability to determine a groundwater flow gradient; or
- samples from other wells are as representative or more representative of background groundwater quality than samples from a hydraulically upgradient well.

Intrawell comparisons conducted at the BASA do not appear to meet these requirements, as discussed below.

- 40 C.F.R. § 257.93(c) – The rate and direction of groundwater flow must be determined each time groundwater is sampled. The determination of the rate of groundwater flow has not been included in the Annual GWMCA Reports.

When conducting "intrawell" data comparison, samples taken at different times from the same well are used to characterize both background groundwater quality and downgradient groundwater quality. When conducting "interwell" data comparison, samples from one or more upgradient or side-gradient wells characterize background groundwater quality and samples from one or more down-gradient wells characterize groundwater quality down-gradient from the unit.

TEC has utilized intrawell comparisons at certain wells for certain constituents in Appendix IV to 40 C.F.R. part 257, for which interwell comparisons would have yielded a statistically significant level (SSL) (e.g., see Table II in the 2019 Annual GWMCA Report for the BASA for MW-9 for arsenic and cobalt and MW-10 for arsenic). This approach was implemented for the October 2019 sampling event, after TEC prepared an ASD in which TEC claimed there was natural variation in groundwater quality occurring below the BASA, for particular Appendix IV constituents only.

TEC has not provided data that indicate a groundwater flow gradient is not present at the BASA. Accordingly, the first criterion set forth at 40 C.F.R. § 257.91(a)(1)(i), that would allow background to be established in a non-upgradient well, is not met. With respect to the second criterion set forth at 40 C.F.R. § 257.91(a)(1)(ii), TEC has provided no information that indicates that the samples taken from the downgradient wells at the BASA are as or more representative of background groundwater quality than could be obtained from an up-gradient well.

If background groundwater quality samples are obtained from either an upgradient or a side-gradient well, interwell data comparisons would necessarily be used to identify SSIs or SSLs, because samples to characterize groundwater quality at the downgradient unit boundary would necessarily come from different wells than background samples. Additionally, samples that characterize background groundwater quality must always be taken from a well unimpacted by releases from a CCR unit.

If it can be demonstrated that samples obtained from wells located at the downgradient boundary of the CCR unit characterize background groundwater quality as accurately or more accurately than samples from an upgradient well, then all data analyzed for SSIs or SSLs would come from the same wells, and intrawell data comparisons would be used. As noted above, samples that characterize background groundwater quality must always be taken from a well unimpacted by releases from the CCR unit. Like many other CCR units, the BASA operated for decades (since construction in 1968) prior to becoming regulated by the CCR Rule. The 2019 Annual GWMCA Report indicates in a footnote to Table II that data collected through June 2019 were used to characterize background in the intrawell statistical analysis of the October 2019 groundwater data. Samples would need to have been obtained from these wells long before that time in order for them to be known to be unimpacted by the CCR unit. Therefore,

intrawell data comparisons are inappropriate to demonstrate compliance with the requirements of the CCR Rule at the BASA.

4) Assessment Monitoring program

Whenever there is an SSI over background levels for one or more of the constituents in Appendix III to 40 C.F.R. part 257 at any monitoring well at the waste boundary, an assessment monitoring program must be established. The following issues with the assessment monitoring program at the BASA have been identified:

- 40 C.F.R. § 257.95(b) – The assessment monitoring program requires annual sampling for all constituents in Appendix IV to 40 C.F.R. part 257. This sampling was last conducted at the BASA on June 25, 2019. No sampling was conducted in 2020 to meet this requirement, as reported in Section 2.3.3 of the 2020 Annual GWMCA Report (amended March 6, 2021).

- 40 C.F.R. § 257.95(d)(1) – The assessment monitoring program requires semi-annual monitoring at all wells for all constituents in Appendix III to 40 C.F.R. part 257 and for those constituents in Appendix IV to 40 C.F.R. part 257 that were detected in the sampling event conducted in accordance with 40 C.F.R. § 257.93(b). This sampling was last conducted timely on March 20-21, 2019. The next sampling event occurred on October 10, 2019, beyond the semi-annual timeframe. No sampling was conducted in 2020 to meet this requirement, as reported in Section 2.3.3 of the 2020 Annual GWMCA Report (amended March 6, 2021).

5) The Alternate Source Demonstrations (ASD)

In order to rebut the site-specific monitoring data and analysis that resulted in an SSI or SSL, an ASD must be supported by site-specific facts and analytical data. Merely speculative or theoretical bases for the conclusions are insufficient. An ASD should be conclusive, rather than probable or possible.

At the BASA, constituents in Appendix IV to 40 C.F.R. part 257 were detected at SSLs in September 2018 and March 2019. The 2019 Annual GWMCA Report included ASDs for these sampling events. These ASDs do not support a determination that the SSLs detected (arsenic in MW-9 and MW-10 and cobalt in MW-9) in both September 2018 and March 2019 are due to an alternate source rather than the BASA, in accordance with requirements in 40 C.F.R. § 257.95(g)(3)(ii). Specific concerns regarding the validity of the ASDs include:

- No alternative source was credibly identified that would have contributed to the SSIs/SSLs detected. The EPA has previously outlined the expectations for a valid ASD in the Solid Waste Disposal Facility Criteria, Technical Manual[2] for the Municipal Solid Waste Landfill regulatory program at 40 C.F.R. part 258. In Chapter 5, beginning on page 286, and further explained on page 280, a facility seeking an ASD must document that "*an* alternative source exists" and that a hydraulic connection exists between *the* alternative source and the well with the significant increase. Furthermore, the facility must document that "constituents (or precursor constituents) are present at *the alternative source* or along the flow path *from the alternative source* prior to possible release from the regulated unit." The ASD regulatory

[2] Solid Waste Disposal Facility Criteria, Technical Manual (November 1993), EPA530-93-017 https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/subparte.pdf

language at 40 C.F.R. part 258 tracks the ASD regulatory language at 40 C.F.R. part 257. Just as this approach makes sense and has been appropriate for ASDs under Part 258 for over 25 years, the Agency believes the same approach is appropriate for Part 257.

- Claims that variation in groundwater quality between upgradient and downgradient wells is occurring naturally are unsupported by data in the ASD. While the ASD highlights average decreasing concentrations of some constituents (e.g., boron, chloride and sulfate) from upgradient to downgradient wells as evidence of the BASA not impacting groundwater, the ASD neglects to address that higher calcium concentrations exist downgradient, and fluoride concentration patterns are mixed; the Appendix III sampling data are inconclusive in proving natural groundwater variation. Some Appendix IV sampling data show similar uneven concentration patterns, but some are more clearly at elevated levels downgradient for key constituents like arsenic. Sampling results do not indicate the presence of Appendix IV constituents at unexpected high concentrations in the aquifer matrix downgradient of the background wells. Other possible reasons for such variations include improper characterization of background groundwater quality (see prior discussion on the 2018 groundwater potentiometric maps), or changes in groundwater chemistry below the unit caused by releases from the BASA to the aquifer. Sampling from additional wells or other environmental media could better substantiate a claim of groundwater natural variability as the cause of constituent concentration patterns.

- The leachate tests are of limited value for the following reasons:

    - Not enough information is provided about the sampling collection protocols (e.g., depth, volume, location of samples), the typical residence time of ash in the unit, or how the composition of ash being disposed may have changed over time.

    - Ash collected from the impoundment may have already leached a substantial fraction of the contaminant mass and provide an incomplete estimate of total release potential.

    - Not enough information is provided to determine whether the selected leachate test accurately reflects field conditions. This is in part due to the lack of field parameter results in Annual GWMCA Reports. These tests are not useful in an ASD if they are not similar to conditions in the unit (e.g., pH of liquid or the liquid to solid ratio).

    - The leaching test results do not provide evidence to refute that elevated arsenic and cobalt at MW-9 and MW-10 are being at least partially caused by the unit.

- The evidence presented, primarily leachability testing, does not outweigh the significant amount of field data indicating the detections are the result of a leak in the BASA. This evidence includes the following:

    - The BASA does not have a liner to inhibit infiltration of releases into the underlying, uppermost aquifer.

    - Approximately 20 feet of hydraulic head was present within the BASA during operation to drive the sluiced ash water into the underlying, uppermost aquifer throughout the 35 years of operational history.

- Following dewatering of the BASA in September 2019, the groundwater elevations dropped approximately nine feet in MW-8, MW-9 and MW-10, confirming a direct hydraulic connection between sluiced ash in BASA and groundwater at these downgradient wells.

- Multiple SSIs above background occurred at all three downgradient wells (MW-8, MW-9, MW-10) in each of the four monitoring events in 2018 and 2019.

Because an ASD meeting the requirements of 40 C.F.R. § 257.95(g)(3)(ii) was not completed within 90 days of finding that an SSL was detected, TEC became subject to the requirements of 40 C.F.R. § 257.95(g) and was also required to initiate an Assessment of Corrective Measures within 90 days after detecting the SSL in accordance with 40 C.F.R. § 257.96.

While the EPA is not foreclosing TEC from continuing its efforts to identify an alternative source, TEC must, in parallel, work through the assessment monitoring and corrective action program.

6) Closure and post-closure requirements

For the reasons stated above, the EPA believes the BASA is subject to corrective action requirements. Accordingly, the Closure Plan must be amended, and a Post-closure Care Plan must be developed to reflect that the unit has triggered corrective action requirements. The Post-closure Care Plan must incorporate changes necessary to reflect that closure will be complete when constituent concentrations throughout the unit and any areas affected by releases from the CCR unit have been removed and groundwater monitoring concentrations do not exceed the groundwater protection standards, in accordance with 40 C.F.R. § 257.102(c).

Regarding the 322 Landfill, the EPA identified issues associated with the Post-closure Care Plan. In general, the plan should document actions to be taken to comply with the performance standards for post-closure care in 40 C.F.R. § 257.104. The Post-closure Care Plan lacked specificity regarding actions to be taken, frequency or timing of activities discussed, and criteria for implementing described contingencies. By failing to provide specific measures or any guiding procedures or principles, it fails to serve as a plan. As such, the Landfill Post-closure Care Plan does not meet the requirements at 40 C.F.R. § 257.104(d):

- 40 C.F.R. § 257.104(d)(1)(i) requires that the plan contain a description of monitoring and maintenance activities required in 40 C.F.R. § 257.104(b)(1), to maintain the integrity and effectiveness of the final cover system. Section 5.1 of the Landfill Post-closure Plan states that inspections will initially occur weekly, then quarterly or semi-annually, and that "Inspection frequency will be reduced as final cover conditions are found to be stable and depending on the need for periodic maintenance." The Plan does not provide any criteria for evaluating stability or any method for conducting inspections. It does not specify what level of periodic maintenance might warrant more or less frequent inspections.

- Additionally, potential damage to the final cover, due to the lack of planned actions to restrict public access to the cover, necessitates the need for more frequent inspections than semi-annual.

- Section 5.2 of the Landfill Post-closure Plan provides a list of possible measures that could be used to control public access to the landfill (e.g., site security, fencing, lockable gates, and/or site surface water features) to prevent cover damage. This list simply represents a broad range of options, all or none of which may be implemented. If any of these measures were to be implemented, there is no information about their design (e.g., fence height) or requirements for maintenance or inspection.

ENCLOSURE 2
Proposed Compliance Schedule
Tecumseh Energy Center

#	CCR Rule	Summary of Issues Discussed	Projected Time Frame for Correction
1	40 C.F.R. § 257.90(e)	Incomplete Reports	30 days
2	40 C.F.R. § 257.91(c)	BASA groundwater monitoring system lacked sufficient number of wells	30 days
3	40 C.F.R. § 257.91(f)	Incomplete groundwater monitoring system certification	30 days
4	40 C.F.R. § 257.93(c)	Failure to report groundwater flow rate	30 days
5	40 C.F.R. § 257.95(b)	Conduct annual assessment monitoring for all constituents in Appendix III and IV	30 days
6	40 C.F.R. § 257.95(d)	Conduct semi-annual assessment monitoring for all constituents in Appendix III and for Appendix IV identified in sampling required by item 5	90 days
7	40 C.F.R. § 257.91	Submit a plan to install additional wells at 322 Landfill	45 days
8	40 C.F.R. § 257.95(g) and 40 C.F.R. § 257.96	Submit a plan to conduct initial fieldwork to characterize nature and extent of release from BASA and initiate an assessment of corrective measures (ACM)	45 days
9	40 C.F.R. § 257.93(d) and § 257.91(a)(1)	Establish background levels in wells as required and re-analyze groundwater monitoring data to identify SSLs for inclusion in ACM	45 days
10	40 C.F.R. § 257.104 and §§ 257.102(b), (c)	Develop a BASA Post-closure Care Plan and amend the Closure Plan to reflect the fact that corrective actions requirements apply	45 days
11	40 C.F.R. §257.104	Amend 322 Landfill Post-closure Plan to identify planned land use and to include a plan for actions in accordance with requirements to prevent damage to cap.	45 days
12	40 C.F.R. § 257.105-257.107	Notification and reporting requirements	Ongoing

DOCUMENT 29

Rees, Jeromy

From: LeCrone, Darin <Darin.LeCrone@Illinois.gov>
Sent: Tuesday, December 19, 2023 11:58 AM
To: Dunaway, Lynn
Subject: Draft Responses
Attachments: Draft Responses to NGOs DEL 12.19.23.docx

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

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1) **Status of applications for operating and closure permits**, including particularly sites classified in Categories 1-4 of the prioritization categories under Part 845. Specific sites we would like to focus on include: Lincoln Stone Quarry, Wood River, CWLP, Edwards, and Vermilion.

a. How is IEPA determining the order in which it evaluates permit applications? Is it taking into consideration those prioritization categories in determining which to evaluate?

As you are aware, the regulations are fairly complex, the applications are extensive, and we had 7 adjusted standard filings with the Board, and two variance requests. The Agency did its best to prioritize those in categories 1-4, in consideration of Board filings and other site specific considerations. Some of these sites are very complex, and have multiple ponds that must be considered.

Wood River – No application received. This matter has been referred to the Attorney Generals Office for enforcement.

Lincoln Stone Quarry – Unlike at most other sites, the Agency is separating out the initial operating and closure construction permitting actions. A draft initial operating permit has been prepared, but has not yet been sent for 15-day notice. That 15-day notice to the applicant will happen soon after the first of the year. Public notice will follow. The closure construction portion is still under review and a review letter will be sent for that application, also as soon as possible after the first of the year.

CWLP – A review letter was sent in October, and the Agency had a follow-up meeting with CWLP to discuss our letter. This letter covered both the operating and closure construction applications.

Edwards – A review letter was sent in October covering both the operating and closure construction applications.

Vermilion – As you are aware, this site had many complex issues to address, including the enforcement case. As part of that process, the Consent Order set in motion many activities. The Agency issued the NPDES permit for the facility on 11/17/23, and became effective 12/1/23. This issuance of this permit was a significant step in the site schedule. The Consent Order for the site laid out the path forward.

b. In addition to sites where adjusted standard petitions remain pending, are there other categories of sites that IEPA is choosing not to focus on in permitting? If so, what are those categories of sites and why is IEPA not moving forward on them for the moment?

The only permit applications that are not currently under consideration, are those with pending adjusted standard requests before the Board. There has not been any Agency decision to "not focus" on any category or site.

c. What other factors are slowing/hindering IEPA review of permit applications?

The sites histories, geological and geotechnical considerations and the complex nature of the regulations and applications, make these reviews highly complex and time intensive. The adjusted standard processes and related Board proceedings have require a large amount of staff time and effort. The Agency has had to deal with staff turnover and the training of new staff that are responsible for not only

the permit applications, but also the adjusted standard petitions. These staff are also responsible for other groundwater and wastewater permitting programs.

2) Deficiency letters:

a. Can you describe your process for reviewing these applications and how these letters fit into the process? Agency staff have conducted an initial review of most of these applications and sent out a review letter for those sites where at least an initial review was conducted. The review letter serves as a written list of deficiencies, questions, comments etc., but it does NOT serve as an Agency final decision or determination. Across all of the DWPC permitting programs, the Agency routinely has to ask for additional information or obtain clarification on information submitted in an application. These questions or inquiries can be made by phone, by email, or by a review letter. The best option really depends on the complexity of what is being asked. For these applications, given their complexity, the Agency determined that at least at this stage, submitting the information requests to the applicants by letter was the most appropriate method.

b. Do those letters reflect a full review of the applications, or are they more of a "completeness" review with further in-depth review to follow?

It depends on the site. All of these reviews and follow-up letters are conducted and written on a case by case basis. The deficiencies identified and/or the information requested varies from site to site.

c. Can IEPA remind companies to ensure that follow-up submissions are posted on their website as part of their permit application? Yes, we are doing that.

d. What actions will IEPA take if a permit applicant does not respond to a review letter, takes too long to respond, or their response is insufficient? We will be having follow-up calls or meetings with the companies to ensure that things keep moving. We have had some of those discussion already, and will be following up with all of them after the first of the year.

e. Would IEPA consider including a deadline for companies to respond, understanding that those deadlines will vary by the severity of the deficiency and how long it would take to provide the necessary information? Any such consideration will be made on a case by case basis. It is really dependent on what was being requested, and is also why those follow-up conversation are necessary.

3) **Engagement with USEPA:**

a. "Primary" or "delegation" application:

i. Regarding the primacy application, you mentioned in the October meeting that some of us were in that some documents or questions had been shared with USEPA, but IEPA was waiting to hear back from USEPA. Have you heard back?

ii. Is IEPA continuing the conversation with USEPA about the application?

iii. Do you have any sense of the timeline for submission of the full "primacy" application to USEPA?

b. USEPA decisions and guidance:

i. Is IEPA in communication with USEPA considering individual permit decisions?

ii. Is IEPA reviewing or considering USEPA's implementation of the federal CCR rule (e.g. proposed and final "Part A" decisions, letters to operators and states, rule preambles) in evaluating permit applications and/or determining scope of regulated impoundments? If so, in what ways?

4) **Questions concerning specific sites**:

a. Wood River i. What is the status of CTI's operating permit application? As discussed before, the application CTI submitted on 11/1/2022 is deficient (incomplete, frequently refers to a different site, etc). In March 2022, and again in June 2022, IEPA said it was working with CTI on this issue. What has happened since then?

Wood River – No application received. This matter has been referred to the Attorney Generals Office for enforcement.

ii. What is the status of CTI's closure permit application? IEPA issued a Violation Notice to CTI for failure to submit a closure permit application on July 26, 2022. The only related document we have seen so far is a 12/2022 closure alternatives analysis for the East Ash Pond. We have seen no other filings re: closure of the East Ash Pond, and no filings at all re: closure of the West Ash Pond Complex.

iii. We wanted to make sure you're aware that CTI's CCR reporting website has **zero** documents from 2023 and **one** document (closure alt. analysis for East Pond) in all of 2022. Has IEPA discussed this lack of documentation with CTI? If not, what does IEPA plan to do about it?

b. Lincoln Stone Quarry i. What is the status of IEPA review of the applications for this site? Have you had discussions with the applicant or USEPA concerning this site?

Lincoln Stone Quarry – Unlike at most other sites, the Agency is separating out the initial operating and closure construction permitting actions. A draft initial operating permit has been prepared, but has not yet been sent for 15-day notice. That 15-day notice to the applicant will happen soon after the first of the year. Public notice will follow. The closure construction portion is still under review and a review letter will be sent for that application, also as soon as possible after the first of the year.

ii. Have you reviewed the analyses we sent regarding concerns with the application? Yes?

c. Edwards: i. *Note: We will plan to share analysis discussing multiple significant concerns with the closure and operating permit applications in advance of this meeting.

??? I think we received something didn't we?

ii. Have you discussed, with the applicant or USEPA, any additional deficiencies in the application beyond those noted in the 10/2023 letter? If so, what are those?

5) **NPDES permits**:

Is IEPA considering the relationship between NPDES permits re dewatering (ponded and subsurface waters) and CCR closure permits? How so, and how does that affect IEPA's timeline in issuing one

before the other? IEPA seems to be issuing NPDES permits for dewatering (that is, removing both ponded and subsurface water) before approval of closure plans (e.g. Vermilion, Coffeen). Does closure method have no bearing on dewatering? For example, at Coffeen, the dewatering plan is to put the reject water back into the impoundment. This would seem to rule out closure by removal.

In most cases, the ash impoundment will require dewatering regardless of which closure method is chosen. The NPDES permit is necessary for other reasons independent of the CCR closure process, so we don't want to delay the issuance of the NPDES permit while the CCR permitting process continues.

6) **Alternate Source Determinations**: How is IEPA addressing ASDs when it hasn't yet evaluated the groundwater monitoring system to determine if monitoring program meets regulatory requirements?

DOCUMENT 30

From: Hunt, Lauren
To: Summers, Michael; Mullenax, Heather; Bierwagen, Justin; Dunaway, Lynn; Garee, Matthew J.
Subject: Dynegy Statistics Discussion

I realize not everyone can make this, but at least Heather and Mike seem to be able to make this meeting. We need to discuss Dynegy Statistics with Mike Summers before he leaves. thanks. Lauren

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DOCUMENT 31

Rees, Jeromy

From: Brown, Michael L. <Michael.L.Brown@Illinois.gov>
Sent: Wednesday, December 20, 2023 8:23 AM
To: Logan-Pugh, Joey L.
Subject: FW: Statistics follow up

FYI

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Tuesday, December 19, 2023 5:08 PM
To: Brown, Michael L. <Michael.L.Brown@Illinois.gov>
Subject: Statistics follow up

Hi Mike.
Just to recap our conversation. Our team does not have any one with experience in statistics. During my reviews of the statistics for previous projects, I have leaned on Mike Summers because he had statistics experience from working in Land. However, we did find that some of our projects here in BOW were not following the regulations as they are written prior to 845 (845 and other Title 35 gw regs require the use of the USEPA unified code unless the RP is using the basic methods outlined in the regulations specifically). Thus our team did NOT have anyone with any statistical experience prior to Mike Summers and will lose the only statistical reviewer when he leaves.
No one on our team feels comfortable with having the reviewing job for statistics going forward.
Case in Point—today in the meeting with Dynegy: Dynegy asked specific questions about Coffeen statistics review comments and we were not able to answer at the time. We will need to get with Mike Summers and figure out a path forward before he leaves.
Thank you.
Lauren

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DOCUMENT 32

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 20, 2023 11:45 AM
To: Summers, Michael
Subject: RE: For Statistics meeting later today.

Just an FYI. So Dynegy is taking issue with our review of the statistics at Coffeen. However, in conversations with their hydro after the meeting, the software they were using has failed several times and is proprietary to EPRI. Additionally, they do not provide any of the information that we have identified below to review their statistics submittals. So we want to have a short list of statistics review checklist so everyone is on the same page going forward. Thanks. Lauren

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From: Summers, Michael <Michael.Summers@Illinois.gov>
Sent: Wednesday, December 20, 2023 11:42 AM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Cc: Brown, Michael L. <Michael.L.Brown@Illinois.gov>
Subject: RE: For Statistics meeting later today.

Attached is an old basic statistical program that I've used in the past to calculate UCL, TL for multiple data sets. Along with standard basics values, normality, and outliers. This is an older version of excel. I don't "update" the program because things may change in the set up. Its easy to use and give basic info. Just a basic quick calculations.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 20, 2023 9:48 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: For Statistics meeting later today.

Hi all.
We have drafted the following Checklist for statistics reviews. We need to discuss details and how to implement these steps at our meeting later today.

1. Identify the statistics software being used.

   a. If the software is proprietary and not commercially available, then the software must be validated. The software validation must be documented and signed off on by at least the software validation draftee, senior reviewer and project manager/quality manager.
   b. A software validation package must include the following: data inputs, empirical formulas and output from empirical formulas in addition to the software data inputs, assumptions and outputs that matched the empirical production of the statistical analysis.
2. Identify all data sets (constituents) for which there must be statistical analysis provided.
3. Identify the data set being used for inputs for each constituent.
4. Identify the laboratory reports or EDD that validate the data inputs are accurate.
5. Identify the assumptions being used to analyze the data set.
6. Identify the statistical method(s) used to analyze the data set.
7. Identify the non-detects and review the statistical methods guidance for appropriate use of non-detects in the statistical methods provided. (EPA QA/G-9S).
8. Identify Outlier analysis
   a. Are there more than 32 data points? If not then the outlier analysis is not accepted.
   b. Are the data points valid?
   c. Is the outlier analysis method appropriate for the data set and the statistical analysis methods performed above?

Let me know if you have any input to the list.

Thanks, Lauren

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DOCUMENT 33

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 20, 2023 4:03 PM
To: Mullenax, Heather; Dunaway, Lynn
Cc: Summers, Michael
Subject: Coffeen Statistics letter

Hi Heather.
I just talked to Darin. He said to go ahead and draft the letter as a GW review letter, but CC the permit engineer assigned. Mike can sign off as before he leaves.
Thanks. Lauren

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DOCUMENT 34

Rees, Jeromy

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, December 21, 2023 7:55 AM
To: Hunt, Lauren; Dunaway, Lynn
Cc: Summers, Michael
Subject: RE: Coffeen Statistics letter

Hi everyone,

I will get this letter done today for edits and review before I leave early. I do have a question. Since a lot of the Dynegy sites are either exact or almost exact with their statistics or explanation, should we only send this out for Coffeen, each of the other sites that are similar in their statistics, or write an overall statistics letter to Dynegy explaining the information we are looking for when discussing statistics?

Thanks,

Heather D. Mullenax, M.S.
Environmental Protection Geologist 1
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
1021 N. Grand Avenue
Springfield, IL 62702
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Cell: 270-564-1551
Heather.mullenax@illinois.gov
Hours: 7:30 am to 5:30 pm Mon-Wed
7:30 am to 5:00 pm Thurs
Fridays off

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 20, 2023 4:03 PM
To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: Coffeen Statistics letter

Hi Heather.
I just talked to Darin. He said to go ahead and draft the letter as a GW review letter, but CC the permit engineer assigned. Mike can sign off as before he leaves.
Thanks. Lauren

Lauren I. Hunt, M.S.
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Environmental Protection Geologist III
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DOCUMENT 35

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Thursday, December 21, 2023 9:06 AM
To: Mullenax, Heather; Hunt, Lauren
Cc: Summers, Michael
Subject: RE: Coffeen Statistics letter

Since there have been no operating permits issued, addressing it as a permit condition or in discussions that may take place prior to draft permit publication, may be a method to address the issue without adding another letter.

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, December 21, 2023 7:55 AM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: RE: Coffeen Statistics letter

Hi everyone,

I will get this letter done today for edits and review before I leave early. I do have a question. Since a lot of the Dynegy sites are either exact or almost exact with their statistics or explanation, should we only send this out for Coffeen, each of the other sites that are similar in their statistics, or write an overall statistics letter to Dynegy explaining the information we are looking for when discussing statistics?

Thanks,

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Heather.mullenax@illinois.gov
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7:30 am to 5:00 pm Thurs
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From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, December 20, 2023 4:03 PM
To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
~~~~~~~~~~~~~~~~~

Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: Coffeen Statistics letter

Hi Heather.
I just talked to Darin. He said to go ahead and draft the letter as a GW review letter, but CC the permit engineer assigned. Mike can sign off as before he leaves.
Thanks. Lauren

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DOCUMENT 36

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, December 21, 2023 9:08 AM
To: Dunaway, Lynn; Mullenax, Heather
Cc: Summers, Michael; LeCrone, Darin
Subject: RE: Coffeen Statistics letter

Darin said to issue the comments as a review letter with Mike signing before he left next week. we are taking a look at the other Dynegy sites and will be updating the GWS memos or issuing a letter (if a review letter has been issued by permits) on an as needed basis.
Thanks. Lauren

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To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
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Sent: Thursday, December 21, 2023 7:55 AM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: RE: Coffeen Statistics letter

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Sent: Wednesday, December 20, 2023 4:03 PM
To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>
Subject: Coffeen Statistics letter

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Thanks. Lauren

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DOCUMENT 37

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Thursday, December 21, 2023 9:49 AM
To: Mullenax, Heather; Summers, Michael
Cc: Hunt, Lauren; Garee, Matthew J.; Bierwagen, Justin
Subject: RE: Dynegy Coffeen Statistics Letter Draft

I discussed my comments with Lauren and she will provide combined edits.

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, December 21, 2023 9:26 AM
To: Summers, Michael <Michael.Summers@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: Dynegy Coffeen Statistics Letter Draft

Good morning everyone,

I have written a letter about comments on the statistics found at Dynegy Coffeen Power Plant site. Please let me know if there are any edits to add to this letter.

Thank you,

Heather D. Mullenax, M.S.
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DOCUMENT 38

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, December 21, 2023 10:23 AM
To: Dunaway, Lynn; Mullenax, Heather; Summers, Michael
Cc: Garee, Matthew J.; Bierwagen, Justin
Subject: RE: Dynegy Coffeen Statistics Letter Draft
Attachments: Coffeen Statistics review Letter.docx; Coffeen Statistics review Letter draft with comments.docx

Here are my edits in tracked changes and then the letter clean. I also saved this on the N Drive in the Coffeen permit application folder. Let me know if you have any feedback.
Thanks, Lauren

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(she/they/he)
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Sent: Thursday, December 21, 2023 9:49 AM
To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Dynegy Coffeen Statistics Letter Draft

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To: Summers, Michael <Michael.Summers@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: Dynegy Coffeen Statistics Letter Draft

Good morning everyone,

I have written a letter about comments on the statistics found at Dynegy Coffeen Power Plant site. Please let me know if there are any edits to add to this letter.

Thank you,

Heather D. Mullenax, M.S.
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~~~~~~~~~~~~~~~~~~

217-782-1020

August 5, 2024

Phil Morris
Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No.1, Ash Pond No. 2, GMF Gypsum Stack Pond, and GMF Recycle Pond; W1350150004-001, W1350150004-002, W1350150004-003, and W1350150004-004
Comments on Statistical Methods of Dynegy Sites

Dear Mr. Morris:

The purpose of this correspondence is the Illinois Environmental Protection Agency (Illinois EPA) requests additional information based on part 845.640(f) and (g) otherwise known as statistical methods. The Illinois EPA requests the following:

1. The statistical methods must define the following in order to review the statistical method plan in accordance with *Illinois EPA Quality Management Plan (A17-001), Guidance on Assessing Quality Systems (EPA QA/G-3), Data Quality Assessment: Statistical Methods for Practitioners EPA QA/G-9S, Data Quality Assessment: A Reviewer's Guide EPA QA/G-9R and/or Guidance on Environmental Data Verification and Data Validation (EPA QA/G-8)*:
    a. The software program that is being used for statistical evaluation must be identified. If the software program is proprietary, software validation must be performed, documented and signed off by at least the software validation draftee, senior reviewer, and project manager/quality manager. (EPA QA/G-3)
        i. Software validation packages must include at least a known data set, empirical evaluation including formulas to prove the validity of the software, and outputs from both the software and the empirical calculations exhibiting that the software is producing the same output as the empirical evaluation. (EPA QA/G-3)
    b. All input data sets for each constituent must be provided in a table in accordance with SW-846 chapter 1, incorporated by reference in 35 IAC 845. Chapter 1 of SW846 states that regulatory decisions must be made with environmental data.
        i. All data sets, used for statistical analysis, must be within the last eight consecutive quarterly sampling events in order to validate the statistical methods for recent activity (35 IAC 845.650(b))

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1. If an impoundment is considered closed by the Agency, the data sets must be used from the eight consecutive quarters after closure or most recent eight consecutive quarters.

c. Illinois Power Generating Company (Illinois Power) must provide the laboratory reports or EDD to validate the data input sets are accurate and follow 845.640(i) and 845.640(j).

d. Illinois Power must identify the assumptions being used to analyze the data sets and any other methods. (EPA QA/G-9S).

e. Illinois Power must identify the non-detects within the data set. Illinois Power must review the statistical methods guidance for appropriate use of non-detects in the statistical methods provided and provide a detailed explanation of the rationale including empirical formulas for examples of the implementation of the statistical methods. (EPA QA/G-9S).

f. The Agency's position on outliers is that verified data from a NELAP certified laboratory is representative of the aquifer properties analyzed. Outliers cannot be evaluated for exclusion from any dataset without explicit data validation identifying discrepancies from the laboratory and/or field procedures that would qualify a data point to be considered an outlier. Illinois Power must use the USEPA data validation procedures to determine when or if a data point is to be excluded from a data set. (EPA QA/G-8).

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If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, Groundwater Section DPWS #13, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Michael Summers, P.G.
Manager, Groundwater Section
Division of Public Water Supplies
Bureau of Water

cc: Heather Mullenax
Keegan MacDonna
Lauren Hunt
Lynn Dunaway
Records Files 06M

217-782-1020

August 5, 2024

Phil Morris
Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No.1, Ash Pond No. 2, GMF Gypsum Stack Pond, and GMF Recycle Pond; W1350150004-001, W1350150004-002, W1350150004-003, and W1350150004-004
Comments on Statistical Methods of Dynegy Sites

Dear Mr. Morris:

The purpose of this correspondence is the Illinois Environmental Protection Agency (Illinois EPA) requests additional information based on part 845.640(f) and (g) otherwise known as statistical methods. The Illinois EPA requests the following:

1. The statistical methods must define the following in order to review the statistical method plan in accordance with *Illinois EPA Quality Management Plan (A17-001), Guidance on Assessing Quality Systems (EPA QA/G-3), Data Quality Assessment: Statistical Methods for Practitioners EPA QA/G-9S, Data Quality Assessment: A Reviewer's Guide EPA QA/G-9R and/or Guidance on Environmental Data Verification and Data Validation (EPA QA/G-8)*:
    a. The software program that is being used for statistical evaluation must be identified. If the software program is proprietary, software validation must be performed, documented and signed off by at least the software validation draftee, senior reviewer, and project manager/quality manager. (EPA QA/G-3)
        i. Software validation packages must include at least a known data set, empirical evaluation including formulas to prove the validity of the software, and outputs from both the software and the empirical calculations exhibiting that the software is producing the same output as the empirical evaluation. (EPA QA/G-3)
    b. All input data sets for each constituent must be provided in a table in accordance with SW-846 chapter 1, incorporated by reference in 35 IAC 845. Chapter 1 of SW846 states that regulatory decisions must be made with environmental data.
        i. All data sets, used for statistical analysis, must be within the last eight consecutive quarterly sampling events in order to validate the statistical methods for recent activity (35 IAC 845.650(b))

1. If an impoundment is considered closed by the Agency, the data sets must be used from the eight consecutive quarters after closure or most recent eight consecutive quarters.

c. Illinois Power Generating Company (Illinois Power) must provide the laboratory reports or EDD to validate the data input sets are accurate and follow 845.640(i) and 845.640(j).
d. Illinois Power must identify the assumptions being used to analyze the data sets and any other methods. (EPA QA/G-9S).
e. Illinois Power must identify the non-detects within the data set. Illinois Power must review the statistical methods guidance for appropriate use of non-detects in the statistical methods provided and provide a detailed explanation of the rationale including empirical formulas for examples of the implementation of the statistical methods. (EPA QA/G-9S).
f. The Agency's position on outliers is that verified data from a NELAP certified laboratory is representative of the aquifer properties analyzed. Outliers cannot be evaluated for exclusion from any dataset without explicit data validation identifying discrepancies from the laboratory and/or field procedures that would qualify a data point to be considered an outlier. Illinois Power must use the USEPA data validation procedures to determine when or if a data point is to be excluded from a data set. (EPA QA/G-8).

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, Groundwater Section DPWS #13, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Michael Summers, P.G.
Manager, Groundwater Section
Division of Public Water Supplies
Bureau of Water

cc: Heather Mullenax
Keegan MacDonna
Lauren Hunt
Lynn Dunaway
Records Files 06M

DOCUMENT 39

Rees, Jeromy

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Thursday, December 21, 2023 10:29 AM
To: Hunt, Lauren; Mullenax, Heather; Summers, Michael
Cc: Garee, Matthew J.; Bierwagen, Justin
Subject: RE: Dynegy Coffeen Statistics Letter Draft

I have no further comments

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, December 21, 2023 10:23 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Dynegy Coffeen Statistics Letter Draft

Here are my edits in tracked changes and then the letter clean. I also saved this on the N Drive in the Coffeen permit application folder. Let me know if you have any feedback.
Thanks, Lauren

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
Illinois Environmental Protection Agency
Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
Lauren.hunt@illinois.gov
Hours: 8:30 am to 5:30 pm Tuesday through Friday
8:30 am to 4 pm Mondays and alternating Mondays off
Working remotely Mondays and Fridays.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Thursday, December 21, 2023 9:49 AM
To: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Dynegy Coffeen Statistics Letter Draft

I discussed my comments with Lauren and she will provide combined edits.

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, December 21, 2023 9:26 AM
To: Summers, Michael <Michael.Summers@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: Dynegy Coffeen Statistics Letter Draft

Good morning everyone,

I have written a letter about comments on the statistics found at Dynegy Coffeen Power Plant site. Please let me know if there are any edits to add to this letter.

Thank you,

Heather D. Mullenax, M.S.
Environmental Protection Geologist 1
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
1021 N. Grand Avenue
Springfield, IL 62702
~~~~~~~~~~~~~~~~~
You can contact me:
Office: 217-785-3246
Cell: 270-564-1551
Heather.mullenax@illinois.gov
Hours: 7:30 am to 5:30 pm Mon-Wed
7:30 am to 5:00 pm Thurs
Fridays off

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~~~~~~~~~~~~~~~~~

DOCUMENT 40

Rees, Jeromy

From: Microsoft Outlook <MicrosoftExchange329e71ec88ae4615bbc36ab6ce41109e@ilgov.onmicrosoft.com> on behalf of Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, December 21, 2023 1:18 PM
To: Hunt, Lauren
Subject: Meeting Forward Notification: Coffeen ASD Letters (2) signing

Your meeting was forwarded

Hunt, Lauren has forwarded your meeting request to additional recipients.

Meeting

Coffeen ASD Letters (2) signing

Meeting Time

Thursday, January 11, 2024 8:30 AM-8:35 AM.

Recipients

Brown, Michael L.

All times listed are in the following time zone: (UTC-06:00) Central Time (US & Canada)

Sent by Microsoft Exchange Server

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DOCUMENT 41

From: Hunt, Lauren
To: Rompot, Derek; Seif, Josiah; Mullenax, Heather; LeCrone, Darin
Cc: Dunaway, Lynn; Summers, Michael
Subject: Canceled: Coffeen ASDs Letters (2) signing
Importance: High

Cancelling bc public comment started on Monday December 18th. Thanks.

Darin—we will be revising the template and providing a copy once we have it reviewed and the public comment has come in. this letter has to be signed and sent out by January 12th because of holidays and such.

Hi all.
Heather is out of the office all next week, so she is drafting the letters for Coffeen and sending them to Lynn and me. I will make sure this gets reviewed, signed and placed on the N Drive on the 29th.

I want to get these signed before the end of the year. The only date we can sign them is December 29th. So let's plan to get them signed as a last order of business for CCR. I may come in that day to usher it through.

Thanks,

Lauren

State of Illinois - CONFIDENTIALITY NOTICE: The information contained in this communication is confidential, may be attorney-client privileged or attorney work product, may constitute inside information or internal deliberative staff communication, and is intended only for the use of the addressee. Unauthorized use, disclosure or copying of this communication or any part thereof is strictly prohibited and may be unlawful. If you have received this communication in error, please notify the sender immediately by return e-mail and destroy this communication and all copies thereof, including all attachments. Receipt by an unintended recipient does not waive attorney-client privilege, attorney work product privilege, or any other exemption from disclosure.

DOCUMENT 42

From: Hunt, Lauren
To: Mullenax, Heather; Dunaway, Lynn; Rompot, Derek; LeCrone, Darin; Seif, Josiah
Subject: Coffeen ASD Letters (2) signing

Hi All.

Heather will be reviewing the ASD letters for Coffeen that were received on December 15th and publicly noticed on December 18th.

Once Heather provides a draft letter to Lynn. Lynn reviews the letter.

Once the letter is approved by Lynn, Heather or I will bring it over for Darin to sign. (Heather is off on Fridays so we are doing this on Thursday before the 30 days are up.)

After Darin signs the letter, Heather will scan it and place it on the N Drive and provide the hard copy to Sherri Richardson. Heather will also email anyone from the list serve that provided comments with an electronic copy.

We need the letter signed and to Sherri Richardson by 1 pm. So this must happen before lunch.

Darin—if you need us to move up the signing by a few days to accommodate a busy schedule that day, please let me know.

Thanks everyone.

Lauren

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DOCUMENT 43

From: Hunt, Lauren
To: Rompot, Derek; Summers, Michael; Seif, Josiah; Dunaway, Lynn; Mullenax, Heather
Subject: Coffeen ASDs Letters (2) signing

Hi all.
Heather is out of the office all next week, so she is drafting the letters for Coffeen and sending them to Lynn and me. I will make sure this gets reviewed, signed and placed on the N Drive on the 29th.

I want to get these signed before the end of the year. The only date we can sign them is December 29th. So let's plan to get them signed as a last order of business for CCR. I may come in that day to usher it through.

Thanks,

Lauren

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DOCUMENT 44

Rees, Jeromy

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, January 4, 2024 8:46 AM
To: Hunt, Lauren
Subject: Coffeen ASD Letters Review
Attachments: Draft ASD Coffeen Cobalt letter Dec 2023.docx; Draft ASD Coffeen TDS Sulfate letter Dec 2023.docx; Coffeen ASD Comments.docx

Good morning Lauren,

I have reviewed both of the ASDs for Coffeen and created a nonconcurrence letter for both letters. I have added my comments/summary as well in the "Coffeen ASD Comments". I also added these on the N drive with the ASDs here:

\\Illinois.gov\EPA\AgencyShared\BOW\Bow_Share\DPWS\Groundwater\Part 845\845 Compliance\Groundwater Monitoring Submittals\Coffeen\Dec 2023 Coffeen ASDs

Let me know if I need to go back on edits or add anything else.

Thanks,

Heather D. Mullenax, M.S.
Environmental Protection Geologist 1
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
1021 N. Grand Avenue
Springfield, IL 62702
~~~~~~~~~~~~~~~~~
You can contact me:
Office: 217-785-3246
Cell: 270-564-1551
Heather.mullenax@illinois.gov
Hours: 7:30 am to 5:30 pm Mon-Wed
7:30 am to 5:00 pm Thurs
Fridays off

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Coffeen ASD Comments

Here are my comments in addition to the non-concurrence ASD letter in case there needs to be anything added…

Things to note: both ASDs are discussing an impoundment that is already closed before July 30, 2021. AP2 was capped in 1980s and has berms. AP2 is unlined.

Sulfate and TDS ASD

- Their alternative source is that there is a groundwater divide that runs through the facility that separates the Ash Pond No. 2 that is closed and the exceedance well G407.
- For evidence, they provide the Ash Pond No.2 cross section (not past the pond), the borehole log of G407, multiple potentiometric surface maps, and a groundwater model where they have put an interpreted line of the groundwater divide after.
    - There are no cross sections that go through the interpreted groundwater divide. It stops at the edge of the CCR impoundment. **(2nd comment is for this)**
- They plot the boron concentrations of all the wells on a separate potentiometric map.
    - No lab reports or charts provided to show data around the boron or the sulfate/TDS in nearby wells. **(1st comment is for this)**
    - They use a time plot to show boron concentrations but again, do not have lab reports to check.

Cobalt ASD

- Their alternative source is the cobalt is found in the aquifer solids and is mobilized by iron solids when right chemistry.
- Cobalt has been an exceedance before in AP2
- One evidence mentions there is no cobalt in the porewater and show lab reports from 2016 and then show a lab report in 2020 where cobalt was detected in the CCR source water at 0.046 mg/L (exceedance at 0.110 mg/L for context) **(1st comment is what I used for this)**
    - Proceed to cite 4 EPRI documents where it talks about the leachability in porewater or composition of porewater. **(2nd comment is for this)**
    - Explanation for the hit on cobalt in the porewater is that it is less than the lower confidence limit of the exceedance well calculated at 0.0629 mg/L (no proof or data for calculation)
- In the solids sampling, only the exceedance and background well were sampled and compared.
    - Background was at 7.3 total cobalt, exceedance was at 7.7 total cobalt
    - Total metals report show cobalt at 6.1 at the exceedance well and 10 at the background
        - Also show high iron
    - If this would be a data gap to add to the letter, I will add it in

217-782-1020

August 5, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No. 2; W1350150004-02
Alternative Source Demonstration Submittal

Dear Ms. Tickner:

The purpose of this correspondence is to notify you that the Illinois Environmental Protection Agency (Illinois EPA) does not concur with the Coffeen Ash Pond No.2 Alternative Source Demonstration (ASD) for cobalt dated December 15, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Source characterization of the CCR at Ash Pond No.2 include total solids sampling in accordance with SW846.
    a. 35 IAC 845.650(e) states "the owner or operator of a CCRSI may…submit a demonstration to the Agency that a source other than the CCRSI caused the contamination and the CCRSI did not contribute to the contamination… Either type of ASD must include a report that contains the factual or evidentiary basis for any conclusions…"
        i. The Illinois EPA cannot concur with ASDs that do not include source characterization of the CCR with adequate sampling and analysis of the CCR which must characterize the CCR horizontally and vertically within the CCRSI.
2. Research on porewater characterizing the CCRSI does not come from a peer reviewed source
    a. The Illinois EPA cannot concur with the ASDs that do not use peer reviewed sources as the basis of research.

Commented [MH1]: How would this be cited for regulation? Would this work for the EPRI comment?

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, WPC #15, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Darin E. LeCrone, P.E.
Manager, Permit Section

Division of Water Pollution Control
Illinois Environmental Protection Agency

cc: Heather Mullenax
Lauren Hunt
Keegan MacDonna
Records Files 06M

217-782-1020

August 5, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No. 2; W1350150004-02
Alternative Source Demonstration Submittal

Dear Ms. Tickner:

The purpose of this correspondence is to notify you that the Illinois Environmental Protection Agency (Illinois EPA) does not concur with the Coffeen Ash Pond No.2 Alternative Source Demonstration (ASD) for sulfate and total dissolved solids (TDS) dated December 15, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Characterization to include sample and analysis in accordance with 35 IAC 845.640 must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods, field and laboratory reports, and quality control and quality assurance.
    b. 35 IAC 845.650(e) requires evidence of the alternative source, see item 1(a)(i) above. SW846 chapter 1, incorporated by reference in 35 IAC 845, states that regulatory decisions must be made with environmental data.
2. Updated geologic cross sections that include data surrounding the groundwater divide and the exceedance well G407 in accordance with 845.620(b)(9).

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, WPC #15, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

cc: Heather Mullenax
Lauren Hunt
Keegan MacDonna
Records Files 06M

DOCUMENT 45

Rees, Jeromy

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, January 4, 2024 9:03 AM
To: Mullenax, Heather
Subject: RE: Coffeen ASD Letters Review

I posted those as final on the N Drive. could you update the CC list to include any commenters. I believe Jenny Cassel and company commented, but please verify and let me know. Thanks. Lauren

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
Illinois Environmental Protection Agency
Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
Lauren.hunt@illinois.gov
Hours: 8:30 am to 5:30 pm Tuesday through Friday
8:30 am to 4 pm Mondays and alternating Mondays off
Working remotely Mondays and Fridays.

From: Mullenax, Heather <Heather.Mullenax@Illinois.gov>
Sent: Thursday, January 4, 2024 8:46 AM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Subject: Coffeen ASD Letters Review

Good morning Lauren,

I have reviewed both of the ASDs for Coffeen and created a nonconcurrence letter for both letters. I have added my comments/summary as well in the “Coffeen ASD Comments”. I also added these on the N drive with the ASDs here:

\\Illinois.gov\EPA\AgencyShared\BOW\Bow_Share\DPWS\Groundwater\Part 845\845 Compliance\Groundwater Monitoring Submittals\Coffeen\Dec 2023 Coffeen ASDs

Let me know if I need to go back on edits or add anything else.

Thanks,

Heather D. Mullenax, M.S.
Environmental Protection Geologist 1
Illinois Environmental Protection Agency
Bureau of Water
Division of Public Water Supplies
Groundwater Section
1021 N. Grand Avenue

Springfield, IL 62702
~~~~~~~~~~~~~~~~~
You can contact me:
Office: 217-785-3246
Cell: 270-564-1551
Heather.mullenax@illinois.gov
Hours: 7:30 am to 5:30 pm Mon-Wed
7:30 am to 5:00 pm Thurs
Fridays off

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~~~~~~~~~~~~~~~~~

DOCUMENT 46

From: Hunt, Lauren
To: Brown, Michael L.; LeCrone, Darin
Cc: Mullenax, Heather
Subject: Coffeen ASD Letters for review and approval
Date: Thursday, January 4, 2024 3:19:51 PM
Attachments: Draft Final ASD Coffeen TDS Sulfate letter Dec 2023.docx
Draft Final ASD Coffeen Cobalt letter Dec 2023.docx

Hi Mike and Darin.
I am sending these out early because it looks like Darin has an ongoing family emergency.
Heather drafted the letters and I reviewed them.
Please see attached.
Darin—Let us know what date and time works best for you between now and January 12th. The latest date we can sign and send is the 12th. TIA. Hope you father in law improves.
Thank you.
Lauren

Lauren I. Hunt, M.S.
(she/they/he)
Environmental Protection Geologist III
Illinois Environmental Protection Agency
Bureau of Water
Groundwater Section
1021 N. Grand Avenue
PO Box 13
Springfield, IL 62702
D: 217-524-9048
C: 309-361-0037
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Hours: 8:30 am to 5:30 pm Tuesday through Friday
8:30 am to 4 pm Mondays and alternating Mondays off
Working remotely Mondays and Fridays.

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217-782-1020

August 5, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No. 2; W1350150004-02
Alternative Source Demonstration Submittal

Dear Ms. Tickner:

The purpose of this correspondence is to notify you that the Illinois Environmental Protection Agency (Illinois EPA) does not concur with the Coffeen Ash Pond No.2 Alternative Source Demonstration (ASD) for sulfate and total dissolved solids (TDS) dated December 15, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Characterization to include sample and analysis in accordance with 35 IAC 845.640 must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods, field and laboratory reports, and quality control and quality assurance.
    b. 35 IAC 845.650(e) requires evidence of the alternative source, see item 1(a)(i) above. SW846 chapter 1, incorporated by reference in 35 IAC 845, states that regulatory decisions must be made with environmental data.
2. Updated geologic cross sections that include data surrounding the groundwater divide and the exceedance well G407 in accordance with 845.620(b)(9).

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, WPC #15, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

cc: Heather Mullenax
Lauren Hunt
Keegan MacDonna
Records Files 06M

217-782-1020

August 5, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

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Alternative Source Demonstration Submittal

Dear Ms. Tickner:

The purpose of this correspondence is to notify you that the Illinois Environmental Protection Agency (Illinois EPA) does not concur with the Coffeen Ash Pond No.2 Alternative Source Demonstration (ASD) for sulfate and total dissolved solids (TDS) dated December 15, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Characterization to include sample and analysis in accordance with 35 IAC 845.640 must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods, field and laboratory reports, and quality control and quality assurance.
    b. 35 IAC 845.650(e) requires evidence of the alternative source, see item 1(a)(i) above. SW846 chapter 1, incorporated by reference in 35 IAC 845, states that regulatory decisions must be made with environmental data.
2. Updated geologic cross sections must be provided and must include data surrounding the hydrogeologic divide and the exceedance well G407 in accordance with 845.620(b)(9).

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, WPC #15, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

cc: Heather Mullenax
Lauren Hunt
Keegan MacDonna
Records Files 06M

DOCUMENT 47

From: Hunt, Lauren
To: Dunaway, Lynn
Subject: Canceled: Coffeen ASD Letters (2) signing
Importance: High

Hi All.

Heather will be reviewing the ASD letters for Coffeen that were received on December 15th and publicly noticed on December 18th.

Once Heather provides a draft letter to Lynn. Lynn reviews the letter.

Once the letter is approved by Lynn, Heather or I will bring it over for Darin to sign. (Heather is off on Fridays so we are doing this on Thursday before the 30 days are up.)

After Darin signs the letter, Heather will scan it and place it on the N Drive and provide the hard copy to Sherri Richardson/Ryan Jett. Heather will also email anyone from the list serve that provided comments with an electronic copy.

We need the letter signed and to Sherri Richardson by 1 pm. So this must happen before lunch.

Darin—if you need us to move up the signing by a few days to accommodate a busy schedule that day, please let me know.

Thanks everyone.

Lauren

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DOCUMENT 48

From: Hunt, Lauren
To: Mullenax, Heather; Dunaway, Lynn; Rompot, Derek; LeCrone, Darin; Seif, Josiah
Subject: Coffeen ASD Letters (2) signing

Hi All.

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DOCUMENT 49

From: Hunt, Lauren
To: Brown, Michael L.
Subject: FW: Coffeen ASD Letters (2) signing

-----Original Appointment-----
From: Hunt, Lauren
Sent: Wednesday, December 20, 2023 10:25 AM
To: Hunt, Lauren; Mullenax, Heather; Rompot, Derek; LeCrone, Darin; Seif, Josiah
Subject: Coffeen ASD Letters (2) signing
When: Thursday, January 11, 2024 8:30 AM-8:35 AM (UTC-06:00) Central Time (US & Canada).
Where:

Hi All.

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Lauren

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DOCUMENT 50

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
1021 NORTH GRAND AVENUE EAST, P.O. BOX 19276, SPRINGFIELD, ILLINOIS 62794-9276 · (217) 782-3397
JB PRITZKER, GOVERNOR JOHN J. KIM, DIRECTOR

217-782-1020

January 11, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Coffeen Power Plant Ash Pond No. 2; W1350150004-02
Alternative Source Demonstration Submittal

Dear Ms. Tickner:

The purpose of this correspondence is to notify you that the Illinois Environmental Protection Agency (Illinois EPA) does not concur with the Coffeen Ash Pond No.2 Alternative Source Demonstration (ASD) for sulfate and total dissolved solids (TDS) dated December 15, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Characterization to include sample and analysis in accordance with 35 IAC 845.640 must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods, field and laboratory reports, and quality control and quality assurance.
    b. 35 IAC 845.650(e) requires evidence of the alternative source, see item 1(a)(i) above. SW846 chapter 1, incorporated by reference in 35 IAC 845, states that regulatory decisions must be made with environmental data.
2. Updated geologic cross sections must be provided and must include data surrounding the hydrogeologic divide and the exceedance well G407 in accordance with 845.620(b)(9).

If you have any questions, please contact: **Heather Mullenax** Illinois EPA, Bureau of Water, WPC #15, P.O. Box 19276, Springfield, Illinois 62794-9276. If you have any questions concerning the investigation described above, please call 217-782-1020.

Sincerely,

Darin E. LeCrone, P.E.
Manager, Permit Section
Division of Water Pollution Control
Illinois Environmental Protection Agency

cc: Heather Mullenax
Lauren Hunt
Keegan MacDonna
Records Files 06M