BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

ELECTRIC ENERGY, INC.	)	
	)	
Petitioner,	)	
	)	
v.	)	**PCB 2024-45**
	)	**(Alternative Source Demonstration – Petition for Review)**
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY,	)	
	)	
	)	
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 (consisting of 63 parts), a copy of which is attached hereto and hereby served upon you.

Respectfully submitted,

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

By: /s/ Samuel Henderson
Assistant Attorney General
Environmental Bureau
500 South Second Street
Springfield, Illinois 62706
(217) 720-9820
samuel.henderson@ilag.gov
ARDC No. 6336028

CERTIFICATE OF SERVICE

I hereby certify that I did on May 24, 2024, prior to 5:00 PM, cause to be served by electronic mail, a true and correct copy of the following instruments entitled NOTICE OF FILING, CERTIFICATE OF SERVICE (3 pages), CERTIFICATE OF RECORD ON APPEAL (6 pages), and RECORD (1854 pages, consisting of 63 parts), consisting of 1863 pages in total, to:

Joshua R. More
Bina Joshi
Samuel A. Rasche
ARENTFOX SCHIFF LLP
233 South Wacker Drive, Suite 7100
Chicago, Illinois 60606
Joshua.More@afslaw.com
Bina.Joshi@afslaw.com
Sam.Rasche@afslaw.com

Carol Webb
Hearing Officer
Illinois Pollution Control Board
1021 North Grand Avenue East
P.O. Box 19274
Springfield, IL 62794-9274
carol.webb@illinois.gov

s/ Samuel Henderson
Assistant Attorney General
Environmental Bureau

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

ELECTRIC ENERGY, INC.	)	
	)	
Petitioner,	)	
	)	
v.	)	**PCB 2024-45**
	)	**(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 Joppa Power Plant East Ash Pond Alternative Source Demonstration ("ASD") which is attached and consists of the following documents:

Document #	Description	Date	Start	End
1	Pages used as geochemical background to make decisions, from Drever, James 1997 Geochemistry of Natural Waters	12/31/1997	R000002	R000011
2	Pages used as background information on fractures in bedrock that occur at Joppa, from Faybishenko, Boris Dynamics of Fluids in Fractured Rock Chapter on Fracture Connections	12/31/2000	R000013	R000022
3	Pages used as geochemical background to make decisions, from Eby, G 2004 Principles of Environmental Geochemistry	12/31/2004	R000024	R000031

4	US EPA SW846 Method 1315	7/31/2017	R000033	R000069
5	US EPA SW846 Method 1316	7/31/2017	R000071	R000090
6	USEPA GW Guide 2017	9/19/2017	R000092	R000121
7	Pages used as background information to make decisions, from Contaminant Hydrogeology by Fetter et al 2017	1/1/2018	R000123	R000390
8	TITLE 35: Environmental Protection, SUBTITLE G: Waste Disposal, CHAPTER I: Pollution Control Board, SUBCHAPTERj: Coal Combustion Waste Surface Impoundments, PART 845: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments	4/21/2021	R000392	R000531
9	Operating permit application of Joppa Power Plant East Ash Pond	11/1/2021	R000533	R001373
10	Region 4 USEPA Laboratory Services & Applied Science Division: Operating Procedure - Pore Water Sampling	4/22/2023	R001375	R001389
11	External meeting with Dynegy to discuss CCR permit applications and begin discussions on ASDs - part 1 of 2 notes	10/19/2023	R001391	R001391
12	External meeting with Dynegy to discuss CCR permit applications and begin discussions on ASDs - part 2 of 2 notes	10/19/2023	R001393	R001393
13	Alternative Source Demonstration submitted by Dynegy on October 20, 2023, for exceedances observed from the Quarter 2 2023 sampling event	10/21/2023	R001395	R001498

14	Notification of Joppa ASD being received by the IEPA-DWPC/CCR on October 23, 2023	10/23/2023	R001500	R001500
15	Internal ASD Discussion Meeting Status with Groundwater Section Management	10/25/2023	R001502	R001641
16	Internal ASD Discussion Meeting Notes with Groundwater Section Management	10/26/2023	R001643	R001643
17	Email from Lauren Hunt to Phil Morris, Bran Voelker, Stuart Cravens and IEPA staff RE: Newton and Joppa ASD Questions.	10/26/2023	R001645	R001645
18	Email from Lauren Hunt to Rhys Fuller and IEPA staff RE: Joppa and Newton ASD data gap discussion	10/26/2023	R001647	R001647
19	Email from Lauren Hunt to Lynn Dunaway RE: Baldwin Power Plant ASD submittal notice	10/26/2023	R001649	R001650
20	Webex Invite: ASD discussions with Dynegy - 10/31/2023	10/31/2023	R001652	R001653
21	Email thread Michael Summers, Lauren Hunt, Lynn Dunaway and IEPA staff RE: Joppa West Adjusted Standard Recommendation meeting follow up	11/1/2023	R001655	R001658
22	Email from Lynn Dunaway to Stefanie Diers, with subject "Joppa AS"	11/1/2023	R001660	R001660
23	Email from Stefanie Diers to Lynn Dunaway, RE: Joppa AS	11/2/2023	R001662	R001663

24	Email from Jenny Cassel to Lauren Hunt, Heather Mullenax, Lynn Dunaway RE: Earthjustice, Prairie Rivers Network, and Sierra Club comments on ASDs for Newton, Joppa, and Baldwin	11/6/2023	R001665	R001665
25	Public Comments from Earthjustice, Prairie Rivers Network, and Sierra Club for Newton, Joppa, and Baldwin CCR surface impoundments	11/6/2023	R001667	R001680
26	Email from Josiah Seif with subject "Joppa Power Plant notification letter – Exceedance of Boron in Groundwater"	11/6/2023	R001682	R001682
27	Email from Brian Voelker to epa.ccr.part845, Lauren Hunt, et al RE: Joppa ASD November 6, 2023 Comment Letter	11/6/2023	R001684	R001684
28	Letter from Electric Energy, Inc. to epa.ccr.part845 RE: ASD for Joppa Power Plant East Ash Pond	11/6/2023	R001686	R001837
29	Email from Lauren Hunt to Brian Voelker RE: new email address setup for Groundwater Section CCR submittals	11/7/2023	R001839	R001840
30	Email from Lynn Dunaway to Darin LeCrone, FW: Environmental Groups' Comments on Joppa, Baldwin, and Newton ASDs	11/7/2023	R001842	R001842
31	Email from Derek Rompot, with subject "Joppa ASD: No comments received by Derek & Josiah"	11/16/2023	R001844	R001844
32	Email from Lauren Hunt to Lynn Dunaway, with title "Joppa ASD letter"	11/16/2023	R001846	R001846

33	Copy of draft Letter of Nonconcurrence, from Mike Summers to Dianna Tickner, RE: ASD Submittal	11/16/2023	R001848	R001849
34	Email from Lauren Hunt to Michael Summers and IEPA staff RE: Final ASD Nonconcurrence Letter	11/16/2023	R001851	R001851
35	Final Letter of Nonconcurrence from Michael Summers to Dianna Tickner RE: ASD Submittal	11/16/2023	R001853	R001854

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

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

Respectfully submitted,

KWAME RAOUL,
Attorney General of the
State of Illinois,

MATTHEW J. DUNN, Chief
Environmental Enforcement/Asbestos
Litigation Division

By: /s/Mallory Meade
Mallory Meade

/s/Samuel Henderson
Samuel Henderson

Assistant Attorney Generals
Illinois Attorney General's Office
Environmental Bureau
500 South Second Street
Springfield, IL 62706
(217) 557-9457

Dated: May 23, 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.

:HAVIOR 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

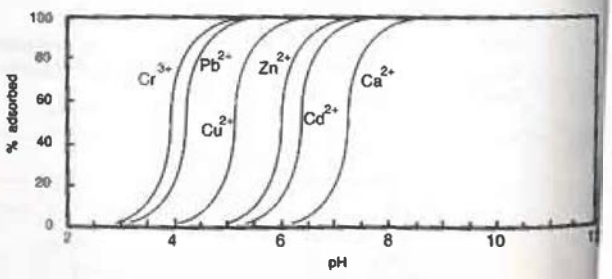


FIGURE 9-17 Adsorption of Cu^{2+}, Cd^{2+}, Zn^{2+}, Pb^{2+}, Cr^{3+}, and Ca^{2+} (for comparison) on hydrous ferric oxide as a function of pH. Each metal shows an adsorption "edge"; at pH values below the edge, the ion is not adsorbed or very weakly adsorbed. At pH values above the edge, the ion is 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).

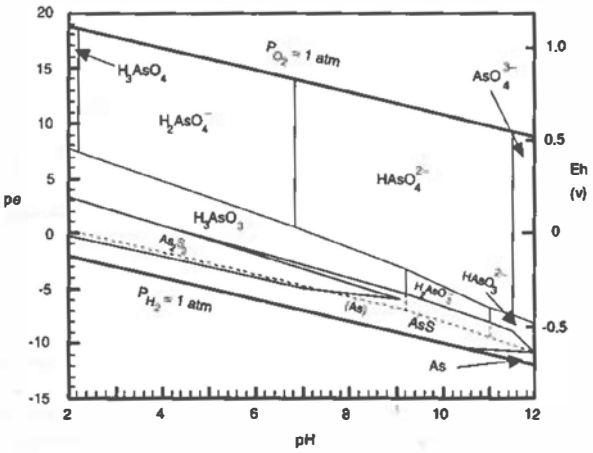


FIGURE 9-18 Simplified pe–pH diagram for the system As–O–H_2O at 25°C and one atm. Total activity of sulfur species = 10^{-2}. Light lines are boundaries involving dissolved species only. Dashed line is field of solid elemental arsenic in the absence of sulfur. Solubility is defined as a dissolved As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

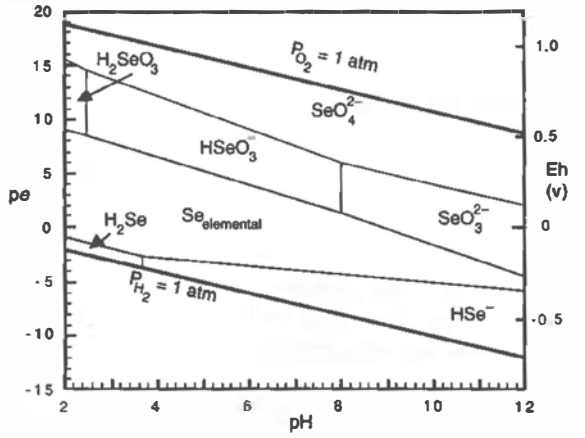


FIGURE 9-19 Simplified pe–pH diagram for the system Se–O–H_2O at 25°C and one atmosphere. Solubility is defined as a dissolved Se activity of 10^{-6}. Data are from Cowan (1988).

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.

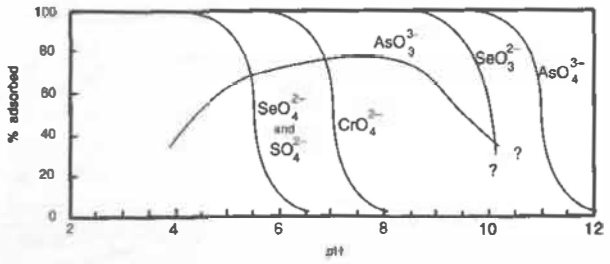
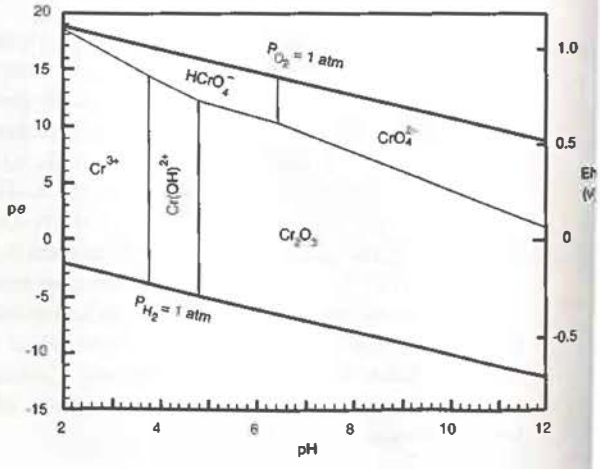


FIGURE 9-20 Adsorption of arsenate, arsenite, selenate, selenite, chromate, and sulfate (for comparison) on hydrous ferric oxide as a function of pH. Most of the anions show an adsorption "edge"; at pH values above the edge (for anions), the ion is not adsorbed or very weakly adsorbed. At pH values below 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).

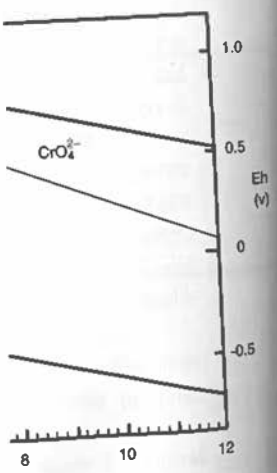
FIGURE 9-21 pe–pH diagram for the system Cr–O–H_2O at 25°C and one atm. Solubility is defined as a dissolved Cr activity of 10^{-6}. Data from Brookins (1988).



R000006

ılfate (for comparison)
'edge"; at pH values above
below the edge, the ion
sO_3^{3-} is fully protonated
xidation state. Conditions
ırength of 0.1 m. The edges
From data in Dzombak and

ps of elements discussed
hromate) is stable as an
ig. 9-20) and is therefore
tions, Cr(III) is the stable
s. It is soluble (largely as
ıgly adsorbed (Fig. 9-17).
enerally Cr(VI).



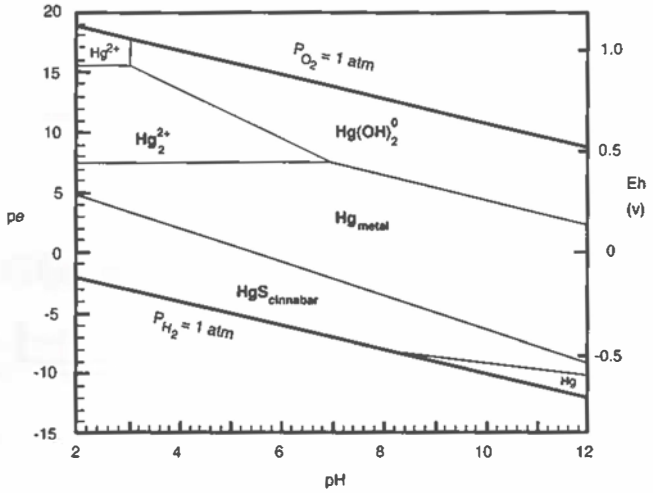


FIGURE 9-22 pe–pH diagram for the system Hg–S–O–H_2O at 25°C and one atm. Solubility is defined as a dissolved Hg activity of 10^{-6}. Total activity of sulfur species = 10^{-2}. The diagram is the same in the absence of S species, with the HgS (cinnabar) field replaced by Hg (metal). In the presence 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.

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 retardation 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.

R000007

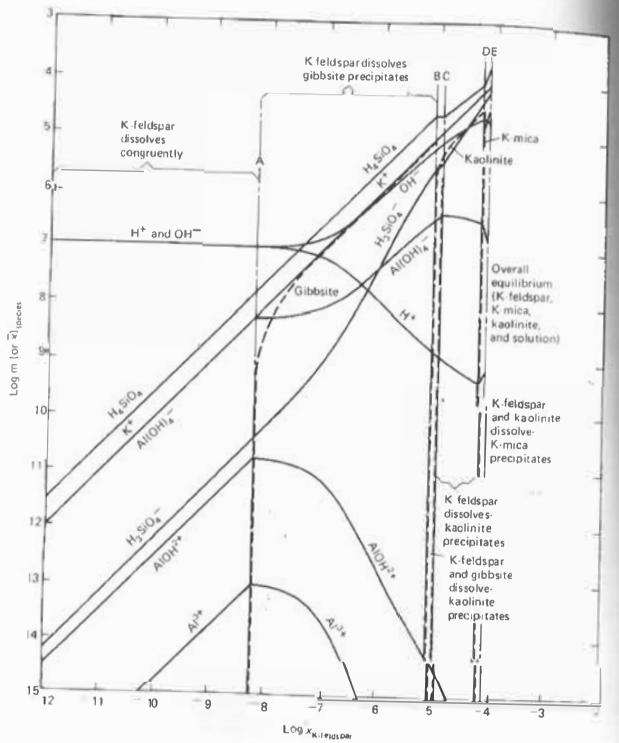
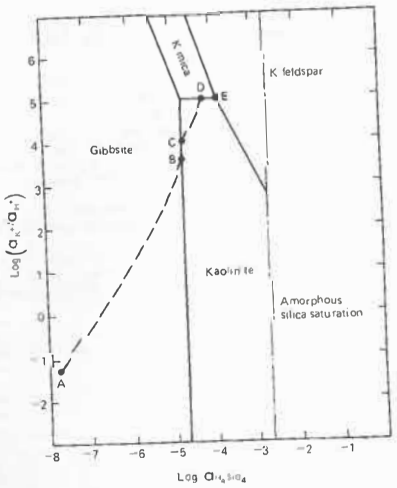


FIGURE 16-10 Concentration (m) of species in the aqueous phase (solid lines) and amounts (mol/kg H_2O) of minerals produced and destroyed (dashed lines) as K-feldspar reacts with water at 25°C and 1 atm pressure. The abscissa represents the number of moles of K-feldspar destroyed per kg H_2O. The letters 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	

R000008

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 $10^{-3.7}$ 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       8.445    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)

R0000009

```
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.

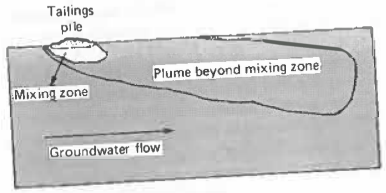


FIGURE 16-12 Schematic illustration of migration of contaminants from a uranium mill tailings pile.

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

R000010

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 1×10^{-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	3.87	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

ALABARÈDE, F. (1995). *Introduction to Geochemical Modeling*. Cambridge, England: Cambridge University Press.

ANDERSON, M. P. (1979). Using models to simulate the movement of contaminants through groundwater flow systems. *CREC Critical Reviews in Environmental Control* (pp. 97–156). Boca Raton, FL: CREC Press.

ANDERSON, M. P., and W. W. WOESSNER. (1992). *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*. San Diego, CA: Academic Press, Inc.

APPELO, C. A. J., and D. POSTMA. (1993). *Geochemistry, Groundwater, and Pollution*. Rotterdam, Germany: Balkema.

FETTER, C. W. (1994). *Applied Hydrogeology*, (3rd ed.). New York: Macmillan.

FREEZE, R. A., and J. A. CHERRY. (1979). *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall. Chapters 7 (Chemical Evolution of Natural Groundwater) and 9 (Groundwater Contamination).

LICHTNER, P. C.; C. I. STEEFEL; and E. H. OELKERS, (Eds.) (1996). Reactive transport in porous media. *Reviews in Mineralogy*, (v. 34). Washington, DC: Mineralogical Society of America.

R000011

DOCUMENT 2

Predicting Hydrology of Fractured Rock Masses from Geology

Paul R. La Pointe

Golder Associates, Inc., Redmond, WA 98052

Fracture network connectivity often dominates movement rate, flow volume, and mass transport through rock masses. These networks influence the effectiveness of petroleum reservoir development, safe disposal of nuclear waste, delineation of water supply or establishment of well-head protection plans, recovery from geothermal reservoirs, solution mining, construction of underground openings, and the remediation of contaminated rock. Well tests can provide a great deal of useful information on the hydraulic properties of fracture systems, but they are often expensive or logistically infeasible. These tests also may not provide an accurate description of the hydrologic properties of the rock volume under consideration. Methods to model fractured rock can be improved by quantifying the relation between geologic parameters and the hydrologically conductive fractures. This study illustrates the application of four statistical and pattern recognition methods—evaluation of correlation coefficients, contingency table analysis, multivariate regression, and neural net analysis. The data for the study consist of borehole and well-test information from eight boreholes used for characterizing a proposed low-level radioactive waste repository in Wake County, North Carolina. The analyses show that high localized flow rates are related to the presence of increased fracture intensity, and that this intensity is controlled by a complex interplay of structural geology and lithology. Some of the initial hypotheses concerning the relation of geology to hydrology were not substantiated by the data, leading to a refined conceptual model that differed in significant ways from the initial model. Although the techniques used are of general applicability, the precise nature of the correlation between geology and hydrology is site dependent.

1. INTRODUCTION

1.1 Overview

Fractures are geologic features that form networks capable of transporting fluids through rock over long distances. The rate of movement, the volume of flow, the amount of mass transport through the system interconnected fractures affect petroleum reser development, safe disposal of nuclear waste, delineatio water supply or establishment of well-head protec plans, recovery from geothermal reservoirs, the efficie of solution mining, the construction of undergro openings, and the remediation of contaminated rock.

It is common for engineers and hydrologists to emp hydrologic testing to directly characterize fracture netw flow parameters. However, well tests are often expen:

Dynamics of Fluids in Fractured Rock
Geophysical Monograph 122
Copyright 2000 by the American Geophysical Union

or logistically infeasible. For example, the number and spatial reach of wells drilled from an offshore oil platform are very much restricted. This may cause direct hydrologic test results to be very sparse for the volume of rock under consideration. It also presents a problem because hydrologic heterogeneity is often quite significant, so that and, therefore, a few tests may not provide an accurate description of the hydrologic properties of the large volume of rock under consideration. Such a situation makes it necessary to infer parameters from the well or boreholes to a much larger volume of rock.

There are two broad approaches to modeling flow and transport in fractured rock [*National Research Council*, 1996]: the Discrete Fracture Network (DFN) approach and the Stochastic Continuum (SC) approach. Both methods have advantages and disadvantages.

DFN models require the specification of the geometry, location, and hydraulic properties of the fractures that play a significant role in the rock permeability.

SC models need permeability and porosity values that reflect the local matrix and fracture systems' effective properties at the scale and shape of the numerical grid. SC models incorporate geology to delineate large-scale statistically homogeneous regions, often referred to as *domains* or *zones*. Parameter values within these domains can be assigned according to statistical distributions or conditioned to geologic parameters. Often, the relation between mappable geology and values of effective permeability is not well understood. Parameter assignment within each domain is carried out using a spatial statistical model or an inversion that matches known well test results, but is constrained elsewhere to statistical parameters only [*Zimmerman et al., 1998*]. Better geologic conditioning of the parameter values within zones and better definition of zones can greatly improve model accuracy [*La Pointe et al.*, 1996; *National Research Council*, 1996].

Over the past decade, DFN models [*Hudson and La Pointe*, 1980; *Long et al.*, 1982; *Dershowitz*, 1984; *Endo et al., 1984; Robinson*, 1984; *Smith and Schwartz, 1984*] have evolved to successfully address problems of regional fracture network connectivity [*Cacas et al.*, 1990a,b; *Dershowitz et al.*, 1992; *Swaby and Rawnsley*, 1996]. The models represent fractures as polygons with flow and transport properties. However, the specification of these models relies upon accurately describing the geologic context of the subset of fractures that contribute to large-scale flow. This subset of fractures constitutes the network of *conductive* fractures. As detailed surveys of wellbores prove, only a portion, often less than 10% [*National Research Council*, 1996] play a role in flow at the scale of contaminant dispersal, energy production, or containment of nuclear waste. It is the intensity, geometry, and fluid-flow properties of this conductive subset that control the important behavior of fracture-dominated flow systems.

Thus, better understanding of the geologic habitat of conductive fractures could lead to improved DFN modeling, as well as a better understanding of why some fractures play a significant role in regional flow, while others play a limited, or insignificant role.

The attractiveness of geologically conditioning DFN or SC models rests on the presumption that hydrology relates to geology. By understanding the geologic characteristics that are associated with hydrologic variability, it is possible to describe the conductive fracture network or assign values of permeability (or other properties) at unsampled locations based upon the geologic characteristics.

The geologic approach is very appealing, since it is much more flexible in handling hydrologic variability as a result of variability in underlying geology than any zonal statistical model. This is because the geologic approach need not conform to overly simplistic statistical models. Moreover, a demonstrated connection between mappable geology and flow modeling is important in many licensing applications for proposed waste repositories or other facilities. Another advantage is that the geology is often known with reasonably high accuracy and resolution throughout the site.

However, the attempt to relate flow in fractured rock masses to underlying geology has proven challenging, particularly in fracture-dominated flow systems. Fracture network connectivity often controls flow and transport. This means that local geologic conditions might be affected by the properties of individual fractures and may not correlate to the larger-scale fracture network connectivity.

The current study attempts to understand the geologic habitat of fractures that play an important role in regional flow and mass transport. The focus of the study is a preliminary site investigation of a proposed low-level nuclear waste repository in Wake County, North Carolina. Licensing of the site requires modeling of possible movement of radionuclides through the rock and soil.

The goal of this work was to investigate the interrelation of hydrologic behavior and geologic characteristics by using multivariate analysis or other techniques, as appropriate, to help prepare the initial site conceptual model and support the development of the preliminary groundwater flow simulations. The identification of key geologic parameters was also important. These parameters needed to be measured in a manner sufficient for subsequent hydrologic modeling and so as to identify how data collection protocols might be altered in order to obtain the necessary data.

The problem of relating geology to hydrology is one of pattern recognition. Powerful and sophisticated tools to recognize patterns and correctly classify new data into proper groups are in common use in many disciplines. These tools differ in mathematical assumptions and outcomes, but all share the ability to classify data into categories. Section 1.4 below describes the methodology employed in this study in greater detail.

1.2 Data

A thorough data set was obtained for this study from geochemical surveys, hydrophysical logging, packer tests, and geologic logging. The data came from a series of eight wells, aligned from west to east. The line formed by these wells transects a prominent fault north-striking a normal fault (Figure 1). Wells W206 through W208 lie to the east of the fault in the footwall of the normal fault. Wells W201 through W205 lie in the hanging wall. As shown in Figure 1, well W205 cuts through the fault plane. Each of these boreholes was carefully logged to record both the lithologic characteristics and the attributes of any fractures present. Subsequently, the core and the borehole imagery was interpreted to create a data set in which fractures were identified, and their measured depths, orientations, apertures, and types recorded. Lithologic information was also recorded. This included grain-size classification, ranging from conglomerate to claystone, as well as the orientation and measured depth of contacts separating strata of contrasting lithology.

Hydrophysical anomalies were identified as part of the testing and logging program carried out in the eight wells. Such anomalies were determined as follows. First, a borehole was filled with deionized water and a logging tool to measure electrical conductivity is placed in the borehole. Next, the nonconductive deionized water was slowly pumped out, which allowed the conductive groundwater to flow through fractures or other permeable pathways into the borehole and be sensed by the logging tool. Continuous recording of the conductivity made it possible to identify locations and rate of groundwater flow into the borehole. The term "strength," as used in this study, refers to the magnitude of the conductivity change between the nonconductive, deionized water and the inflowing groundwater. The magnitude of the anomaly is a function of flow rate, and is used as a surrogate for fracture transmissivity or local wellbore permeability. The tool used in this study has a 1 ft (0.3 m) resolution. Together with image logs, it is possible to relate hydrophysical anomalies to fractures or other geologic features within the 1 ft intervals. Figure 2 summarizes the interpreted lithology, and shows the location and geometric aperture of detected fractures, as well as the location and magnitude of flow for hydrophysical anomalies. Figure 3 and Table 1 show the directly measured and derived geologic parameters used in this study. Parameters related to the four nearest fractures were included to account for the 1 ft resolution of the hydrophysical logs, and for any small misregistration among the hydrophysical logs, the borehole imagery, and the core.

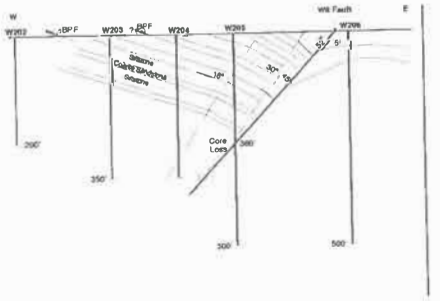


Figure 1. Geologic cross section along trench GM-1. Trench is oriented along an east-west axis. The normal fault, denoted as W8, strikes approximately north-south.

1.3 Initial Hypotheses

A preliminary focus of efforts at the Wake County site was to clarify the role of jointing and faulting in the site-scale hydrology. It was thought that fracture intensity at the site might be related to depth, weathering, structural deformation, and structural position. Thus, the study focused on evaluating some initial hypotheses concerning the relations between site geology and conductive flow features. These hypotheses are:

1. Hydrophysical anomalies are caused by fracture flow.
2. Fracture intensity is greater in the hanging-wall deformation zone.
3. Proximity to contacts between strongly contrasting lithological units leads to an increase in fracturing.
4. Fracture intensity relates to lithology.
5. Fracture intensity changes with depth/elevation because of weathering or lithostatic effects.
6. None of the above.

1.4 Methodology

A number of statistical and pattern-recognition techniques were applied to the data in order to investigate possible relations between geologic parameters and fracture flow. These studies were designed not only to test existing hypotheses, but also to uncover other unsuspected relations between geologic parameters and the

R000014

Table 1. Directly measured and derived geologic parameters.

Directly Measured Parameters	Symbol	Dimensions
Fracture Parameters		
Measured depth to fracture	MDF	Feet
Fracture dip and dip direction	DIP,DPDIR	Degrees
Fracture type: Shear or bedding	TYPE	
Fracture Aperture	AP	Inches
Lithologic Parameters		
Lithologic classification, based on grain size, gradated from 1 to 9 (1 being coarsest; 9 being finest): Conglomerate (Cnglom) = 1 Very coarse sandstone (VCrsSS) = 2 Coarse sandstone (CrsSS) = 3 Medium sandstone (MedSS)= 4 Fine sandstone (FineSS)= 5 Very fine sandstone (VFineSS)= 6 Siltstone (SiltS) = 7 Mudstone (MudStone) = 8 Claystone (Claystone) = 9	LITH	Grain size
Measured depth to contact between lithologic units	MDCON	Feet
Orientation of contact between lithologic units	CONDIP, CONDPDIR	Degrees
Layer (lithologic unit) thickness , distance measured vertically	UTHICK	Feet
Dip of contact above anomaly	DIP_A	Degrees
Dip of contact below anomaly	DIP_B	Degrees

hydrophysical anomalies. The following statistical techniques were used:

1. Evaluation of correlation coefficients among all parameters.
2. Contingency table analysis.
3. Multivariate regression.
4. Neural net analysis.

Correlation coefficients are very useful in examining the first-order relations between continuous variables such as the strength of the hydrophysical anomaly and its proximity to the boundary of a contrasting lithologic unit, or between the depth of a fracture and its aperture. These coefficients are also important in gaining an understanding of which variables may be redundant. Identifying redundant variables is important when data are sparse. When there are more variables—degrees of freedom—than hydrophysical anomalies, it is possible to predict the anomalies with a good degree of accuracy without actually determining any significant relations among the parameters.

Two-way contingency table analysis is a method for looking at the correlation among class or ordinal variables. It is also useful for examining relations between a parameter-like lithologic unit and a hydrophysical anomaly.

Contingency table analysis and correlation coefficients examine relations between pairs of variables. Multiple regression takes into account the combined relations among many variables. Multiple regression assumes that the dependent variable is a linear combination of independent (uncorrelated) variables.

Neural nets are the most complex of the methods used to investigate the relations among dependent variables and hydrophysical anomalies. This approach does not assume a simple or hypothesized model among the variables, nor does it require linear independence. Unlike multiple regression, it can also include class or ordinal variables such as lithologic type. Since the variable of interest, i.e., the hydrophysical anomaly flux rate, is a continuous variable, a Generalized Regression Neural Network

Table 1 (continued).

Derived Parameters		
Distance from hydrophysical anomaly to four nearest fractures	D1, D2, D3, D4	Feet
Apertures of four fractures nearest to a hydrophysical anomaly	W1, W2, W3, W4	Inches
Lithology of four nearest fractures (ranging from conglomerate to mudstone, 1 to 8)	L1, L2, L3, L4	Grain size
Depth of four nearest fractures	MD1, MD2, MD3, MD4	Feet
Lithology contrast between layer containing hydrophysical anomaly lithology and layer above; grain-size class of layer above used for computation	LCA	Dimensionless
Lithology contrast between layer containing hydrophysical anomaly lithology and layer below; grain-size class of layer above below for computation	LCB	Dimensionless
Absolute contrast above; computed as ABS(LCA)	ALCA	Dimensionless
Absolute contrast below; computed as ABS(LCB)	ALCB	Dimensionless
Total contrast between lithological unit containing anomaly and units above and below; computed as LCA+LCB	TC	Dimensionless
Total absolute contrast between lithological unit containing anomaly and units above and below; computed as ALCA+ALCB	ATC	Dimensionless
Distance from anomaly to nearest upper contact; computed as distance perpendicular to contact interface	CDA	Feet
Distance from anomaly to nearest lower contact; computed as distance perpendicular to contact interface	CDB	Feet
Minimum distance to contact; computed as MIN(CDA, CDB	CMIN	Feet
Grain size contrast with nearest unit	C_NEAR	Dimensionless
Apparent distance to upper contact	APCDA	Feet
Apparent distance to upper contact	TDIST_MIN	Feet
Apparent distance to lower contact	APCDB	Feet
Angular difference between upper and lower contact; computed as DIP_B - DIP_A	UNCONF	Degrees
Absolute value of UNCONF	ABS(UNCF)	Degrees
Bed thickness	THICK	Feet

(GRNN), was employed. This type of network architecture has proven very useful for this type of application [*Ward*, 1996].

2. RESULTS

2.1 Correlation Coefficients

Table 2 shows the correlation coefficients for all of the independent variables with hydrophysical anomaly strength. This strength has been expressed in two ways: the arithmetic strength, which is the actual measured value, and the base-ten logarithm of the measured strength. The logarithmic transformation of a variable reduces the impact of extreme values, which may be outliers or spurious measurements.

Correlation coefficients vary between −1.0 (perfect anticorrelation) and +1.0 (perfect correlation). The statistically significant correlations at the 95% level in Table 2 are those in which the absolute value of the

R000015

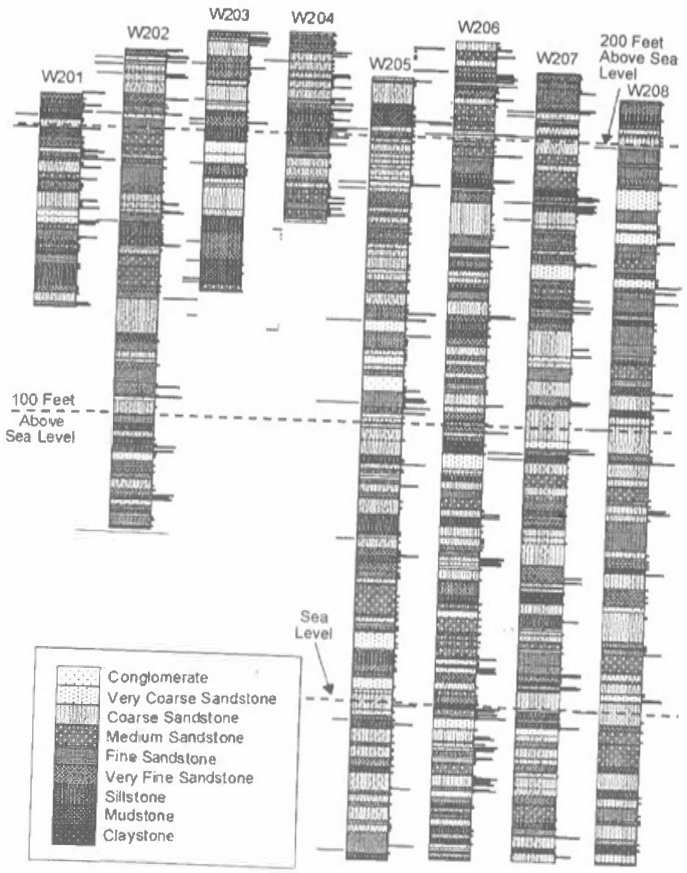


Figure 2. Summary of lithology, fractures, and hydrophysical anomalies. For each borehole, the location of hydrophysical anomalies and fractures are shown by horizontal lines. The length of the line to the left of the borehole is proportional to the logarithm of the hydrophysical anomaly magnitude, while the length of the line to the right of the borehole is proportional to the logarithm of the fracture aperture. In both cases the lines represent relative, not absolute lengths.

correlation coefficient is greater than or equal to 0.35.

This table shows that the anomaly strength and the log of the anomaly strength are positively correlated with the fracture width (aperture), the lithology of the unit in which the hydrophysical anomaly occurs, and the surrounding lithologic units, their contrast, and the dip of the contact between lithologic units. The positive correlation with lithology means that finer-grained lithological units have stronger anomalies. The positive correlation with the absolute total contrast (ATC) implies that stronger anomalies tend to be in lithologies, unlike the units immediately above and below. The correlation with contact dip may reflect structural disruption in the hanging wall of the fault, but other explanations may also be possible. The log of the anomaly strength is negatively correlated with the distance to the nearest fractures (in other words, the closer the fractures to the anomaly and the more there are of them, the stronger the anomaly).

Table 2. Correlation coefficients for flow anomaly and $\log_{10}$(anomaly) with geological parameters. Absolute values of the coefficient equal to 0.35 or greater are significant at the 95% level.

Variable	Anomaly	Log_{10} (anomaly)
W2	0.36	0.53
ALCA	0.31	0.48
ATC	0.20	0.47
W3	0.40	0.40
LITH	0.08	0.31
CONDIPB	0.47	0.27
CNEAR	−0.02	0.27
ALCB	0.00	0.23
W1	0.00	0.19
W4	−0.03	0.18
LCB	0.15	0.16
LCA	−0.25	0.15
LITHA	0.38	0.14
LITHB	−0.11	0.13
MDF	0.19	0.08
CONDIPA	0.23	0.01
APCDB	−0.01	0.00
CDB	−0.04	−0.02
CDA	0.17	−0.12
APCDA	0.19	−0.13
CMIN	0.08	−0.25
D1	−0.12	−0.34
D4	−0.15	−0.39
D3	−0.18	−0.40
D2	−0.18	−0.45

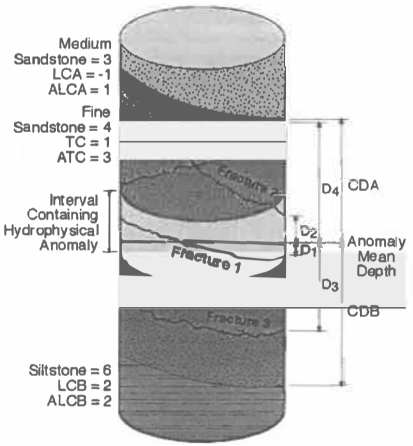


Figure 3. Derived parameters used in the statistical analyses. Table 1 provides additional explanation of these and other parameters.

2.2 Contingency Tables

Contingency tables were computed for various combinations of variables. This type of analysis is useful for determining whether a variable of interest shows up with unusually high or low frequency in some other variable class. For example, do siltstones have an unusually high frequency of fractures or hydrophysical anomalies that is out of proportion to their stratigraphic percentage?

Tables 3, 4, and 5 provide overall lithology and fracture intensity data for the eight wells. Table 3 shows how lithology varies among the eight wells. This Table illustrates that fine-grained lithological layers, particularly siltstone, increase eastward from W201 to W205, where such layers reach upwards of 45% of the total amount. They decrease abruptly in the three wells to the east of W205.

Tables 4 and 5 summarize the fracture intensity by lithology and well. These tables show that fractures in the western wells (W201 through W203) tend to reside in the coarse sandstone, while in the wells nearer to the fault, the fractures tend to occur in the siltstones. However, the

R000016

Table 3. Lithology statistics by well.

	Total Thickness (inches) of Lithological Layers Within Wells									
	Lithology									
Well No.	1 Cnglom	2 VCrsSS	3 CrsSS	4 MedSS	5 FineSS	6 VFineSS	7 SiltSt	8 MudStone	9 ClayStone	Total
W201		50.25	146.74	218.29	108.29	74.42	177.11	79.44		854.54
W202			188.71	432.06	420.76	209.13	550.51	147.26		1948.43
W203		72.8	175.94	351.29	9.41	34.18	354.3	88.82		1086.74
W204		4.43	117.38	107.36	63.42	74.03	326.4	29.17		722.19
W205	30.71	220.76	479.08	1388.54	590.14	299.59	3403.86	648.01	70.87	7131.56
W206	66.35	186.64	304.61	912.62	484.35	611.72	1286.1	349.94	46.55	4248.88
W207	266.82	194.12	349.49	814.3	434.02	546.04	1814.42	402.63		4821.84
W208	110.12	67.26	189.86	474.12	1822.33	759.82	1584.26	429	43.26	5480.03
Total	474	796.26	1951.81	4698.58	3932.72	2608.93	9496.96	2174.27	160.68	26294.21
	Percent of Thickness of Lithological Layers Within Wells									
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	
W201		5.88	17.17	25.54	12.67	8.71	20.73	9.30		
W202			9.69	22.17	21.59	10.73	28.25	7.56		
W203		6.70	16.19	32.33	0.87	3.15	32.60	8.17		
W204		0.61	16.25	14.87	8.78	10.25	45.20	4.04		
W205	0.43	3.10	6.72	19.47	8.28	4.20	47.73	9.09	0.99	
W206	1.56	4.39	7.17	21.48	11.40	14.40	30.27	8.24	1.10	
W207	5.53	4.03	7.25	16.89	9.00	11.32	37.63	8.35		
W208	2.01	1.23	3.46	8.65	33.25	13.87	28.91	7.83	0.79	

greater number of fractures in siltstones near the faults may be due to a higher proportion of siltstone in these wells than in the western wells (Table 3), rather than a greater fracture intensity in siltstones near the faults.

Two series of questions have been formulated to specifically address fracture variability and hydrophysical anomalies among the wells. The first series of questions focuses on the fracturing itself. The correlation between hydrophysical anomaly strength and the number of fractures and their closeness to the anomaly indicates that

Table 4. Total number of fractures by lithology within wells, independent of aperture.

	Total No. of Fractures by Lithology within Wells									
	Lithology									
Well No.	1 Cnglom	2 VCrsSS	3 CrsSS	4 MedSS	5 FineSS	6 VFineSS	7 SiltSt	8 MudStone	9 ClayStone	Total
W201		7	6	32	5	3	16	16		85
W202			22	30	9	2	19	10		92
W203		1	4	36	0	1	10	1		53
W204		0	16	19	11	16	37	2		101
W205	3	36	57	124	60	22	203	82	5	592
W206	2	10	24	54	19	17	82	54	7	269
W207	13	13	27	66	34	14	55	41		263
W208	5	3	7	37	46	40	69	43	13	263
Total	23	70	163	398	184	115	491	249	25	1718
	Percent of Total Fractures by Lithology within Wells									
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	
W201		8.24	7.06	37.65	5.88	3.53	18.82	18.82		
W202			23.91	32.61	9.78	2.17	20.65	10.87		
W203		1.89	7.55	67.92	0.00	1.89	18.87	1.89		
W204		0.00	15.84	18.81	10.89	15.84	36.63	1.98		
W205	0.51	6.08	9.63	20.95	10.14	3.72	34.29	13.85	0.84	
W206	0.74	3.72	8.92	20.07	7.06	6.32	30.48	20.07	2.60	
W207	4.94	4.94	10.27	25.10	12.93	5.32	20.91	15.59		
W208	1.90	1.14	2.66	14.07	17.49	15.21	26.24	16.35	4.94	

Table 5. Total number of fractures by lithology within wells for apertures > 0.03 in

	Total No. of Fractures > 0.03 in. by Lithology within Wells									
	Lithology									
Well No.	1 Cnglom	2 VCrsSS	3 CrsSS	4 MedSS	5 FineSS	6 VFineSS	7 SiltSt	8 MudStone	9 ClayStone	Total
W201		2	2	4	2	0	2	6		18
W202			4	8	1	0	10	1		24
W203		0	0	5	0	0	4	0		9
W204		0	4	5	2	2	8	0		21
W205	0	3	3	9	6	1	27	9	1	59
W206	0	3	3	11	5	3	20	22	4	71
W207	4	3	7	20	9	2	7	18		70
W208	0	1	0	6	7	7	9	7	1	38
Total	4	12	23	68	32	15	87	63	6	310
	Percent of Total Fractures > 0.03 in. by Lithology within Wells									
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	
W201		11.11	11.11	22.22	11.11	0.00	11.11	33.33		
W202			16.67	33.33	4.17	0.00	41.67	4.17		
W203		0.00	0.00	55.56	0.00	0.00	44.44	0.00		
W204		0.00	19.05	23.81	9.52	9.52	38.10	0.00		
W205	0.00	5.08	5.08	15.25	10.17	1.69	45.76	15.25	1.69	
W206	0.00	4.23	4.23	15.49	7.04	4.23	28.17	30.99	5.63	
W207	5.71	4.29	10.00	28.57	12.86	2.86	10.00	25.71		
W208	0.00	2.63	0.00	15.79	18.42	18.42	23.68	18.42	2.63	

the existence of multiple fractures could mean the presence of a strong hydrophysical anomaly.

If fractures are correlated with hydrophysical anomalies, then it is important to determine how fractures vary throughout the site, and what factors influence variations in fracture intensity. Tables 6 through 9 address the following four questions regarding fracture intensity and whether it varies among the wells or lithologic groups:

1. Are fractures distributed uniformly within all logged lithologic layers? If this is true, then it may imply that fracturing is relatively independent of lithological controls or structural position.
2. Are fractures distributed uniformly within each lithological layer in each well? If so, then fracture intensity may be controlled by lithology, and be relatively unaffected by structural position.
3. Are fractures with an aperture of >0.03 in. (0.76 cm) distributed uniformly within all lithologic layers? This question is similar to the first, except the emphasis here is on fractures with the largest geometric apertures. Such fractures may represent only a small subset of the most conductive fractures in a well, which may account for most of the flow.
4. Are fractures with an aperture of >0.03 in. distributed uniformly within each lithological layer within each well? This question is similar to the second, except it focuses on the fractures with the largest geometric apertures, which might in turn represent the most conductive fractures.

Table 6 shows that the p-value (the probability of observing the calculated Chi-Square statistic given that the null hypothesis is true) is essentially 0.0, implying that fracture intensity is not uniform among the wells. Wells W204, W205, and W208 are the most anomalous in terms of fracture intensity, as shown by their high Chi-Square values. Table 7 demonstrates that the frequency of fracture variation from well to well is influenced by lithology. The high Chi-Square value for siltstone and mudstone in well W205 shows that the fracture frequency is anomalous in these fine-grained lithologies in the well. The higher values for the coarser-grained layers in wells W202 and W203 confirm that fracturing is anomalous in these units. The p-values show that fracture intensity varies with lithology within individual wells. Tables 8 and 9 show similar results for fractures with apertures greater than 0.03 in. In summary, these tables indicate that fracture intensity varies among wells, and this variation is due not only to differences in the proportion of different lithologies. For example, siltstones in well W205 have a different frequency than siltstones in well W202.

With regards to the hydrophysical anomalies themselves, several questions arise:

1. Does the strength of the conductivity anomaly or number of anomalies vary by well?
2. Does the strength of an anomaly depend upon being located in a particular lithology?
3. Is the strength of an anomaly influenced by the thickness of the unit in which it occurs?
4. Is the strength of an anomaly influenced by the

R000017

Table 6. Evaluation of the degree to which fractures are distributed uniformly among the wells, using Chi Square criteria.

Well	Total Thickness of Layer (inches)	Total No. of Fractures	Expected No. of Fractures	Chi Square	p-value
W201	854.54	85	55.8	15.24	
W202	1948.43	92	127.3	9.79	
W203	1086.74	53	71.0	4.57	
W204	722.19	101	47.2	61.37	
W205	7131.56	592	466.0	34.09	
W206	4248.88	269	277.6	0.27	
W207	4821.84	263	315.0	8.60	
W208	5480.03	263	358.1	25.23	
Total	26294.21	1718	1718.0	159.16	4.82E-31

proximity to a contact with another lithologic unit?

5. Is the strength of an anomaly correlated to a sharp contrast in the lithologies of units immediately above and below the unit?

Figure 4 shows the percent of hydrophysical anomalies by lithology within each well. There is insufficient information to carry out meaningful contingency table analyses on these data, but the figure clearly illustrates that the anomalies occur in different lithologies in a manner that is not in proportion to the relative net thickness of the lithologic layers in the wells

Figure 5 illustrates the relation of the thickness of a unit containing a hydrophysical anomaly to the thickness of all units found in the eight wells. There is no obvious visual difference.

The hypothesis that lithologic contrasts are related to anomalies was tested by comparing the anomaly strength to:

1. The absolute strength of the contrast (parameter ATC).
2. The contrast with the nearest adjacent lithology (parameter C_NEAR).
3. The distance to the nearest adjacent lithology.
4. Whether anomalies are predisposed to occur more closely to lithologic unit contacts.

Figure 6 shows the relation between both total contrast (TC) and ATC with the strength of the anomaly. The figure illustrates that there is a weak trend between increasing ATC and anomaly strength, but none between TC and anomaly strength. Figure 6 also compares anomaly strength to the contrast of the unit above (ALCA) and the unit below (ALCB). There is no obvious visual trend between these parameters and anomaly strength.

In addition, Figure 6 shows two parameters relating the anomaly strength to the contrast between the unit containing the anomaly (C_NEAR) and the distance to the nearest adjacent unit (CMIN). These data suggest no obvious trend.

The data shown in Figure 6 were tested to determine if hydrogeologic anomalies tend to be within 1 ft of the nearest contact. Does this imply that hydrophysical anomalies tend to occur close to lithology changes? This proposition was tested by selecting a random point in each unit penetrated by the eight wells and then computing the distance to the nearest contact. Figure 7 summarizes the result. Visually these two distributions appear very similar. A Chi-Square test does not reject this hypothesis, showing with an approximate 86% significance that these distributions are the same. This implies that anomalies do not appear to be preferentially located near major changes in lithology, although lithology contrasts have some importance.

The location and relative strength of each hydrophysical anomaly identified in the eight boreholes are indicated in Figure 2 by a line on the left-hand side of the borehole log. The length denotes the log of the flow rate. The figure indicates that the strongest hydrophysical anomalies are in W205, which intersects the fault.

Table 7. Evaluation of the degree to which fractures are distributed uniformly with lithologic layer in individual wells.

	Expected Number of Fractures										
Well No.	1 Cnglom	2 VCrsSS	3 CrsSS	4 MedSS	5 FineSS	6 VFineSS	7 SiltSt	8 MudStone	9 ClayStone	Total	
W201		5.00	14.60	21.71	10.77	7.40	17.62	7.90		85	
W202			8.91	20.40	19.87	9.87	25.99	6.95		92	
W203		3.55	8.58	17.13	0.46	1.67	17.28	4.33		53	
W204		0.62	16.42	15.01	8.87	10.35	45.65	4.08		101	
W205	2.55	18.33	39.77	115.26	48.99	24.87	282.56	53.79	5.88	592	
W206	4.20	11.82	19.29	57.78	30.66	38.73	81.42	22.15	2.95	269	
W207	14.55	10.59	19.06	44.41	23.67	29.78	98.96	21.96		263	
W208	5.28	3.23	9.11	22.75	87.46	36.47	76.03	20.59	2.08	263	
Total	26.59	53.13	135.73	314.47	230.75	159.14	645.52	141.76	10.91	1718	
	Chi-Square Analysis										
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	Total	p-Value
W201		0.80	5.06	4.87	3.09	2.62	0.15	8.30		24.90	0.00036
W202			19.23	4.52	5.94	6.28	1.88	1.34		39.19	2.18E-07
W203		1.83	2.45	20.78	0.46	0.27	3.07	2.56		31.41	0.00002
W204		0.62	0.01	1.06	0.51	3.08	1.64	1.06		7.98	0.23973
W205	0.08	17.05	7.47	0.66	2.48	0.33	22.40	14.79	0.13	65.39	4.05E-11
W206	1.15	0.28	1.15	0.25	4.44	12.19	0.00	45.77	5.57	70.81	3.39E-12
W207	0.17	0.55	3.31	10.49	4.51	8.36	19.53	16.51		63.42	3.13E-11
W208	0.02	0.02	0.49	8.92	19.65	0.34	0.65	24.40	57.48	111.96	1.51E-20

2.3 Multiple Regressions

A series of step-wise multiple regressions was carried out using a data-mining application, SAS™. The results are summarized in Table 10. This table contains the results for the six multiple regressions with the highest R-square value for different numbers of independent variables.

Improvement in R-square decreased significantly after seven variables. Those variables that produced the best R-square values for a given number of parameters are shown in the table and marked by an "X." The table demonstrates that certain variables explain much of the variance in anomaly strength. These variables include the distance to the nearest fractures (D1, D2, D3), the aperture, or width of the fractures (W3), the absolute lithologic contrast (ATC), the dip of the unit below the anomaly (CONDIPB), and the contrast with the unit above (ALCA).

Thus, the multiple regression results suggest that the distances to the three nearest fractures are important, as well as the data on a strong lithology contrast and wider fracture apertures. These variables account for approximately 80% of the variability in anomaly strength.

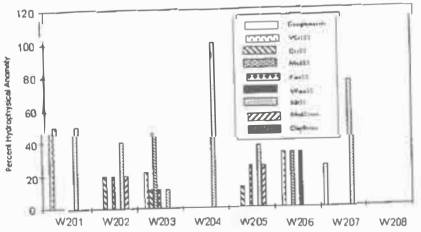


Figure 4. Percent of hydrophysical anomalies by lithology for individual wells. The height of the bars represents the percent of the logged interval of the well comprised by each lithology. Missing bars indicate the absence of a particular lithology in a well.

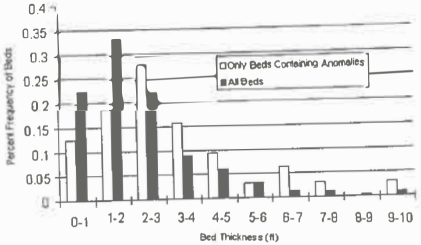


Figure 5. Bed thickness histograms. Open bars represent the histogram of bed thickness for all beds encountered by the wells. Black bars represent the histogram of bed thickness for only those beds containing hydrophysical anomalies. The vertical axis represents the percent of the beds belonging to a particular bed thickness class.

2.4 Neural Net Analyses

All neural net analyses were carried out using NeuroShell II™ Version 3.0 [*Ward*, 1996]. A genetic adaptive GRNN architecture was used [*Specht*, 1991]. GRNNs are designed to predict a continuous variable. They are memory-based feed-forward networks based on the estimation of probability density functions. The classic GRNN contains only one adjustable parameter, termed the *smoothing factor*. The smoothing factor allows the GRNN to interpolate between patterns in the training data set. The genetic adaptive GRNN differs in that it has smoothing factors for each input parameter as well as a conventional overall smoothing factor. These smoothing factors are

R000018

Table 8. Fractures > 0.03 in. are distributed uniformly with lithologic layer.

Well	Total Thickness (inches)	Total Fractures	Expected Fractures	Chi Square	p-value
W201	854.54	18	10.1	6.23	
W202	1948.43	24	23.0	0.05	
W203	1086.74	9	12.8	1.13	
W204	722.19	21	8.5	18.31	
W205	7131.56	59	84.1	7.48	
W206	4248.88	71	50.1	8.73	
W207	4821.84	70	56.8	3.04	
W208	5480.03	38	64.6	10.96	
Total	26294.21	310	310.0	55.93	9.75E-10

optimized by iterative changes in the factors based on cross-validation to minimize the mean squared error of the outputs over the entire test set. The genetic adaptive GRNN is much more robust against noisy data and redundant parameters than traditional GRNNs, and is particularly well suited when the input parameters are of different types, and some may have markedly more impact on predicting the output variable than others.

When an observation, which consists of parameter values for all input parameters under consideration, is presented to the GRNN, it is compared to all of the patterns in the training set to determine how closely this observation corresponds to those patterns. The GRNN essentially computes a weighting factor for each training data-set observation, and then computes an overall output value based upon these weights and the input training set parameter values.

Application of a neural net to the hydrophysical anomaly dataset would be improved if the data set were larger. This is because a small training set and a small test set increase the variability in the results. Also, with a very small training set, it is possible that the training data would not span the n-dimensional parameter space and would thereby have difficulty interpolating to new observations with characteristics outside of the data training subspaces. Likewise, it is important to have fewer degrees of freedom

Table 9. Evaluation of the degree to which fractures > 0.03 in. are distributed uniformly with lithologic layer in individual wells.

All Fractures >,0.03 in. by Lithology within Wells											
Expected Number of Fractures											
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	Total	
W201		1.06	3.09	4.60	2.28	1.57	3.73	1.67		14.89	
W202			2.32	5.32	5.18	2.58	6.78	1.81		10.40	
W203		0.60	1.46	2.91	0.08	0.28	2.93	0.74		5.05	
W204		0.13	3.41	3.12	1.84	2.15	9.49	0.85		2.47	
W205	0.25	1.83	3.96	11.49	4.88	2.48	28.16	5.36	0.59	5.73	
W206	1.11	3.12	5.09	15.25	8.09	10.22	21.49	5.85	0.78	67.51	
W207	3.87	2.82	5.07	11.82	6.30	7.93	26.34	5.85		51.47	
W208	0.76	0.47	1.32	3.29	12.64	5.27	10.99	2.97	0.30	15.45	
Total	6.00	10.02	25.73	57.80	41.30	32.48	109.91	25.10	1.66	172.96	
Chi-Square Analysis											
	Cnglom	VCrsSS	CrsSS	MedSS	FineSS	VFineSS	SiltSt	MudStone	ClayStone	Total	p-Value
W201		0.84	0.39	0.08	0.03	1.57	0.80	11.19		14.89	0.02111
W202			1.21	1.35	3.38	2.58	1.53	0.37		10.40	6.47E-02
W203		0.60	1.46	1.50	0.08	0.28	0.39	0.74		5.05	0.53790
W204		0.13	0.10	1.13	0.01	0.01	0.23	0.85		2.47	0.87224
W205	0.25	0.75	0.23	0.54	0.26	0.88	0.05	2.47	0.29	5.73	6.78E-01
W206	1.11	0.00	0.86	1.18	1.18	5.10	0.10	44.62	13.35	67.51	1.54E-11
W207	0.00	0.01	0.73	5.66	1.16	4.43	14.20	25.28		51.47	7.42E-09
W208	0.76	0.61	1.32	2.24	2.51	0.57	0.36	5.45	1.63	15.45	5.10E-02

(i.e., input variables) in the network than training cases; otherwise, the net "memorizes" the training set without uncovering useful relations.

The performance of a neural net is determined by how well it predicts the strength of the anomaly of a test set as quantified by R and R-square statistics. These statistics vary from 0.0 to 1.0; a perfect prediction has an R and R-square statistic of 1.0. The importance of an input parameter is quantified by its smoothing factor, which can vary from 0.0 (no importance) to 3.0 (very important).

Because of the small (approximately 30) number of hydrophysical anomalies available for use as training and test patterns, the results are sensitive to the random subset selected as the training pattern. For this reason, several random subsets were selected and processed.

Correlation shows up in the smoothing factors as a substitution of one correlated variable in random samples. For example, in one run, the distance to the third nearest fracture might be important. In a subsequent run, this distance might have little importance but the distance to the second nearest fracture would now be important. Highly correlated variables can substitute for one another since virtually all of the information in all of the variables can be contained in any one of the variables.

Neural net regression was much more successful for the logarithm of the anomaly than for the anomaly itself. A series of preliminary neural nets was constructed to look at different components of the data—in particular, fracture-related parameters and lithological parameters. In the preliminary processing that focused on fractures, several parameters played an important role. These included depth of the fractures, width of the fractures, distance from the anomaly to the nearest fractures, and the lithology of the

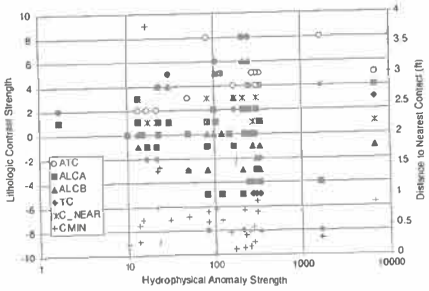


Figure 6. Anomaly strength vs. lithological contrast parameters. The vertical scale on the left-hand side of the graph pertains to the contrast parameters ATC, ALCA, ALCB, TC, and C_NEAR. The vertical scale on the right-hand side indicates the value of the distance parameter CMIN.

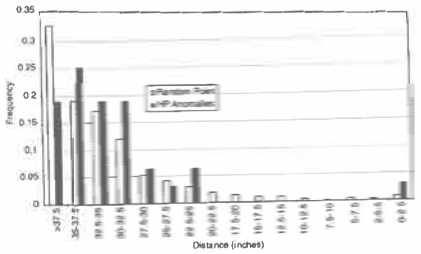


Figure 7. Percent frequency histogram of distance to nearest lithology change. Open bars represent distances between a location randomly assigned in the wells and the nearest contact. Black bars represent the distance from the locations of all hydrophysical anomalies to the nearest contact. The frequencies have been normalized to percentages in order to facilitate visual comparison.

nearest fractures. Depth was probably an artifact of the available dataset, however. Well W205, the deepest well, had the strongest anomalies. The other wells either were not drilled to the depth of W205, or else did not have all of the necessary parameters for the deeper portions of the borehole.

The lithologies above and below the hydrophysical unit did not appear to explain the hydrophysical anomaly. However, the lithologies of the four nearest fractures were quite informative. Although these lithologies correlated very strongly, surprisingly, at least three of them always seemed to have significant smoothing factors. This is reminiscent of the results from the step-wise regression, which showed that the distance to at least three of the four nearest fractures was important. If the information content in any one of these parameters were a good representation of the information content in any other, then it would be expected that only one of the lithology, depth, or aperture parameters would have a significant smoothing factor. The fact that more than one lithology parameter has a significant smoothing factor might be evidence that hydrophysical anomalies are in some way enhanced by the presence of multiple fractures near the anomaly, whether or not these fractures actually have an anomaly associated with them.

These preliminary runs guided the final runs in which redundant variables and depth measures had been eliminated. Tables 11 and 12 summarize those results.

Table 11 shows the mean of the smoothing factors for five randomly drawn training and test sets. The lithology of the fractures (L1 and L2), fracture width (W1 and W2), and proximity (D1 and D2) to fractures to the anomaly are

R000019

Table 10. Results of step-wise regression.

No. of Variables	R-square	ALCA	ATC	CDA	CONDIP A	CON DIPB	D1	D2	D3	D4	LCA	LITH	Log(W1)	Log(W2)	Log(W3)	W1	W2	W3
2	0.477	X												X				
2	0.438		X											X				
2	0.419	X															X	
2	0.402							X						X				
2	0.387							X									X	X
2	0.383		X															X
3	0.527	X						X						X				
3	0.513		X					X										
3	0.511	X					X						X					
3	0.508	X						X						X				
3	0.507		X											X				
3	0.506	X					X							X				
4	0.622						X	X	X						X			X
4	0.596		X					X	X						X			
4	0.591						X	X	X						X			
4	0.581	X						X	X					X				
4	0.580		X				X	X										X
4	0.571	X					X						X	X				
5	0.717		X					X	X						X			X
5	0.711		X					X	X							X		X
5	0.687							X	X									X
5	0.684							X	X					X				X
5	0.679	X						X	X									X
5	0.677		X			X		X	X									
6	0.802		X			X		X	X									X
6	0.783		X	X				X	X						X			
6	0.765		X	X				X	X					X				X
6	0.753	X						X	X					X				X
6	0.751		X					X	X									
6	0.750							X	X						X			X
7	0.828		X	X		X		X	X									X
7	0.823		X	X		X		X	X					X				X
7	0.820		X			X		X	X					X		X		
7	0.817				X	X		X	X		X							
7	0.816		X			X		X	X		X							
7	0.815		X			X		X	X			X						

always important. In particular, the distance to the second closest fracture is much more important than the distance to the closest fracture. Two other parameters, used only in the neural net analysis, also were important—UNCONF and ABS(UNCF). These variables were introduced to assess structural or stratigraphic disruption, an area also important in the neural net analyses. Absolute lithology contrast (ATC), lithology of the anomaly (LITH), and distance to the nearest contact (CMIN), have a moderate impact. Bed thickness (BED_TH) and the contrast between the anomaly unit and the nearest adjacent unit (C_NEAR) play very minor roles.

Table 12 shows the R-square and r-square statistics for both the training and test sets. R-square is the coefficient of multiple determination, whereas r-square is the more familiar coefficient of determination [*Ward*, 1996], which is the square of the correlation coefficient. The R-square value for the training sets averages nearly 92%, with a variation of 81% to 100%. The R-square value for the test sets averages nearly 77%, with a variation of 50% to 97%. Note that the lowest R-square for the test set comes from realization 2, which conversely has the highest value (1.0) for the training sets. The smoothing factors for this realization are also somewhat anomalous. The R-square values for both the training and test sets are higher than for the multivariate regression. This suggests that some of the input parameters have a nonlinear relation with anomaly strength. In general, the GRNN achieves about a 20% improvement over the multivariate regression in terms of R-square values.

Table 13 shows the predictions made by the neural net method for the ten test sets of observations. In general, the predictions are reasonably accurate, the average error being 0.0250 and the standardized mean squared error 0.34.

Thus, the neural net analysis confirms the results of the simpler statistical techniques and suggests that a GRNN offers greater accuracy than multivariate regression.

Table 11. Average smoothing factors for neural net analyses.

Average of 5 Realizations	Smoothing Factor [0 to 3.0]
Lithology to 1st Nearest Fracture	2.37
Distance to 2nd Nearest Fracture	2.24
Lithology to 2nd Nearest Fracture	2.09
Aperture of 1st Nearest Fracture	1.97
Absolute Value of Angular Difference between Upper and Lower Contacts	1.86
Difference between Upper and lower Contacts	1.59
Distance to Nearest Contact	1.28
Aperture of 2nd Nearest Fracture	1.21
Absolute Grain Size Contrast	1.15
Grain Size of Unit Containing Anomaly	1.12
Distance to 1st Nearest Fracture	1.08
Minimum Apparent Distance to Nearest Contact	0.76
Bedding Thickness	0.60
Dip of Contact with Unit Above	0.47
Grain Size Contrast with Nearest Unit	0.29

3. CONCLUSIONS

The statistical results for the Wake Co. site support the following conclusions:

1. There are statistically significant correlations between the geologic variables directly measured or derived from core data or borehole imagery and the strength of hydrophysical anomalies.
2. Hydrophysical anomalies do not appear to be located preferentially in particular lithologies for all eight wells. The frequency histograms and associated statistical test results show that hydrophysical anomalies are located in randomly selected subsets of all of the lithologic units.
3. Hydrophysical anomalies are not preferentially located near to boundaries between contrasting lithologic units. Frequency histograms of the proximity of anomalies to the nearest lithologic boundary are statistically indistinguishable from the distance from a random point located in every unit to its nearest boundary.
4. There is a weak trend between the magnitude of a hydrophysical anomaly and the strength of the contrast between the lithologic unit containing the anomaly and the units above and below it.
5. The trend noted in the conclusion above is independent of whether the anomaly occurs in a fine-grained unit surrounded by coarse-grained units or a coarse-grained unit surrounded by fine-grained units.
6. There is no correlation between the strength of the hydrophysical anomaly and the strength of the contrast with the lithologic unit above or below.
7. There is no correlation between the strength of the hydrophysical anomaly and the distance to either the upper or lower contact with the adjacent lithologic units.
8. The strongest hydrophysical anomalies occur in the fine-grained lithologies in Well W205, which intersected the fault and was drilled and logged deeper than most of the other wells. The anomalies in well W205 have three unique characteristics: they occur preferentially in siltstone or mudstone lithologies,

R000020

Table 12. Statistics for GRNN prediction of hydrophysical anomaly strength.

Training Set	#1	#2	#3	#4	#5	Average
R squared	0.91	1.00	0.99	0.81	0.88	0.92
r squared	0.94	1.00	0.99	0.90	0.88	0.94
Mean squared error	0.05	0.00	0.01	0.12	0.06	0.05
Mean absolute error	0.15	0.00	0.06	0.24	0.07	0.10
Min. Absolute error	0.00	0.00	0.00	0.00	0.00	0.00
Max. Absolute error	0.80	0.00	0.25	1.04	1.35	0.69
Correlation coefficient r	0.97	1.00	0.99	0.95	0.94	0.97
Percent within 5%	45.46%	100.00%	77.27%	27.27%	87.50%	67.50%
Percent within 5% to 10%	36.36%	0.00%	13.64%	22.73%	3.13%	15.17%
Percent within 10% to 20%	13.64%	0.00%	9.09%	31.82%	6.25%	12.16%
Percent within 20% to 30%	0.00%	0.00%	0.00%	9.09%	0.00%	1.82%
Percent over 30%	4.55%	0.00%	0.00%	9.09%	3.13%	3.35%
Test Set	**#1**	**#2**	**#3**	**#4**	**#5**	**Average**
R squared	0.86	0.50	0.97	0.85	0.67	0.77
r squared	0.96	0.53	0.98	0.87	0.73	0.81
Mean squared error	0.04	0.34	0.01	0.02	0.19	0.12
Mean absolute error	0.15	0.29	0.08	0.11	0.20	0.17
Min. Absolute error	0.00	0.00	0.00	0.03	0.00	0.01
Max. Absolute error	0.37	1.70	0.14	0.36	1.35	0.78
Correlation coefficient r	0.98	0.73	0.99	0.93	0.85	0.90
Percent within 5%	50.00%	60.00%	50.00%	80.00%	60.00%	60.00%
Percent within 5% to 10%	10.00%	0.00%	40.00%	0.00%	10.00%	12.00%
Percent within 10% to 20%	10.00%	30.00%	10.00%	10.00%	20.00%	16.00%
Percent within 20% to 30%	20.00%	0.00%	0.00%	0.00%	0.00%	4.00%
Percent over 30%	10.00%	10.00%	0.00%	10.00%	10.00%	8.00%

which is not true for anomalies in other wells; they occur at a greater depth than in the other wells; and the fractures nearest the anomalies have greater apertures than the fractures near anomalies in other wells. The depth correlation is probably an artifact.

9. Away from faults, hydrophysical anomalies are smaller on average and not as strongly associated with siltstone and mudstone. Near faults in the hanging wall, the strength of the anomalies is greater and they are correlated with fractures with larger aperture.
10. The results of our analyses confirm that a fault-related deformation produces new fractures or enhances the aperture of existing fractures in lithological units with lower resistance to shear—mudstones and siltstones—and thereby increases the strength of hydrophysical anomalies.

4. RECOMMENDATIONS

This section offers recommendations for using the results of this study to construct site-scale DFN and SC flow models. The results confirm that it is not correct to assign permeability values to grid cells or flow properties to fractures based on lithologic type alone. The boundaries between contrasting lithologic types do not focus strain. If they did, then the DFN model could have reproduced this effect by having large, bedding-parallel fractures at these interfaces with enhanced transmissivity values. SC models could have approximated this effect by having bedding-parallel layers of grid cells with enhanced subhorizontal permeability. While there is some correlation between lithological contrasts, the correlation is second order and should probably be ignored in preliminary flow models.

Table 13. Comparison of measured hydrophysical anomaly strength with strength predicted by GRNN for ten randomly selected anomalies not used in the GRNN calibration.[a]

#1		#2		#3		#4		#5	
Actual	GRNN	Actual	GRNN	Actual	GRNN	Actual	GRNN	Actual	GRNN
2.52	2.52	3.22	2.62	2.44	2.46	2.52	2.48	3.82	2.48
2.48	2.45	2.52	2.52	2.34	2.29	2.48	2.54	2.52	2.52
2.48	2.39	2.52	2.44	2.32	2.41	2.40	2.35	2.48	2.44
2.22	2.19	2.22	1.92	2.18	2.17	2.35	2.10	2.45	2.39
2.09	2.28	2.09	2.09	1.92	2.03	2.34	2.27	2.40	2.22
2.02	1.99	1.48	1.46	1.48	1.60	2.32	2.43	2.09	2.35
1.99	2.23	1.37	1.37	1.37	1.28	2.18	2.21	1.48	1.47
1.48	1.78	1.34	1.34	1.37	1.32	2.02	1.99	1.37	1.37
1.12	1.37	1.18	1.34	1.12	1.26	1.92	1.83	1.34	1.34
1.00	1.37	0.22	1.92	1.12	1.21	1.12	1.49	1.18	1.34

[a]The ten rows, corresponding to the randomly selected anomalies for each of the five test sets, were sorted by anomaly, from largest anomaly to smallest, to illustrate that the GRNN tends to overpredict the strength of small anomalies (calculations were carried out for five runs).

Fault proximity is a first-order control in and of itself, and lithology plays a significant role near faults. Deformation is greatest in the hanging-wall siltstones and mudstones within the deformation zone that extends from the fault eastward to the fold hinge that intersects the bottom of W204. This implies that fractures in these lithologies and structural positions should have larger aperatures, resulting in higher transmissivity. Alternatively, the grid cells within this region of a SC model would have higher layer-parallel permeability. Based on the data obtained, the footwall appears to be similar to the rock outside of the hanging-wall deformation zone.

The fact that anomalies do exist outside of the hanging-wall zone, but are smaller and not as strongly correlated with lithology, suggests simple "background" fracture and permeability models for the remainder of the rock mass. At least for the preliminary model, the background fracturing would be homogeneous throughout the model. This means that the discrete fractures in the DFN model would be distributed with the same size and orientation distributions, the same transmissivity and transport properties, and the same average intensity independent of depth, lithology, or location. In the SC model, the permeability, porosity, and transport parameter values would be assigned as random (Monte Carlo) draws from a single parent distribution for each parameter. Only in the vicinity of the hanging-wall deformation zone would properties be changed as previously described.

The next stage in refining these DFN or SC models would be to simulate field flow or transport experiments in order to assess whether the models are reproducing the first-order effects, and if so, whether certain second-order effects should be included to improve the modeling forecasts. There is considerable freedom in assigning transmissivity and transport properties either to the fractures themselves in the DFN formulation or as effective properties to the stochastic continuum models. Iterative refinement of these properties to match the field-flow or transport results is usually an important step in the evolution of models that will be used subsequently for forecast or design.

Acknowledgments. Portions of this work were performed under contract to Harding-Lawson Associates, whose support is gratefully acknowledged. The opinions expressed in this paper, however, remain those of the author and do not necessarily coincide with those of Harding-Lawson Associates or any other party involved in the North Carolina LLRW Facility Project.

REFERENCES

Cacas, M. C., E. Ledoux, G. De Marsily, B. Tillie, A. Barbreau, E. Durand, B. Feuga, and P. Peaudecerf, Modeling fracture flow with a discrete fracture network: calibration and validation 1, the flow model, *Water Resour. Res.*, *26*(3), 479–489, 1990a.

Cacas, M. C., E. Ledoux, G. De Marsily, A. Barbreau, P. Calmels, B. Gaillard, and R. Margritta, Modeling fracture flow with a discrete fracture network: calibration and validation 2, the transport model, *Water Resour. Res.*, *26*(3), 491–500, 1990b.

Dershowitz, W. S., *Rock Joint Systems*, Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, Mass., 1984.

Dershowitz, W. S.N. Hurley, and K. Been, Stochastic discrete fracture modeling of heterogeneous and fractured reservoirs, in *Proceedings of the Third International Conference on the Mathematics of Oil Recovery*, Delft University Press, Delft, Holland, 1992.

Endo, H. K., J. C. S. Long, C. K. Wilson, and P. A. Witherspoon,

R000021

el for investigating mechanical transport in fractured *Water Resour. Res.*, *20*(10), 1390–1400, 1984.

. A., and P. R. La Pointe, Printed circuits for studying ass permeability, *Int. J. Rock Mechanics and Mining and Geomechanics Abstracts*, *17*, 297–301, 1980.

, P. R., P. C. Wallmann, and S. Follin, Continuum ig of rock masses: Is it useful?, *Proceedings of the Int. of Rock Mechanics Symposium on Prediction and iance in Rock Mechanics and Rock Engineering—ZK '96*, pp. 343–350, Balkema, Rotterdam, 1996.

. S., J. S. Remer, C. R. Wilson and P. A. Witherspoon, media equivalents for networks of discontinuous s, *Water Resour. Res.*, *18*(3), 645–658, 1982.

Research Council, Committee on Fracture erization and Fluid Flow, *Rock Fractures and Fluid* Chap. 6, pp. 307–404, National Academy Press, gton, D.C., 1996.

P., *Connectivity, flow and transport in network models ured media*, Ph.D. thesis, Oxford University, UK, 1984.

, and F. W. Schwartz, An analysis of the influence of geometry on mass transport in fractured media, *Water Res.*, *20*(9), 1241–1252, 1984.

Specht, D. F., A generalized regression neural network, *IEEE Trans. on Neural Networks, 2*, 568–576, 1991.

Swaby, P. A., and K. D. Rawnsley, An interactive 3D fracture modelling environment, *Proceedings of the Petroleum Computer Conference, SPE 36004*, Society of Petroleum Engineers, Dallas, Tex., 1996.

Ward, Inc., *NeuroShell 2 User's Manual*, Ward Systems Group, Inc., Frederick, Md., 1996.

Zimmerman, D. A., G. De Marsily, C. A. Gotway, M. G. Marietta, C. L. Axness, R. L. Beauheim, R. Bras, J. Carrera, G. Dagan, P. B. Davies, D. P. Gallegos, A. Galli, J. Gómez-Hernández, S.M. Gorelick, P. Grindrod, A. L. Gutjahr, P. K. Kitanidis, A. M. Lavenue, D. McLaughlin, S. P. Neuman, B. S. Rama Rao, C. Ravenne, and Y. Rubin, A comparison of seven geostatistically-based inverse approaches to estimate transmissivities for modeling advective transport by groundwater flow, *Water Resour. Res.*, *34*(6), 1373–1413, 1998.

Paul R. La Pointe, Golder Associates, Inc., 18300 NE Union Hill Rd. #200, Redmond, WA 98052

DOCUMENT 3

Coals

Coals are classified as ***humic coals*** if they are *derived from humic substances with 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.

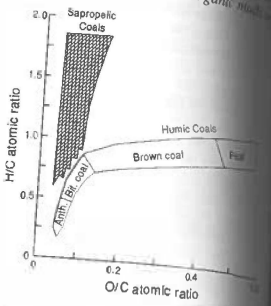


Figure 5–27
van Krevelen (1963) diagram indicating the changes in hydrogen, oxygen, and carbon content during the coalification process. After Killops and Killops (1993).

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.

R0000024

R000025

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.

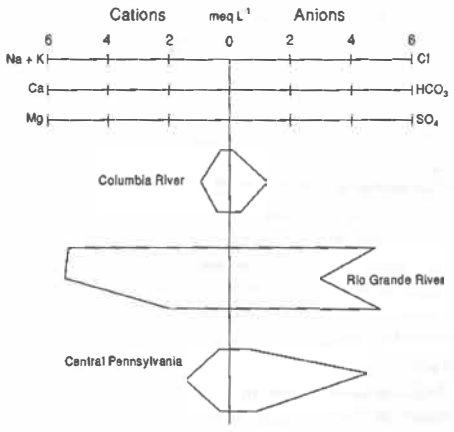


Figure 9–5
Stiff diagram for Columbia and Rio Grande river waters and Central Pennsylvania groundwater. See text for discussion. ■

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. ■

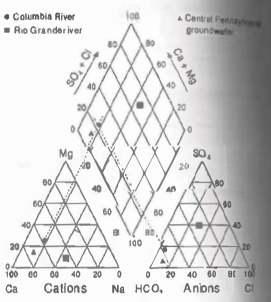


Figure 9–6
Piper diagram for Columbia and Rio Grande river waters and Central Pennsylvania groundwater. See text for discussion.

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.

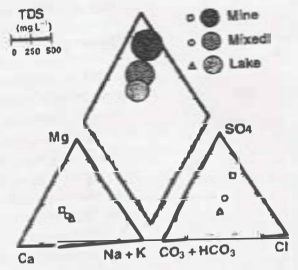


Figure 9–C2–1
Piper diagram showing the compositions of the mine and lake discharges and the mixed stream water. From Foos (1997).

Source: Foos (1997).

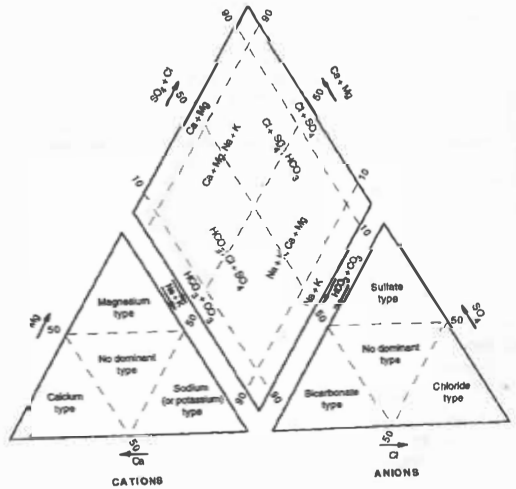


Figure 9–7
Hydrochemical facies. After Back (1966).

R000026

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 distribution 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 soluble complexes with sulfate, and the slight increase in pH at 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:

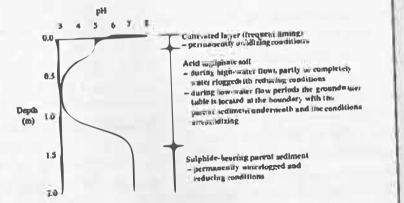


Figure 9–C8–1
pH, redox, and hydrological characteristics of a typical acid sulfate soil. After Åström (2001).

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).

[illegible] 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, adsorption 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 orders for various metals and humic substances: $Mn^{2+} < Cd^{2+} < Co^{2+} < Ni^{2+} < Zn^{2+} < Pb^{2+} < Cu^{2+} < VO^{2+}$.

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 anions, $VO_2(OH)_2^-$, $H_2VO_4^-$, 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,

R000027

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 $pH_{pznpc} \approx 7.8–8.5$), 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

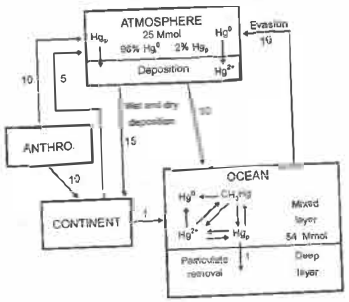


Figure 9–21
Present-day mercury cycle. The fluxes are given in Mmol L^{-1}; Hg_p represents mercury adsorbed to particles. Anthropogenic inputs are approximately 20 Mmol y^{-1}; half is returned to the surface close to the source and the other half is transferred to the atmosphere as volatile mercury.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

R000028

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 di 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 sequ 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 in 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, nu accidents, and the nuclear fuel cycle). Radioactivity and radioactive decay were discu

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 fluoride 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).

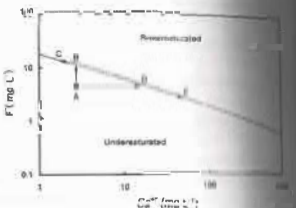


Figure 9–24
Solubility of fluorite at 25°C as a function of F^- and Ca^{2+} concentrations. See text for discussion.

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 concentrations in most rock forming minerals, (2) high solubility of most silicate compounds, (3) virtually no adsorption by particles, (4) lack of volatile compounds, and (5) generally low biochemical fractionations 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, by 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 fluorapatite, which can be removed by acid leaching) ranges from 40 to 1150 ppm, with a mean of 419 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

R000030

R000031

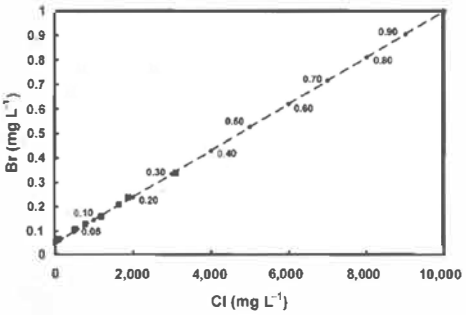


Figure 9–25
Binary mixture of groundwater (0.05 mg L^{-1} Br and 5 mg L^{-1} Cl) and brine (1 mg L^{-1} Br and 10,000 mg L^{-1} Cl). Labeled points are fraction of brine in the mixture. Groundwater samples from an aquifer (filled squares) fall along this line, suggesting they represent mixtures of uncontaminated 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 4

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.

Table of Contents

1.0 SCOPE AND APPLICATION 2
2.0 SUMMARY OF METHOD 3
3.0 DEFINITIONS 4
4.0 INTERFERENCES 5
5.0 SAFETY 5
6.0 EQUIPMENT AND SUPPLIES 5
7.0 REAGENTS AND STANDARDS 8
8.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE 8
9.0 QUALITY CONTROL 8
10.0 CALIBRATION AND STANDARDIZATION 9
11.0 PROCEDURE 9
12.0 DATA ANALYSIS AND CALCULATIONS 15
13.0 METHOD PERFORMANCE 20
14.0 POLLUTION PREVENTION 20
15.0 WASTE MANAGEMENT 20
16.0 REFERENCES 21
17.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA 22

[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.

---

[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.

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

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

1. International Ash Working Group (IAWG), *Municipal Solid Waste Incinerator Residues*, Amsterdam, the Netherlands, 1997.

2. Crank, *Mathematics of Diffusion*, Oxford University Press,, London, 1986.

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.

4. A.C. Garrabrants, D.S. Kosson, R. DeLapp, P. Kariher, P.F.A.B. Seignette, H.A. van der Sloot, L. Stefanski, and M. Baldwin, "Interlaboratory Validation of the Leaching Environmental Assessment (LEAF) Method 1314 and Method 1315," EPA 600/R-12/624, *U.S. Environmental Protection Agency*, Washington, DC, 2012.

5. A.C. Garrabrants, D.S. Kosson, H.A. van der Sloot, F. Sanchez, and O. Hjelmar, "Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods," EPA/600/R-10-170, *U.S. Environmental Protection Agency*, Washington, DC, 2010.

6. J. de Groot, and H. A. van der Sloot, "Determination of Leaching Characteristics of Waste Materials Leading to Environmental Product Certification," in *Solidification and Stabilization of Hazardous, Radioactive, and Mixed Wastes*, 2nd Volume, ASTM STP 1123, T. M. Gilliam, and C. C. Wiles (eds), American Society for Testing and Materials, Philadelphia, PA, 1992.

7. Hinsenveld, and P.L. Bishop, "Use of the shrinking core/exposure model to describe the leachability from cement stabilized wastes," in *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes,*, 3rd Volume, ASTM STP 1240, T. M. Gilliam, and C. C. Wiles (eds), American Society for Testing and Materials,, Philadelphia, PA, 1996.

8. D.E. Hockley, and H.A. van der Sloot, "Long-term Processes in a Stabilized Coal Waste Block Exposed to Seawater," *Environmental Science and Technology*, 25(8) 1408-1414, 1991.

9. NEN 7345, "Leaching Characteristics of Solid Earth and Stony Materials - Leaching Tests - Determination of the Leaching of Inorganic Constituents from Molded and Monolithic Materials with the Diffusion Test," *Dutch Standardization Institute*, Delft, The Netherlands, 1995.

10. ASTM D1557-07, "Standard Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))," *ASTM International*, West Conshohocken, PA,

11. ASTM D1308-95, "Standard Method for Accelerated Leach Test for Diffusive Releases from Solidified Waste and a Computer Program to Model Diffusive, Fractional Leaching from Cylindrical Waste Forms," *ASTM International*, West Conshohocken, PA, 2001.

12. D.S. Kosson, H.A. van der Sloot, F. Sanchez, and A.C. Garrabrants, "An Integrated Framework for Evaluating Leaching in Waste Management and Utilization of Secondary Materials," *Environmental Engineering Science*, 19(3) 159-204, 2002.

13. CEN/TS 15863, "Characterization of waste – Leaching Behaviour Tests – Dynamic Monolithic Leaching Test with Periodic Leachant Renewal," *Comité Européen de Normalisation*, Brussels, Belgium, 2009.

14. Sanchez, "Étude de la lixiviation de milieux poreux contenant des espèces solubles: Application au cas des déchets solidifiés par liants hydrauliques," doctoral thesis, Institut National des Sciences Appliquées de Lyon, Lyon, France, 1996.

15. ANSI/ANS 16.1, "American National Standard Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-term Test Procedure," *American Nuclear Society*, La Grange Park, IL, 1986.

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.

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

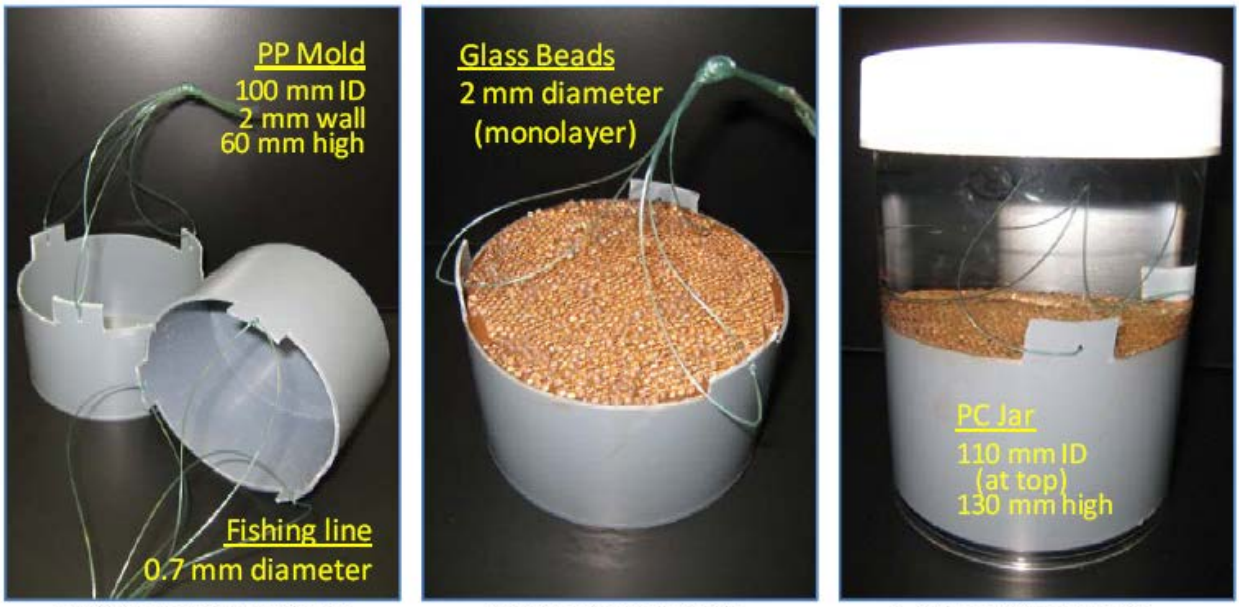
Empty Sample Holder

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

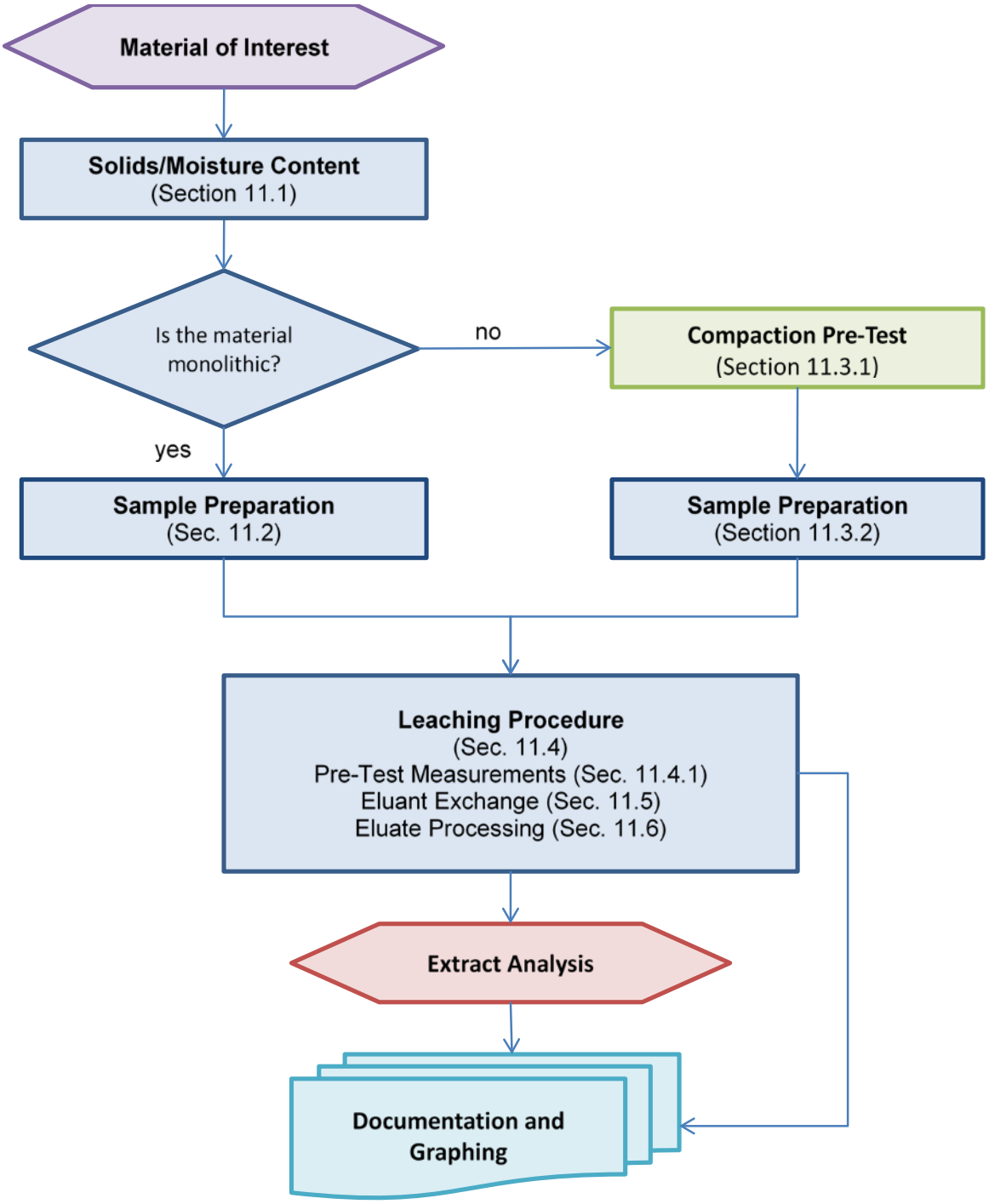


FIGURE 4

EXAMPLE CURVE OF PACKING DENSITY AS A FUNCTION OF MOISTURE CONTENT

$y = 55.975x^3 – 65.036x^2 + 1.8352$

$r^2 = 0.983$

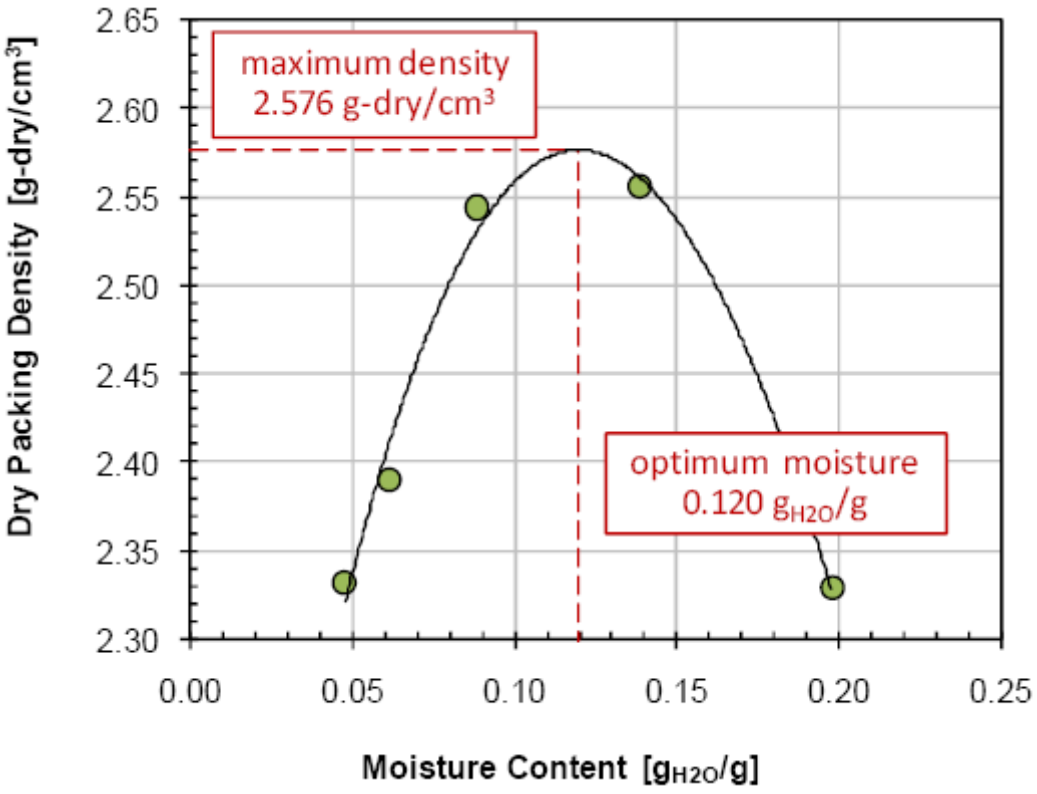


FIGURE 5

SCHEMATIC OF SEMI-DYNAMIC MASS TRANSFER TEST PROCESS

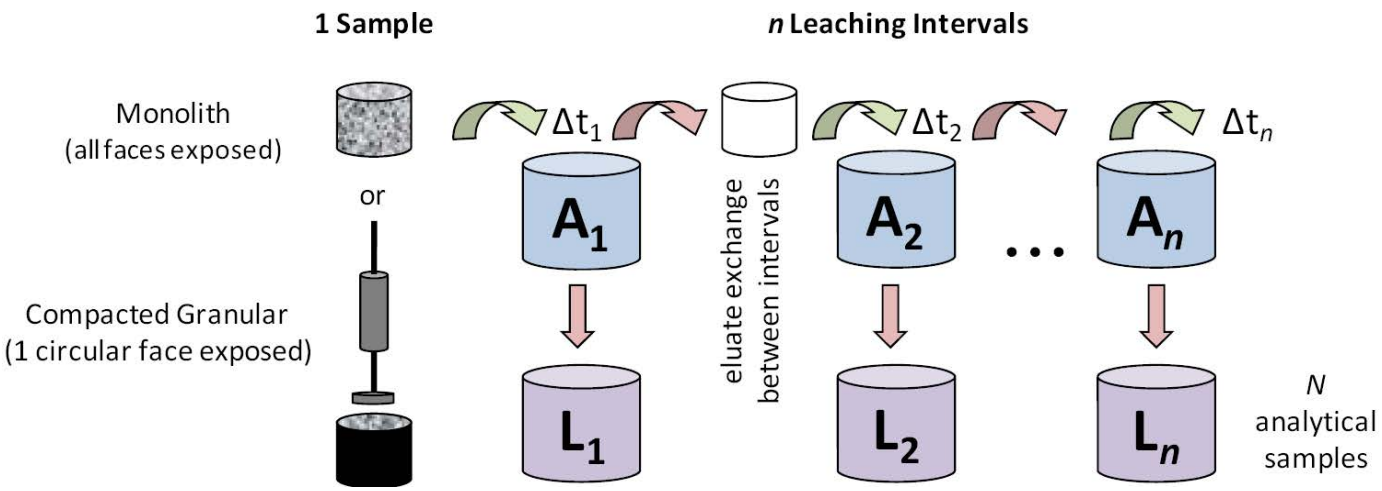
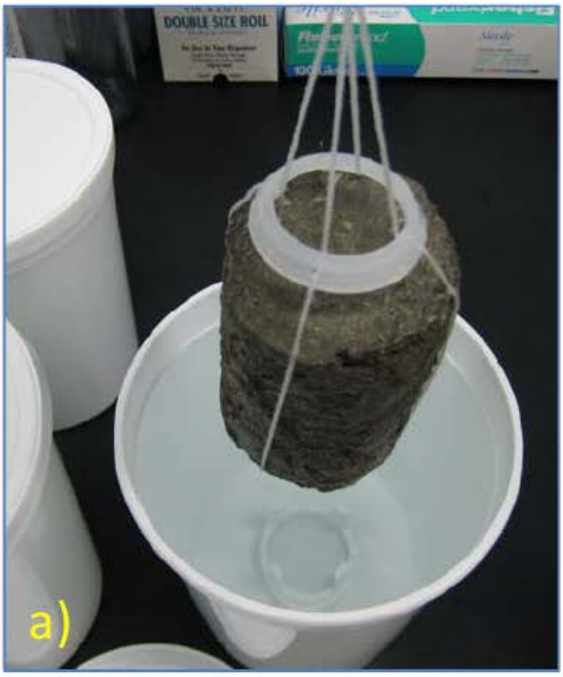


Figure obtained and modified from Ref. 1.

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

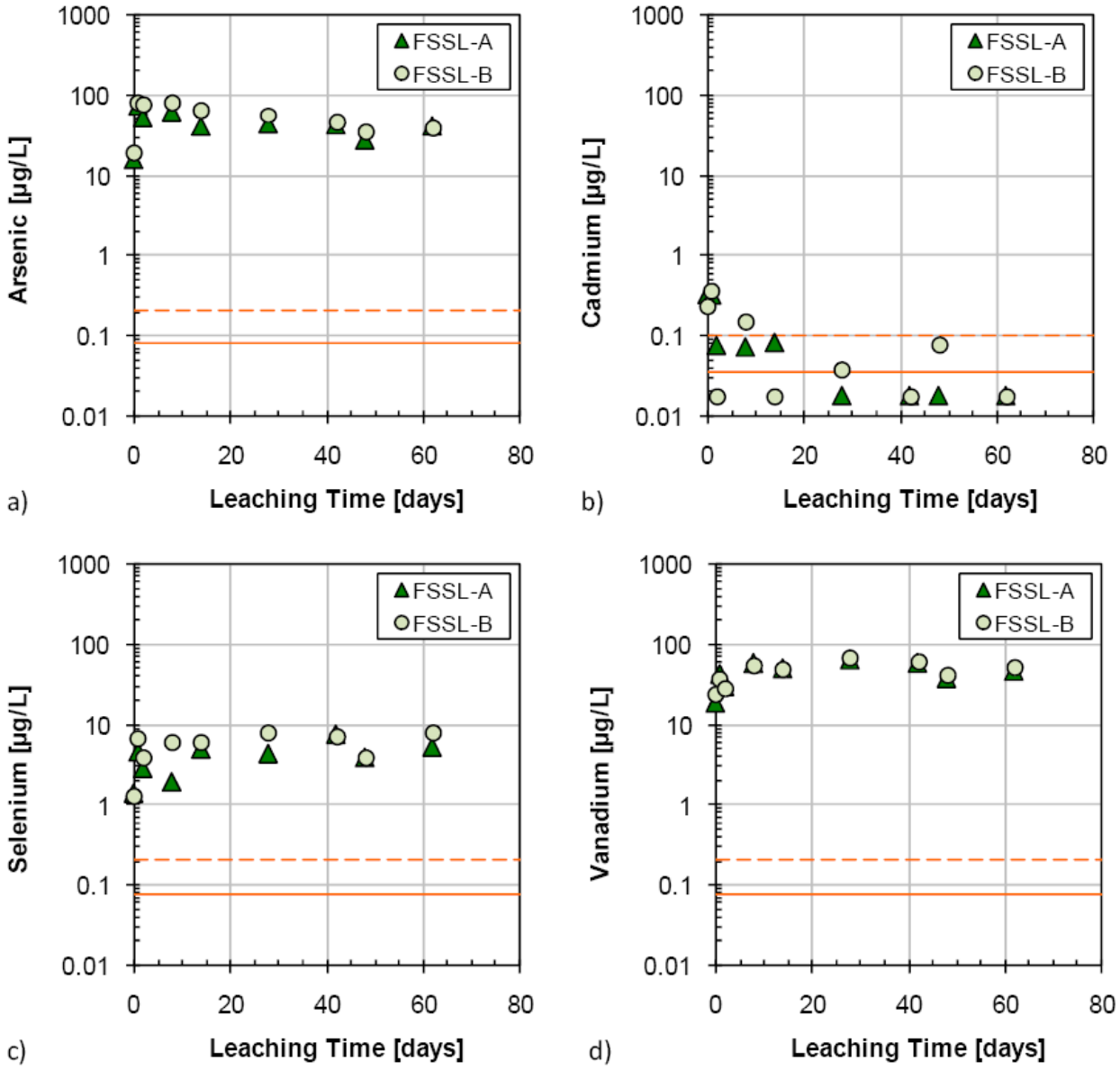
Test Position	Replicate	Value	Units	Method	Note
T02	A				
	Eluate Sample ID	**XYZ-1315-T02-A**			
	Exchange Date	11/1/20xx			
	Target Exchange Time	12:00	PM		
	Actual Exchange Time	12:18	PM		
	Mass of Sample & Holder	1027	g		
	Eluate Mass	725.0	g		
	Eluate pH	9.15	-	EPA 9040	
	Eluate Conductivity	2.8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

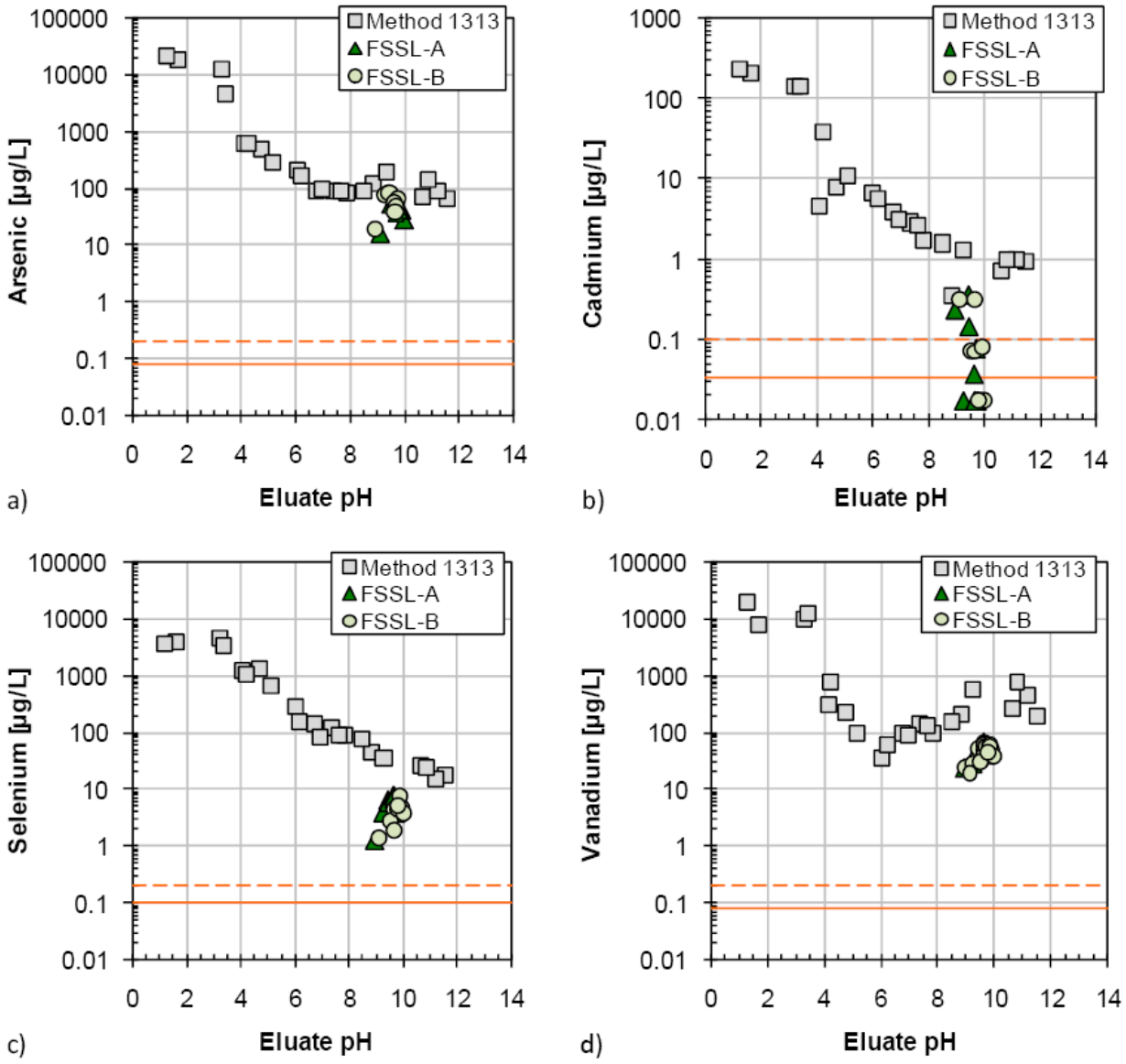
EXAMPLE INTERVAL CONCENTRATION GRAPHS



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

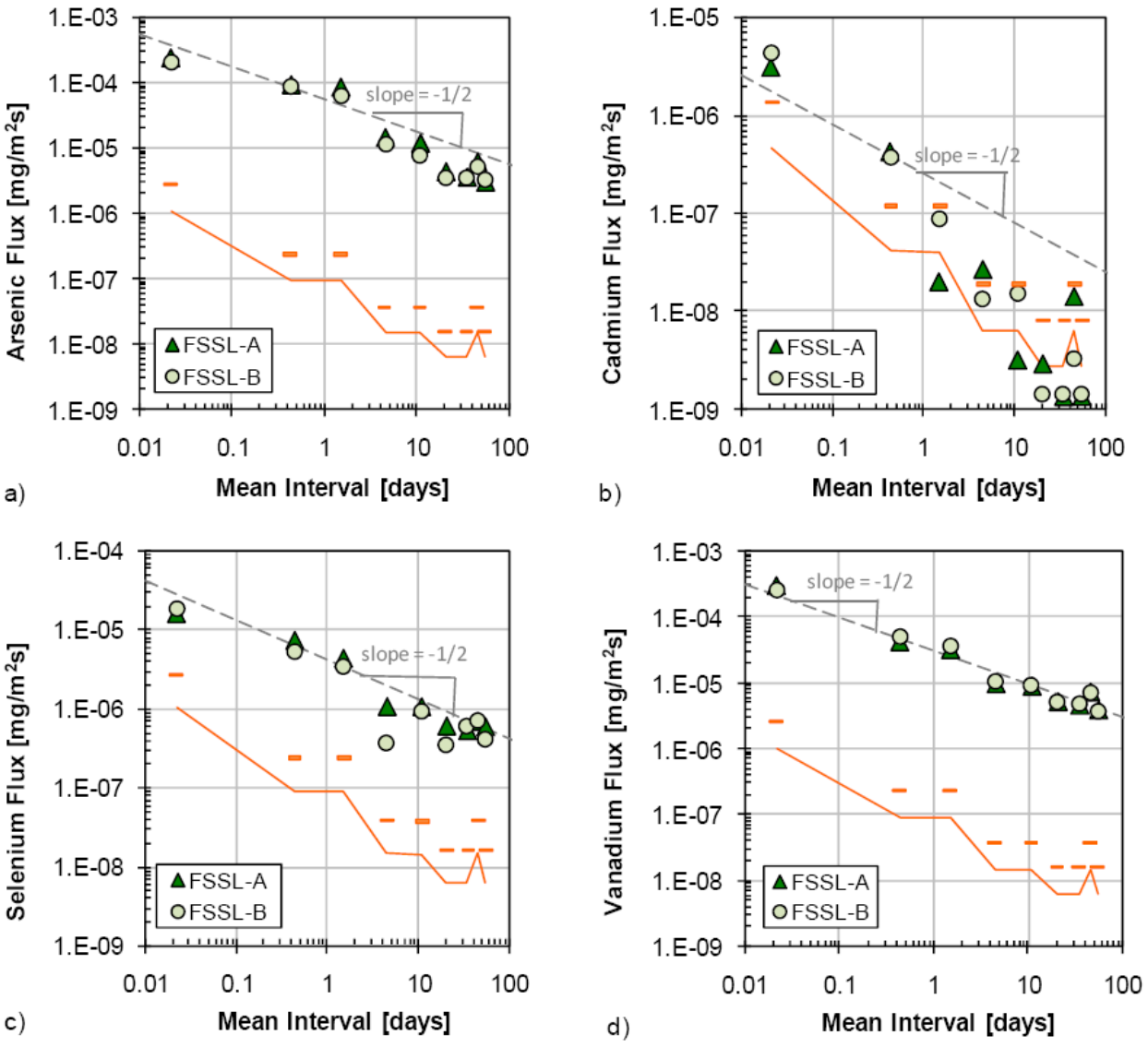
EXAMPLE OF SATURATION CHECK BETWEEN INTERVAL CONCENTRATIONS AND METHOD 1313 DATA



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

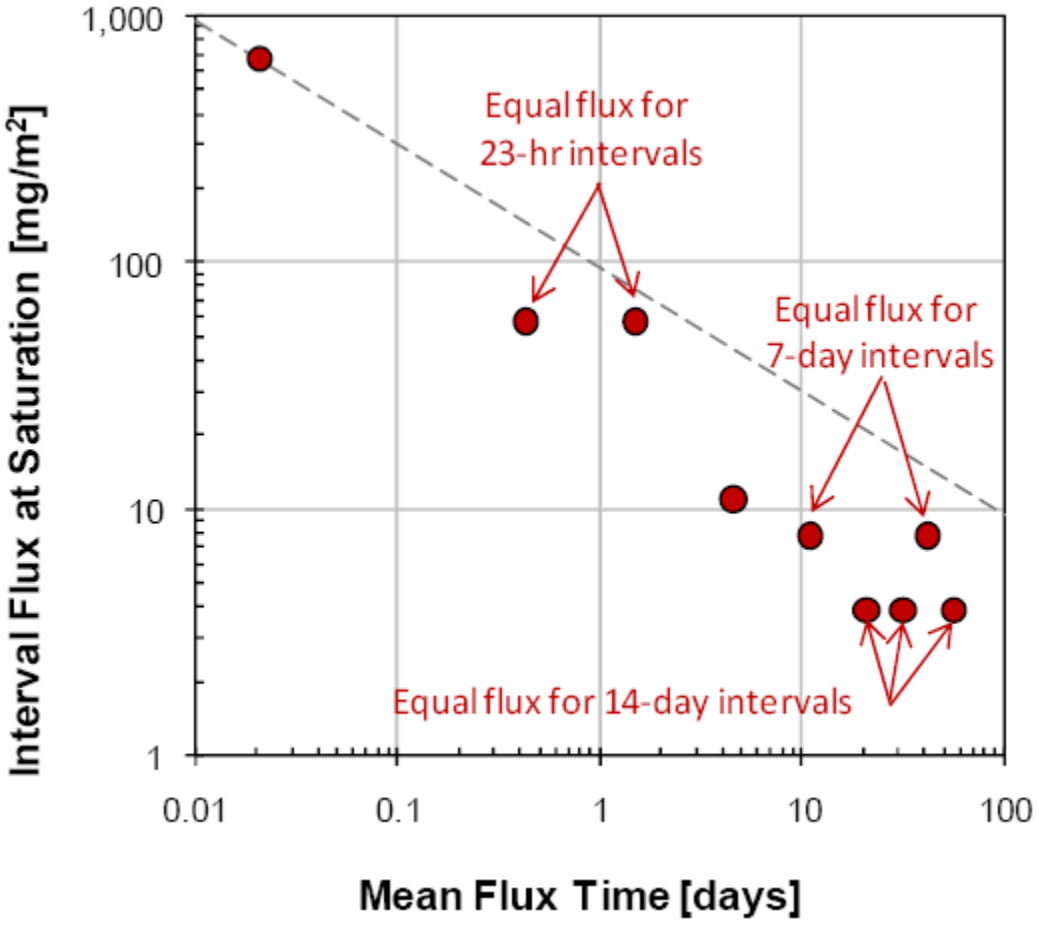
EXAMPLE INTERVAL FLUX GRAPHS



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

FIGURE 11

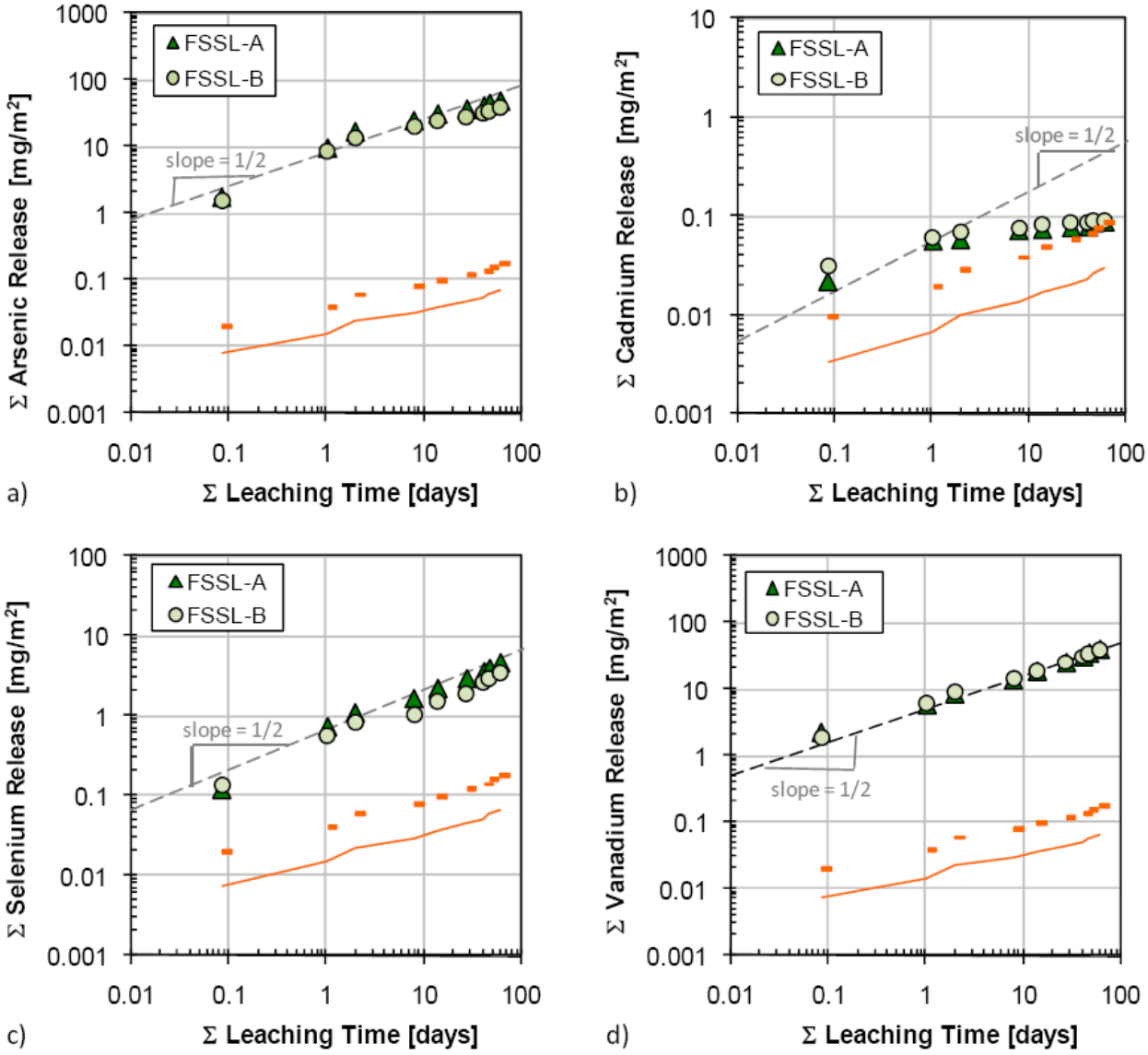
INTERVAL FLUX AT ELUATE SATURATION



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

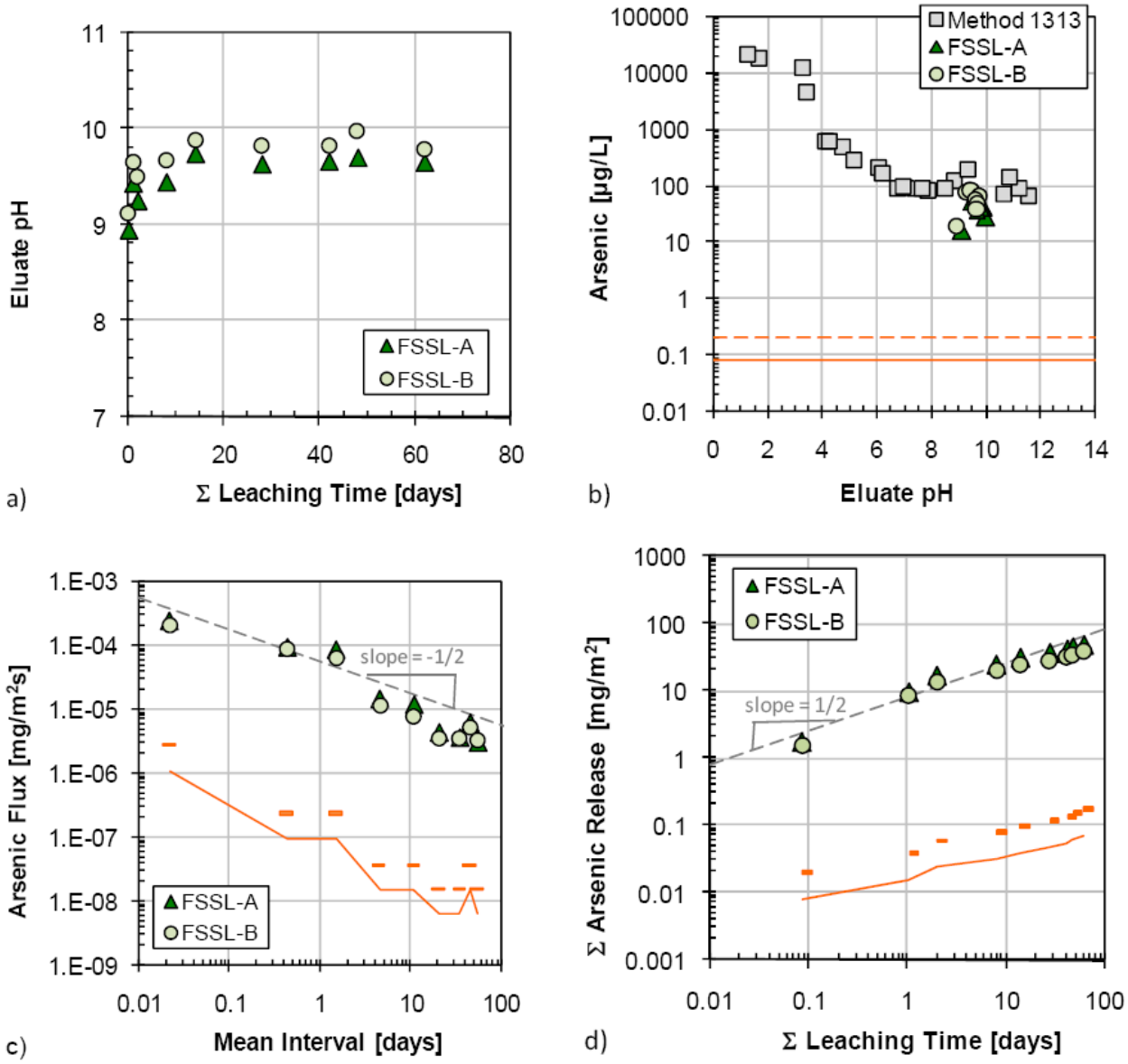
EXAMPLE CUMULATIVE RELEASE GRAPHS



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 5

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.

TABLE OF CONTENTS

1.0 SCOPE AND APPLICATION 2
2.0 SUMMARY OF METHOD 3
3.0 DEFINITIONS 4
4.0 INTERFERENCES 4
5.0 SAFETY 5
6.0 EQUIPMENT AND SUPPLIES 5
7.0 REAGENTS AND STANDARDS 6
8.0 SAMPLE COLLECTION, PRESERVATION, AND STORAGE 7
9.0 QUALITY CONTROL 7
10.0 CALIBRATION AND STANDARDIZATION 8
11.0 PROCEDURE 8
12.0 DATA ANALYSIS AND CALCULATIONS (EXCEL® TEMPLATE PROVIDED) 12
13.0 METHOD PERFORMANCE 13
14.0 POLLUTION PREVENTION 14
15.0 WASTE MANAGEMENT 14
16.0 REFERENCES 14
17.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA 15

[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

1. A.C. Garrabrants, D.S. Kosson, H.A. van der Sloot, F. Sanchez, and O. Hjelmar, "Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods," EPA/600/R-10-170, *U.S. Environmental Protection Agency*, Washington, DC, 2010.

2. A.C. Garrabrants, D.S. Kosson, L. Stefanski, R. DeLapp, P.F.A.B. Seignette, H.A. van der Sloot, P. Kariher, and M. Baldwin, "Interlaboratory Validation of the Leaching Environmental Assessment (LEAF) Method 1313 and Method 1316," EPA 600/R-12/623, *Environmental Protection Agency*, Washington DC, 2012.

3. D.S. Kosson, F. Sanchez, P. Kariher, L.H. Turner, R. DeLapp, and P. Seignette, "Characterization of Coal Combustion Residues from Electric Utilities – Leaching and Characterization Data," EPA-600/R-09/151, *U.S. Environmental Protection Agency*, Washington DC, 2009.

4. D.S. Kosson, H.A. van der Sloot, F. Sanchez, and A.C. Garrabrants, "An Integrated Framework for Evaluating Leaching in Waste Management and Utilization of Secondary Materials," *Environmental Engineering Science*, 19(3) 159-204, 2002.

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

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.

R0000087

FIGURE 1

METHOD FLOWCHART

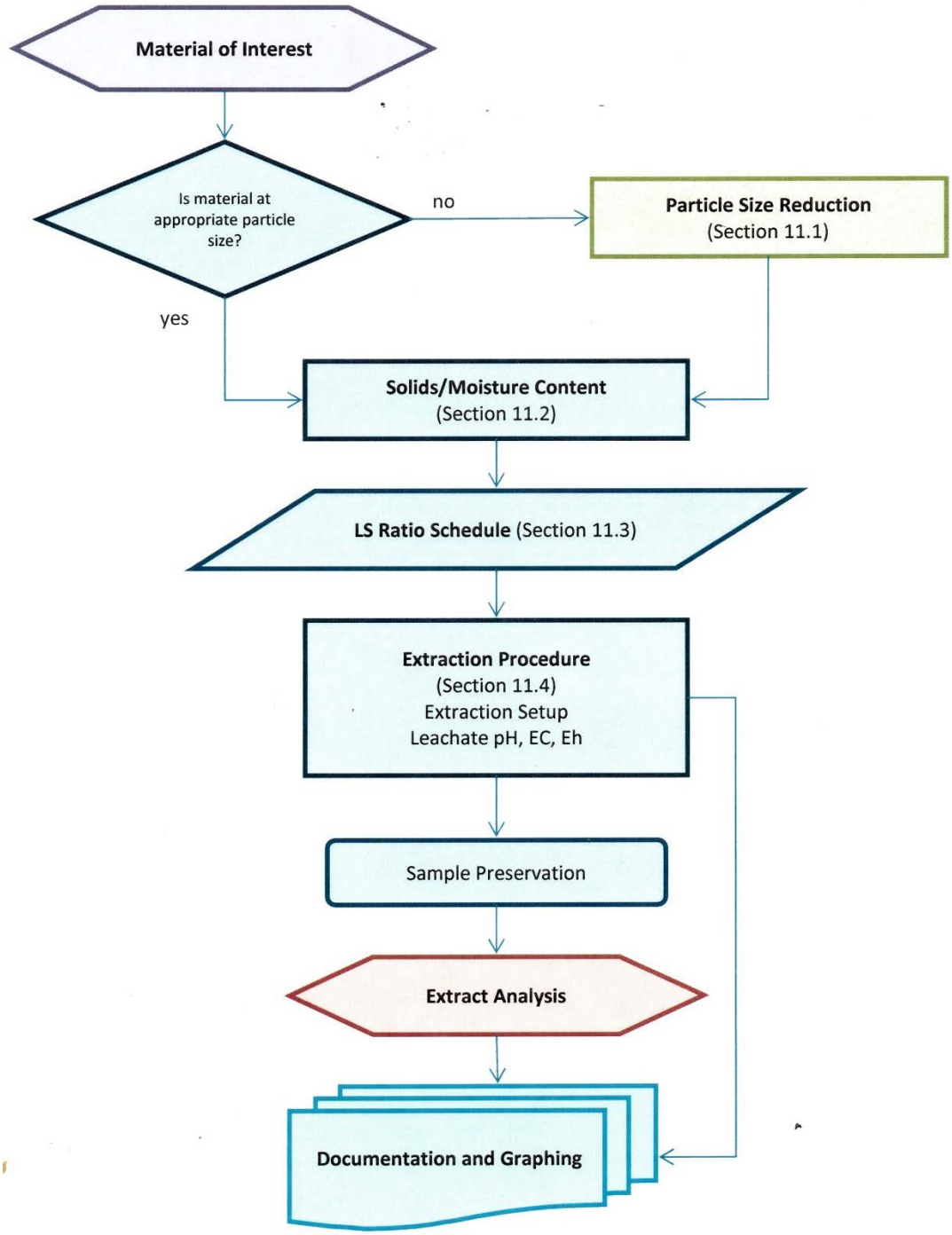


FIGURE 2

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

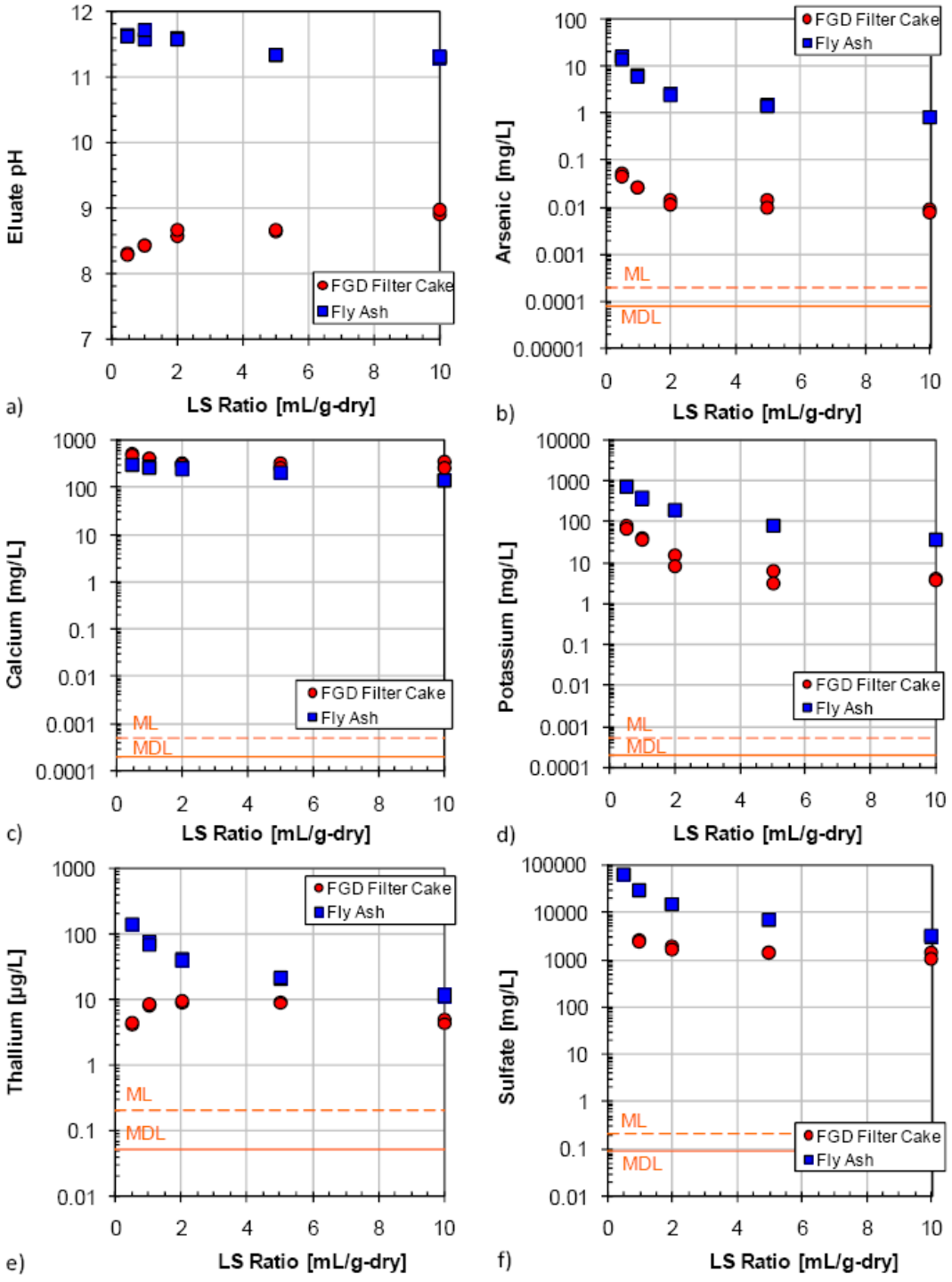
Test Position	Replicate	Value	Units	Method	Note
T02	**A**				
	Eluate Sample ID	**XYZ-1316-T02-A**			
	Solid Material	20.0	g		
	Moisture Content	0.01	g_{H_2O}/g		
	Water Added	400.0	mL		
	Target L/S	5.0	mL/g-		
	Eluate pH	3.86	–	EPA 9040	
	Eluate Conductivity	0.99	mS/cm	EPA 9050	
	Eluate ORP	180	mv		

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 6

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

The controlled version of this document is the electronic version viewed on-line only. If this is a printed copy of the document, it is an uncontrolled version and may or may not be the version currently in use.

This document contains direction developed solely to provide guidance to U.S. Environmental Protection Agency (EPA) personnel. EPA retains the discretion to adopt approaches that differ from these procedures on a case-by-case basis. The procedures set forth do not create any rights, substantive or procedural, enforceable at law by party to litigation with EPA or the United States.

Prepared by: ROBERT REINHART Digitally signed by ROBERT REINHART Date: 2017.09.19 16:15:38 -04'00'
(Robert Reinhart, Quality Assurance Unit) Date

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

Table of Contents

1.0 USE OF TERMS 4
2.0 SCOPE & APPLICATION 5
3.0 BACKGROUND FOR IMPLEMENTATION 6
4.0 HEALTH & SAFETY 7
5.0 CAUTIONS 7
6.0 PERSONNEL QUALIFICATIONS 9
7.0 EQUIPMENT AND SUPPLIES 9
8.0 EQUIPMENT/INSTRUMENT CALIBRATION 13
9.0 PRELIMINARY SITE ACTIVITIES (as applicable) 13
10.0 PURGING AND SAMPLING PROCEDURE 14
11.0 DECONTAMINATION 19
12.0 FIELD QUALITY CONTROL 21
13.0 FIELD LOGBOOK 21
14.0 DATA REPORT 22
15.0 REFERENCES 22
APPENDIX A 24
PERISTALTIC PUMPS 24
APPENDIX B 25
SUMMARY OF SAMPLING INSTRUCTIONS 25
Low-Flow Setup Diagram 29
APPENDIX C 30
WELL PURGING-FIELD WATER QUALITY MEASUREMENTS FORM 30

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).

U.S. Environmental Protection Agency, 1992, *RCRA Ground-Water Monitoring: Draft Technical Guidance*; Washington, DC (EPA/530-R-93-001).

U.S. Environmental Protection Agency, 1987, *A Compendium of Superfund Field Operations Methods*; Washington, DC (EPA/540/P-87/001).

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.

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.

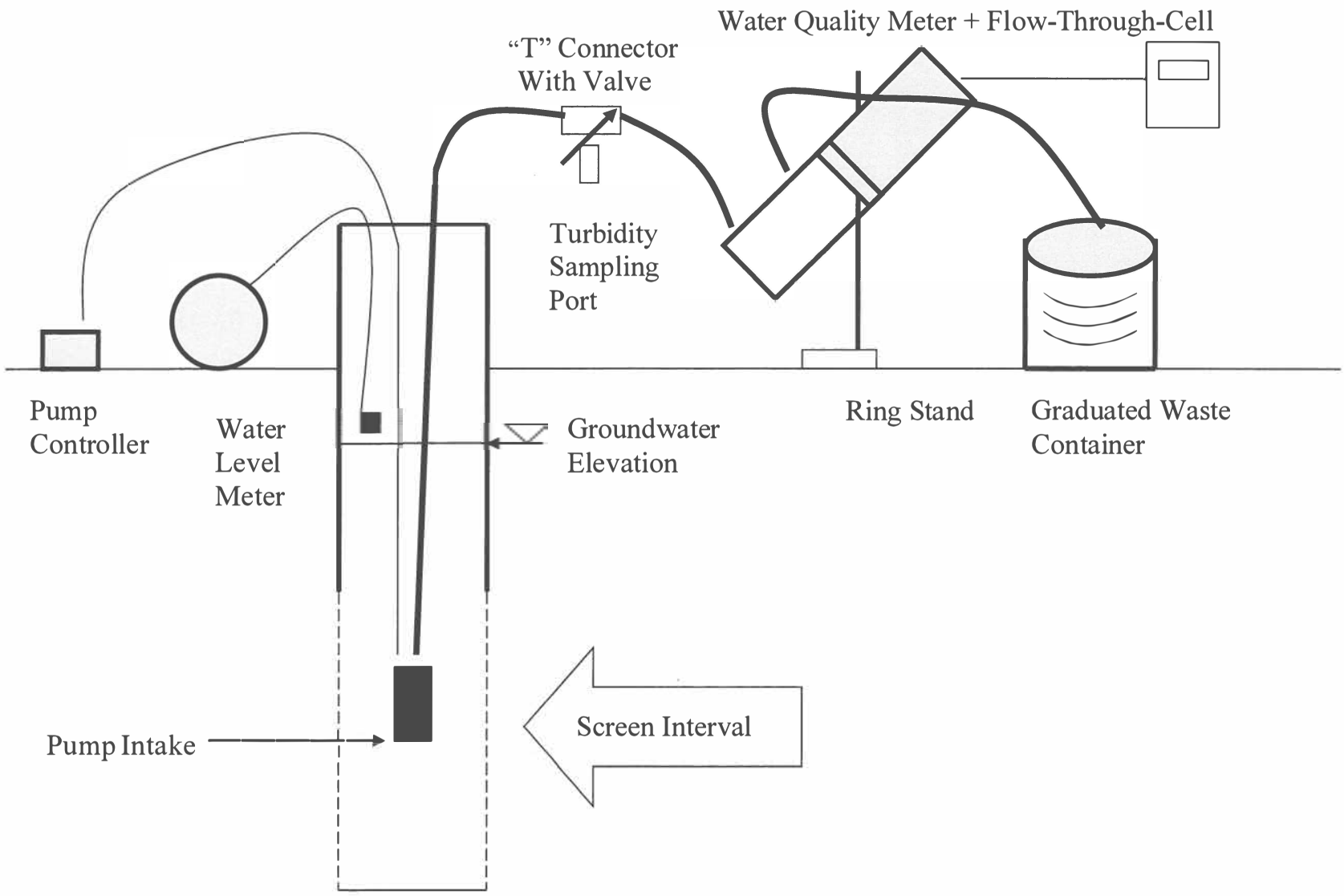
If the pump's tubing is not completely filled with water and the samples are being collected for VOCs and/or dissolved gases analyses using a centrifugal or peristaltic pump, do the following:

> 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



R000120

APPENDIX C

EXAMPLE (Minimum Requirements)

WELL PURGING-FIELD WATER QUALITY MEASUREMENTS FORM

Location (Site/Facility Name)_____
Well Number_____ Date_____
Field Personnel_____
Sampling Organization_____
Identify MP_____

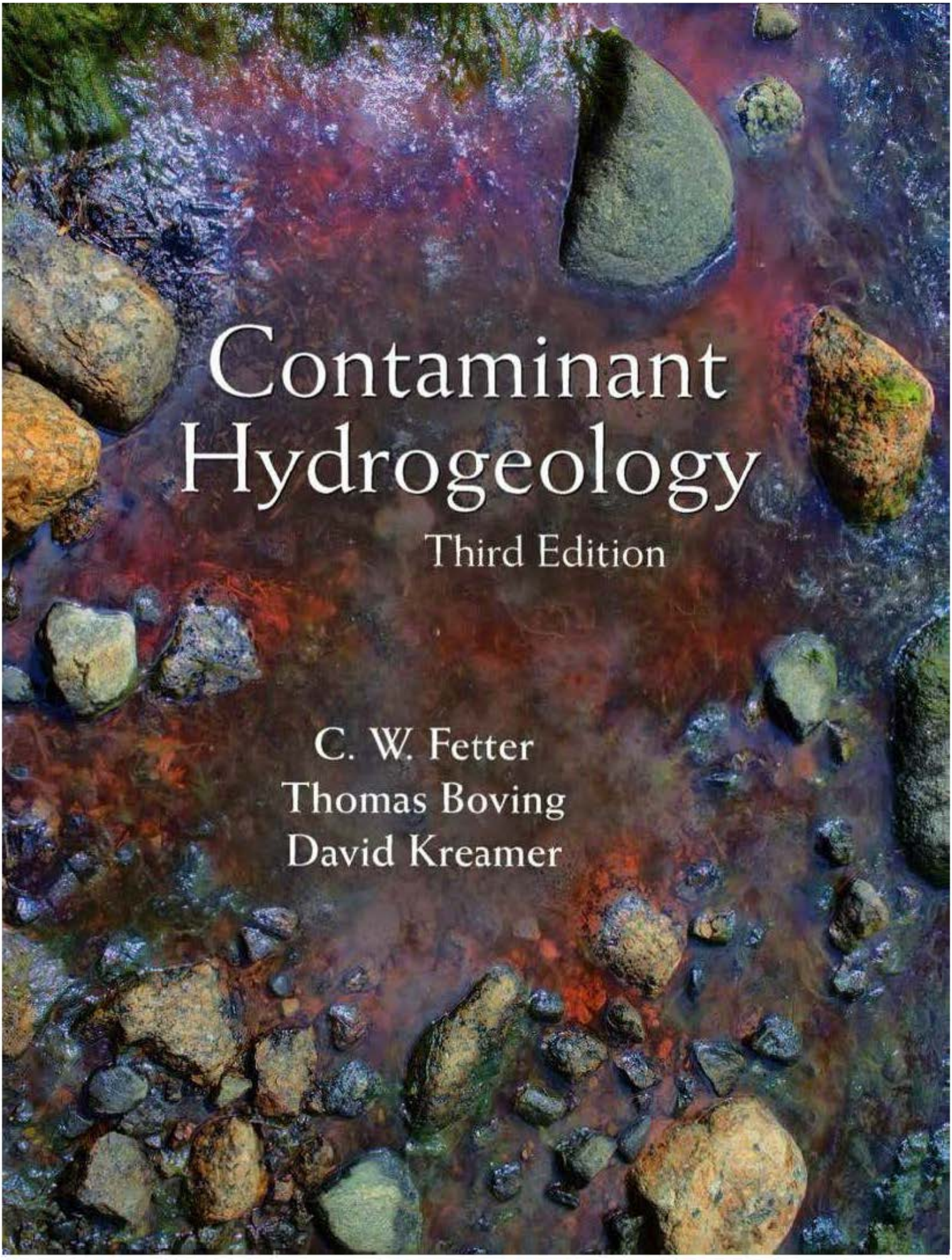
Depth to _____/_____ of screen
(below MP) top bottom
Pump Intake at (ft. below MP)_____
Purging Device; (pump type)_____
Total Volume Purged _____

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)

R000121

DOCUMENT 7


Contaminant
Hydrogeology
Third Edition
C. W. Fetter
Thomas Boving
David Kreamer

For information about this book, contact:
Waveland Press, Inc.
4180 IL Route 83, Suite 101
Long Grove, IL 60047-9580
(847) 634-0081
info@waveland.com
www.waveland.com

Copyright © 2018 by Nancy Fetter, Thomas Boving, and David Kreamer

10-digit ISBN 1-4786-3279-8
13-digit ISBN 978-1-4786-3279-5

All rights reserved. No part of this book may be reproduced, stored in a retrieval system, or transmitted in any form or by any means without permission in writing from the publisher.

Printed in the United States of America

7 6 5 4 3 2 1

Contents

Acknowledgements and Dedication xii
Preface xiii

1 Introduction 1
1.1 Groundwater as a Resource 1
1.2 Types of Groundwater Contaminants 3
1.3 DrinkingWater Standards 16
1.4 Risk and Drinking Water 17
1.5 Sources of Groundwater Contamination 24
1.5.1 Category I: Sources Designed to Discharge Substances 24
1.5.2 Category II: Sources Designed to Store, Treat and/or Dispose of Substances 28
1.5.3 Category III: Sources Designed to Retain Substances During Transport 35
1.5.4 Category IV: Sources Discharging Substances as a Consequence of Other Planned Activities 35
1.5.5 Category V: Sources Providing a Conduit for Contaminated Water to Enter Aquifers 38
1.5.6 Category VI: Naturally Occurring Sources Whose Discharge is Created and/or Exacerbated by Human Activity 39
1.6 Relative Ranking of Groundwater-Contamination Sources and Substances 40
1.7 Groundwater Contamination as a Long-Term Problem 42
1.8 Review of Mathematics and the Flow Equation 44
1.8.1 Derivatives 44
1.8.2 Darcy's Law 46
1.8.3 Scalar, Vector, and Tensor Properties of Hydraulic Head and Hydraulic Conductivity 47
1.8.4 Derivation of the Flow Equation in a Deforming Medium 49
1.8.5 Mathematical Notation 51
References 52
Problems 55

2 Mass Transport in Saturated Media 56
2.1 Introduction 56
2.2 Transport by Concentration Gradients 56
2.3 Transport by Advection 61
2.4 Mechanical Dispersion 63
2.5 Hydrodynamic Dispersion 65
2.6 Derivation of the Advection-Dispersion Equation for Solute Transport 66
2.7 Diffusion versus Dispersion 68
2.8 Moment Analysis 70
2.9 Analytical Solutions of the Advection-Dispersion Equation 75
2.9.1 Methods of Solution 75
2.9.2 Boundary and Initial Conditions 76
2.9.3 One-Dimensional Step Change in Concentration (First-Type Boundary) 77
2.9.4 One-Dimensional Continuous Injection into a Flow Field (Second-Type Boundary) 78
2.9.5 Third-Type Boundary Condition 82
2.9.6 One-Dimensional Slug Injection into a Flow Field 82
2.9.7 Continuous Injection into a Uniform Two-Dimensional Flow Field 83
2.9.8 Slug Injection into a Uniform Two-Dimensional Flow Field 88
2.10 Effects of Transverse Dispersion 92
2.11 Tests to Determine Dispersivity Values 93
2.11.1 Laboratory Tests 93
2.11.2 Quantifying Dispersivity in the Field 96
2.11.3 Single-Well Tracer Test 97
2.12 Scale Effect of Dispersion 98
2.13 Stochastic Models of Solute Transport 103
2.13.1 Introduction 103
2.13.2 Stochastic Descriptions of Heterogeneity 104
2.13.3 Stochastic Approach to Solute Transport 106
2.14 Regression Analysis of Relationship between Apparent Longitudinal Dispersivity and Field Scale 107
2.15 Deterministic Models of Solute Transport 109
2.16 Transport in Fractured Media 117
2.17 Summary 124
Chapter Notation 124
References 126
Problems 131

3 Transformation, Retardation, and Attenuation of Solutes 133
3.1 Introduction 133
3.2 Classification of Chemical Reactions 134

R000127

3.3 Sorption Processes 134
3.4 Equilibrium Surface Reactions 135
3.4.1 Linear Sorption Isotherm 135
3.4.2 Freundlich Sorption Isotherm 138
3.4.3 Langmuir Sorption Isotherm 140
3.4.4 BET Sorption 142
3.4.5 Polanyi–Dubinin–Manes (PDM) Sorption Isotherm 143
3.4.6 Effect of Equilibrium Retardation on Solute Transport 144
3.5 Nonequilibrium (Kinetic) Sorption Models 148
3.6 Sorption of Hydrophobic (Organic) Compounds 153
3.6.1 Introduction 153
3.6.2 Partitioning onto Soil or Aquifer Organic Carbon 154
3.6.3 Estimating K_{oc} from K_{ow} Data 155
3.6.4 Estimating K_{oc} from Solubility Data 156
3.6.5 Estimating K_{oc} from Molecular Structure 161
3.6.6 Quantitative Structure-Property Relationships 163
3.6.7 Multiple Solute Effects 165
3.7 Homogeneous Reactions 168
3.7.1 Introduction 168
3.7.2 Chemical Equilibrium 168
3.7.3 Chemical Kinetics 168
3.8 Radioactive Decay 170
3.9 Biodegradation 171
3.10 Colloidal Transport 176
3.10.1 Colloid Attachment/Detachment and Straining Theory 179
3.11 Summary 187
Chapter Notation 187
References 189
Problems 195

4 Flow and Mass Transport in the Vadose Zone 198
4.1 Introduction 198
4.2 Soil as a Porous Medium 199
4.3 Soil Colloids 200
4.4 The Electrostatic Double Layer 200
4.5 Salinity Effects on Hydraulic Conductivity of Soils 202
4.6 Flow of Water in the Unsaturated Zone 203
4.6.1 Soil-Water Potential 204
4.6.2 Soil-Water Characteristic Curves 204
4.6.3 Hysteresis 210
4.6.4 Construction of a Soil-Water-Retention Curve 211
4.6.5 Measurement of Soil-Water Potential 213
4.6.6 Unsaturated Hydraulic Conductivity 214
4.6.7 Buckingham Flux Law 218
4.6.8 Richards Equation 219

4.7 Liquid Mass Transport in the Unsaturated Zone 220
4.8 Equilibrium Models of Mass Transport 221
4.9 Nonequilibrium Models of Mass Transport 224
4.10 Anion Exclusion 225
4.11 Preferential Flowpaths in the Vadose Zone 229
4.12 Vapor Phase Transport 233
4.12.1 Gaseous Diffusion 233
4.12.2 Gaseous Advection 238
4.12.3 Effusion (Knudsen flow) 239
4.12.4 Combinations of Vapor Transport Processes 239
4.12.5 Other Environmental Factors 239
4.13 Summary 241
Chapter Notation 241
References 243
Problems 246

5 Multiphase Flow **247**
5.1 Introduction 247
5.2 Basic Concepts 248
5.2.1 Saturation Ratio 248
5.2.2 Interfacial Tension and Wettability 249
5.2.3 Capillary Pressure 250
5.2.4 Relative Permeability 253
5.2.5 Darcy's Law For Two-Phase Flow 257
5.2.6 Fluid Potential and Head 258
5.3 Migration of Light Nonaqueous Phase Liquids (LNAPLs) 262
5.4 Capillary and Bond Numbers 267
5.5 Partitioning Interwell Tracer Tests 269
5.6 Volatilization of NAPLs 271
5.7 Vapor Density 277
5.8 Measurement of the Thickness of a Floating Product 278
5.9 Effect of the Rise and Fall of the Water Table on the Distribution of LNAPLs 287
5.10 Migration of Dense Nonaqueous Phase Liquids (DNAPLs) 290
5.10.1 Relative Mobility 290
5.10.2 Vadose Zone Migration 292
5.10.3 Vertical Movement in the Saturated Zone 294
5.10.4 Horizontal Movement in the Saturated Zone 296
5.10.5 DNAPL Flow in Fracture Systems 301
5.10.6 Dissolution of DNAPL 303
5.11 Monitoring for LNAPLs and DNAPLs 305
5.12 Summary 308
Chapter Notation 309
References 310
Problems 315

R000129

6 Inorganic Chemicals in Groundwater 316

6.1 Introduction 316
6.2 Units of Measurement and Concentration 316
6.3 Chemical Equilibrium and the Law of Mass Action 317
6.4 Oxidation-Reduction Reactions 320
6.5 Relationship between pH and Eh 323
6.5.1 pH 323
6.5.2 Relationship of Eh and pH 325
6.5.3 Eh-pH Diagrams 326
6.5.4 Calculating Eh-pH Stability Fields 328
6.6 Metal Complexes and Facilitated Particle Transport 338
6.6.1 Hydration of Cations 338
6.6.2 Complexation 339
6.6.3 Organic Complexing Agents 341
6.6.4 Facilitated Particle Transport 341
6.7 Chemistry of Nonmetallic Inorganic Contaminants 343
6.7.1 Fluoride 343
6.7.2 Chlorine and Bromine 344
6.7.3 Sulfur 344
6.7.4 Nitrogen 346
6.7.5 Arsenic 347
6.7.6 Selenium 348
6.7.7 Phosphorus 350
6.8 Chemistry of Metals 350
6.8.1 Beryllium 350
6.8.2 Strontium 350
6.8.3 Barium 351
6.8.4 Vanadium 351
6.8.5 Chromium 351
6.8.6 Cobalt 353
6.8.7 Nickel 353
6.8.8 Molybdenum 353
6.8.9 Copper 354
6.8.10 Silver 354
6.8.11 Zinc 354
6.8.12 Cadmium 354
6.8.13 Mercury 356
6.8.14 Lead 356
6.8.15 Rare Earth Elements 358
6.9 Radioactive Isotopes 358
6.9.1 Introduction 358
6.9.2 Adsorption of Cationic Radionuclides 359
6.9.3 Uranium 360
6.9.4 Thorium 363
6.9.5 Radium 364

R000130

6.9.6 Radon 367
6.9.7 Tritium 368
6.10 Geochemical Zonation 368
6.11 Summary 371
Chapter Notation 372
References 372
Problems 375

7 Organic Compounds in Groundwater 376
7.1 Introduction 376
7.2 Physical Properties of Organic Compounds 376
7.3 Organic Structure and Nomenclature 378
7.3.1 Hydrocarbon Classes 378
7.3.2 Aromatic Hydrocarbons 382
7.4 Petroleum and Coal Tar 383
7.4.1 Petroleum Distillates 383
7.4.2 Coal Tar 389
7.4.3 Groundwater contamination associated with petroleum products and coal tar 390
7.5 Functional Groups 395
7.5.1 Organic Halides 395
7.5.2 Alcohols 395
7.5.3 Ethers 395
7.5.4 Aldehydes and Ketones 399
7.5.5 Carboxylic and Sulfonic Acids 400
7.5.6 Esters 402
7.5.7 Phenols 404
7.5.8 Organic Compounds Containing Nitrogen 405
7.5.9 Organic Compounds Containing Sulfur and Phosphorus 408
7.5.10 Emerging Contaminants 410
7.6 Degradation of Organic Compounds 415
7.6.1 Introduction 415
7.6.2 Degradation of Hydrocarbons 415
7.6.3 Degradation of Chlorinated Hydrocarbons 418
7.6.4 Degradation of Organic Pesticides 425
7.6.5 Degradation of Gasoline Compounds 427
7.7 Field Studies of Biological Degradation of Organic Molecules 428
7.8 Analysis of Organic Compounds in Groundwater 428
7.9 Fingerprinting Petroleum Distillates and Coal Tar 434
7.10 Summary 442
References 442
Problems 447

R000131

8 Site Characterization—Groundwater and Soil Monitoring 450
8.1 Introduction 450
8.2 Noninvasive Measures 452
8.2.1 Interpretation of Aerial Photography and Remote Sensing 452
8.2.2 The Use of Surface Geophysical Techniques for Site Characterization 453
8.2.3 Rapid Noninvasive Field Surveys and Screening 455
8.3 Minimally Invasive Soil Monitoring 456
8.3.1 Soil Vapor Monitoring—Introduction 456
8.3.2 Methods of Soil Gas Monitoring 457
8.3.3 Soil Water Sampling—Introduction 458
8.3.4 Suction Lysimeters 458
8.3.5 Installation of Suction Lysimeters 460
8.3.6 Phytoscreening 461
8.4 Invasive Methods - Monitoring Well Design 462
8.4.1 General Information 462
8.4.2 Monitoring Well Casing 464
8.4.3 Monitoring Well Screens 472
8.4.4 Naturally Developed and Filter-Packed Wells 473
8.4.5 Annular Seal 474
8.4.6 Protective Casing 475
8.4.7 Screen Length and Setting 476
8.4.8 Summary of Monitoring Design for Single Screened Wells 479
8.4.9 Multiple-level Wells and Multilevel Devices for Groundwater Monitoring 479
8.5 Installation of Monitoring Wells 485
8.5.1 Decontamination Procedures 485
8.5.2 Methods of Drilling 486
8.5.3 Drilling in Contaminated Soil 494
8.5.4 Sample Collection of Solid Material During Drilling 494
8.5.5 Installation of Monitoring Wells 498
8.5.6 Monitoring Well Development 503
8.5.7 Record Keeping During Monitoring Well Construction 507
8.5.8 Monitoring Well and Borehole Abandonment 507
8.6 Well Sampling 509
8.6.1 Introduction 509
8.6.2 Fluid Level and Pressure Measurement 509
8.6.3 Well Purging 510
8.6.4 Well-Sampling Devices 510
8.6.5 Methods of Collecting a Groundwater Sample Without Drilling a Well 514
8.6.6 Low-Flow Purging of Monitoring Wells 516
8.6.7 Sampling Frequency 518

8.7 Other Site Characterization Methods and Groundwater Contamination Forensics 519
8.7.1 Introduction 519
8.7.2 Borehole Geophysics and Downhole Techniques 520
8.7.3 Water Quality Indicators of Groundwater Provenance and Movement—Tracers 522
8.7.4 Water Quality Indicators of Groundwater Provenance and Movement—Groundwater Composition, Compound Ratios, Daughter Products, Degradation Indicators, and Other Indicator Compounds 526
8.7.5 Water Quality Indicators of Groundwater Provenance and Movement—Isotopic Identification of Pollution Sources and Groundwater Pathways 529
8.7.6 Water Quality Indicators of Groundwater Condition—Microbial testing and Genome Sequencing 532
8.8 Summary 534
References 535
Problem 542

9 Site Remediation 543
9.1 Introduction 543
9.2 Source-Control Measures 545
9.2.1 Solid Waste 545
9.2.2 Removal and Disposal 546
9.2.3 Containment 547
9.2.4 Hydrodynamic Isolation 552
9.3 Pump-and-Treat Systems 555
9.3.1 Overview 555
9.3.2 Capture Zones 562
9.3.3 Computation of Capture Zones 563
9.3.4 Optimizing Withdrawal-Injection Systems 563
9.3.5 Permanent Plume Stabilization 566
9.4 Treatment of Extracted Groundwater 568
9.4.1 Overview 568
9.4.2 Treatment of Inorganic Contaminants 569
9.4.3 Treatment of Dissolved Organic Contaminants 570
9.5 Recovery of Nonaqueous Phase Liquids 572
9.6 Removal of Leaking Underground Storage Tanks 576
9.7 Soil Vapor Extraction (SVE) 578
9.8 Air Sparging and Bioslurping 583
9.9 Combination Methods 584
9.10 Bioremediation 589
9.10.1 Introduction 589
9.10.2 Monitored Natural Attenuation 590
9.10.3 Enhanced Bioremediation 592

R000133

9.11 Conceptual Site Models 598
9.12 Permeable Reactive Barriers 599
9.13 Chemically-Enhanced *In Situ* Flushing 606
9.13.1 Surfactant Enhanced *In Situ* Flushing 607
9.13.2 Cosolvent Enhanced *In Situ* Flushing 609
9.13.3 Complexing Agent Enhanced *In Situ* Flushing 610
9.14 *In Situ* Thermal Treatment (ISTT) 612
9.15 *Insitu* Chemical Oxidation (ISCO) 614
9.16 Phytoremediation 616
9.17 Summary 618
Chapter Notation 620
References 620

Appendix A
Error Function Values **629**

Appendix B
Bessel Functions **630**

Appendix C
W(t_D, B) Values **633**

Appendix D
Exponential Integral **635**

Appendix E
Unit Abbreviations **636**

Index **637**
About the Authors **647**

R000134

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)

R000135

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)

R000136

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)

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.

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!

R000139

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

R000140

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 unconrained mine wastes is a threat to surface and groundwater.

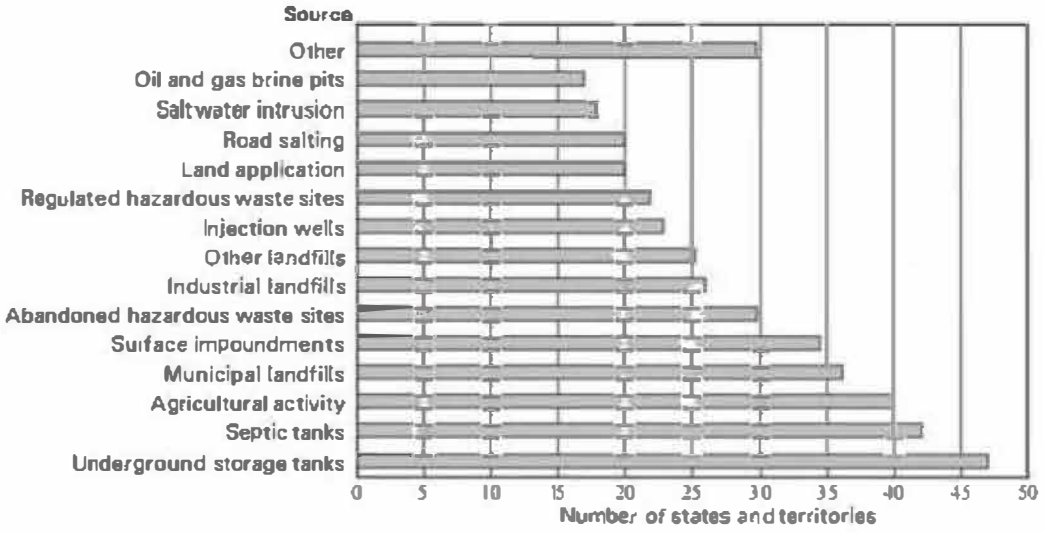
In some cases, *in situ* leach mining is used instead of physical removal of ore-containing rock. In these instances, a chemical mobilizing agent called a lixiviant is pumped down a well where it flows into an ore-bearing formation. After ore is dissolved, the pregnant solution circulating underground 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

R000142

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)/

R000143

FIGURE 1.4 Graph of distance traveled versus time graphically showing speed, which is the first derivative of distance with respect to time.

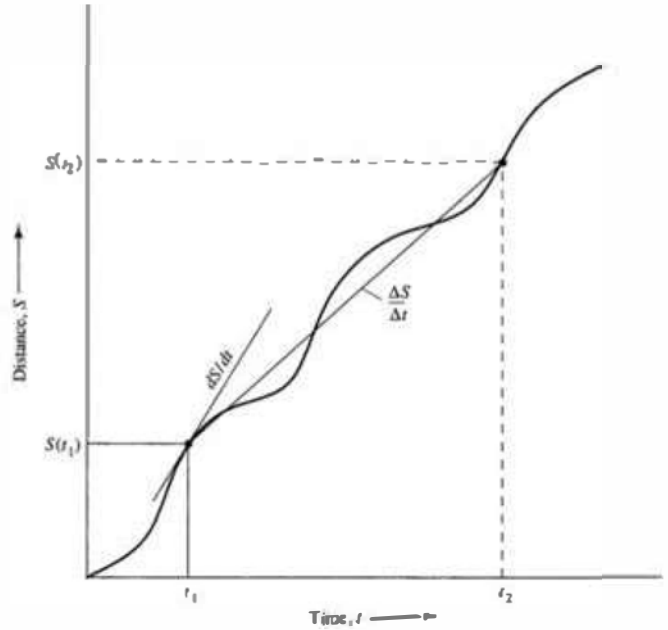
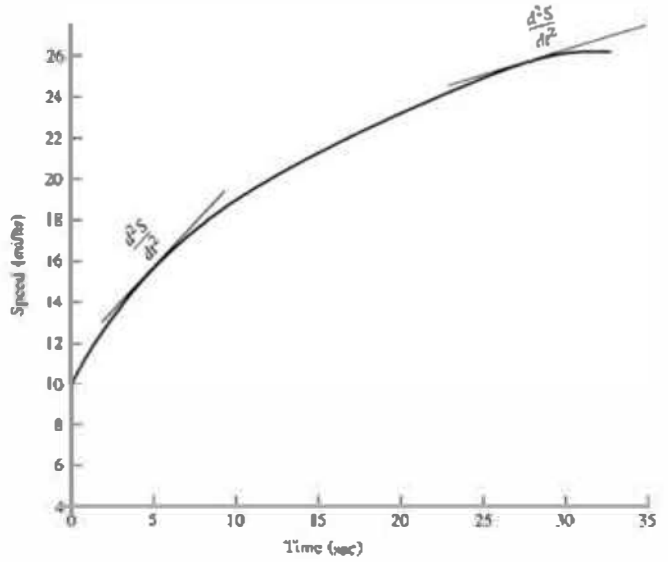


FIGURE 1.5 Graph of speed versus time graphically showing acceleration, which is the second derivative of distance with respect to time.



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

R000144

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

R000145

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

R000147

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:

$$\nabla \cdot v = \text{div}\, v = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \tag{1.15}$$

If we apply the del operator to grad h, the result is the second derivative of head:

$$\nabla \cdot \text{grad}\, h = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} \tag{1.16}$$

1.8.4 Derivation of the Flow Equation in a Deforming Medium

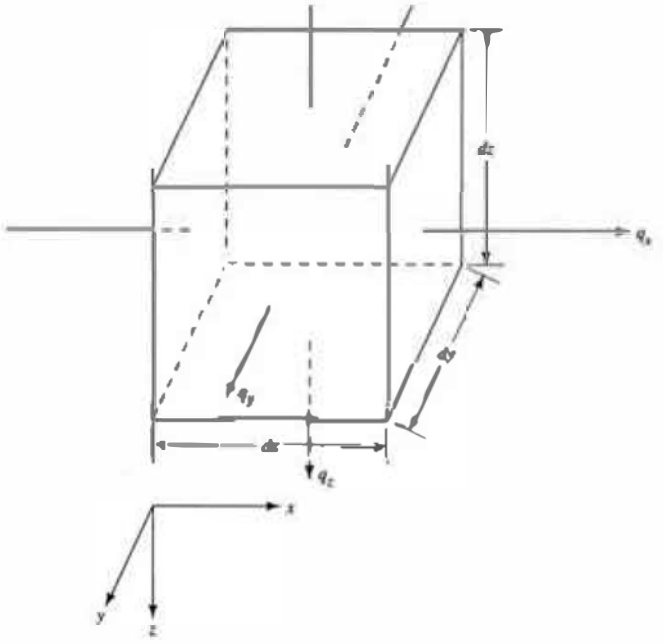
The law of mass conservation states that there can be no net change in the mass of fluid in a small representative elementary volume (REV) of a porous medium. In other words, the mass entering the REV less the mass leaving the REV is equal to the change in mass storage with time.

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

p_w = fluid density (M/L^3)

q_x = specific discharge or volume of flow per cross-sectional 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:

$$\text{Mass outflow rate parallel to } x \text{ axis} = \left[p_w q_x + \frac{\partial (p_w q_x) dx}{\partial x} \right] dy\,dz \qquad (1.18)$$

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

$$\frac{-\partial (p_w q_x) dx\,dy\,dz}{\partial x}$$

Similar terms exist for the net mass accumulation due to flow components parallel to the y and z axes:

$$\frac{-\partial (p_w q_y) dy\,dx\,dz}{\partial y}$$

$$\frac{-\partial (p_w q_z) dz\,dx\,dy}{\partial z}$$

These three terms can be summed to find the total net mass accumulation within the control volume

$$-\left[\left(\frac{\partial}{\partial x}(p_w q_x) + \frac{\partial}{\partial y}(p_w q_y) + \frac{\partial}{\partial z}(p_w q_z) \right) \right] dx\,dy\,dz \qquad (1.19)$$

The mass of water in the REV, M, is the density of water, p_w, times the porosity, n, times the volume, $dx\,dy\,dz$. The change in mass with respect to time is

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial t}(p_w n dx dy dz) \qquad (1.20)$$

From the law of conservation of mass, Equation 1.19 must equal Equation 1.20.

$$-\left[\frac{\partial}{\partial x}(p_w q_x) + \frac{\partial}{\partial y}(p_w q_y) + \frac{\partial}{\partial z}(p_w q_z) \right] dx\,dy\,dz = \frac{\partial}{\partial t}(p_w n)\,dx\,dy\,dz \qquad (1.21)$$

* 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.

R000149

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

R000150

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

$$q = K \cdot \text{grad}\, h \tag{1.31}$$

$$q = K \cdot h \tag{1.32}$$

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.

References

Agency for Toxic Substances and Disease Registry (ATSDR). 2015) Priority List of Hazardous Substances. Available from https://www.atsdr.cdc.gov/spl/#modalIdString_myTable2015

Alavanja, M. C. R. 2009. Pesticides use and exposure extensive worldwide. *Reviews on Environmental Health* 24:303-309.

American Cancer Society. 2015. Cancer Facts & Figures 2014. Accessed August 21, 2015 from http://water.epa.gov/drink/contaminants/index.cfm#List

American Water Resources Association 1975. Status of water borne diseases in the US and Canada. *Journal of American Water Works Association* 67:95-98.

Ames, B. N., L. S. Gold, and W. C. Willett. 1995. The causes and prevention of cancer. *Proceedings of the National Academy of Science* 92:5258-5265.

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)

R000152

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/L^3)

dC/dx = concentration gradient ($M/L^3/L$)

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 ($M/L^3/T$).

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 not 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)

$$D^* = \frac{\sigma_c^2}{2t} \tag{2.4}$$

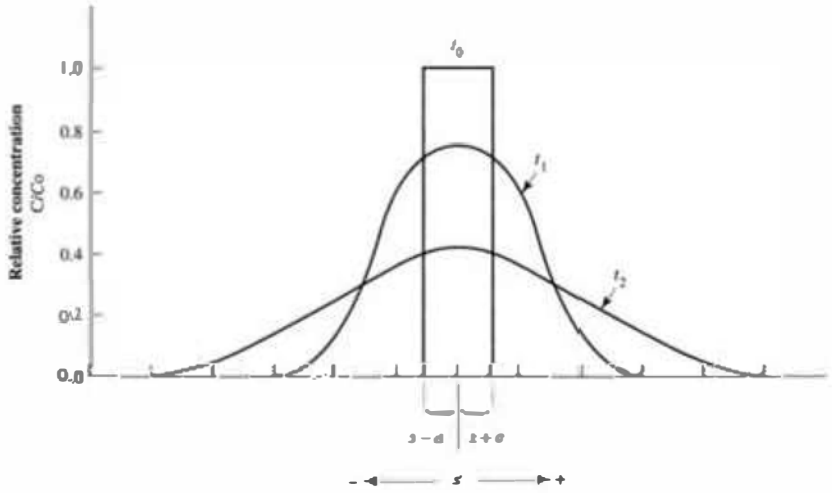
This is an alternative definition of effective diffusion coefficient to the one given in Equation 2.3.

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

R000154

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, $C_t(x, t)$, 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.

$$C_t(x,t) = C_0 \operatorname{erfc} \frac{x}{2(D^* t)^{0.5}} \tag{2.5}$$

where

C_t = the concentration at distance x from the source at time t since diffusion began

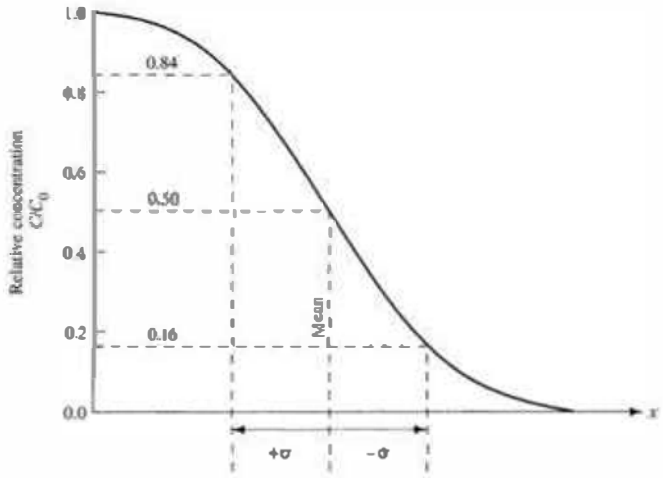
C_0 = the original concentration, which remains a constant

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.

R000156

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:

$$\frac{C_i}{C_0} = \text{erfc} \frac{5}{2(5 \times 10^{-10}\text{m}^2/\text{sec} \times 3.15 \times 10^9\ \text{sec})^{0.5}}$$

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:

$$F_x = v_x n_e C \tag{2.7}$$

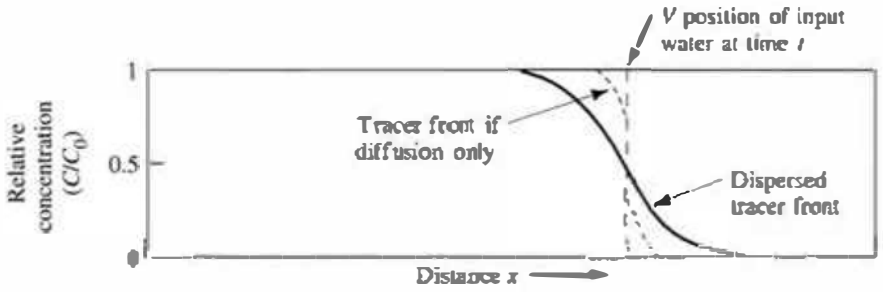
The one-dimensional advective transport equation is

$$\frac{\partial C}{\partial t} = -v_x \frac{\partial C}{\partial x} \tag{2.8}$$

(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

R000158

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 $\times$ 1/1 000 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

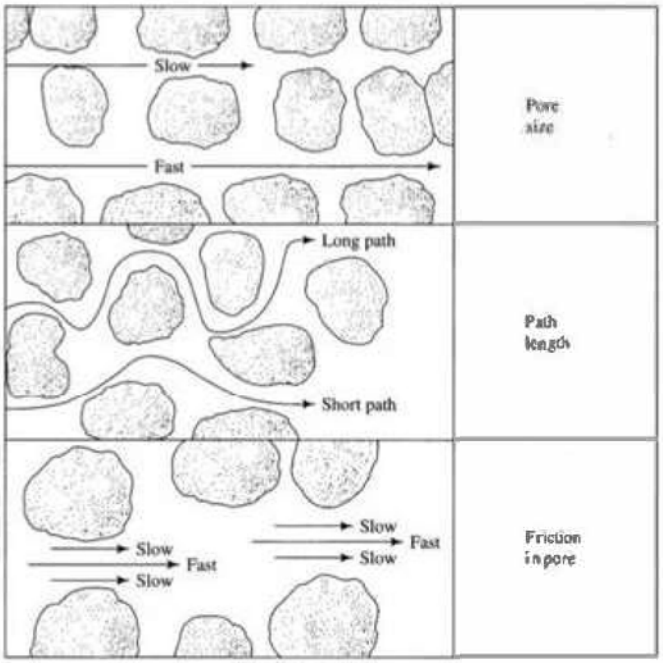
Groundwater is moving at rates that are both greater and less than the average linear velocity. At the macroscopic scale—that is, over a domain including a sufficient volume that the effects of individual pores are averaged (Bear 1972)—there are three basic causes of this phenomenon: (1) As fluid moves 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**.

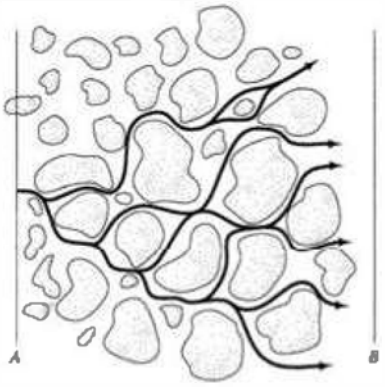
If we assume that mechanical dispersion can be described by Fick's law for diffusion (Equations 2.1 and 2.2) and that the amount of mechanical dispersion is a function of the average linear velocity, then we can introduce a coefficient of mechanical dispersion. This is equal to a property of the medium 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.

R000160

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 dispersivity 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 dispersivity

α_T = transverse dynamic dispersivity

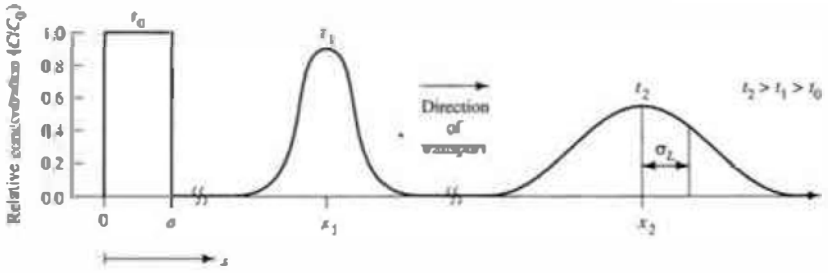
Figure 2.3 shows the effect of diffusion and mechanical dispersion on the relative concentration (C/C_0) of a solute acting as a tracer that has been injected into a porous medium under one-dimensional flow conditions. The vertical line at V represents the advective transport without dispersion. Effects 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

$$D_L = \frac{\sigma_L^2}{2t} \tag{2.12a}$$

R000161

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

$$\text{Advective transport} = v_i n_e C \, dA \tag{2.13}$$

$$\text{Dispersive transport} = n_e D_i \frac{\partial C}{\partial i} dA \tag{2.14}$$

R000162

where dA is the crosssectional area of the element and the i direction is normal to that crosssectional face.

The total mass of solute per unit crosssectional 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

R000163

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.

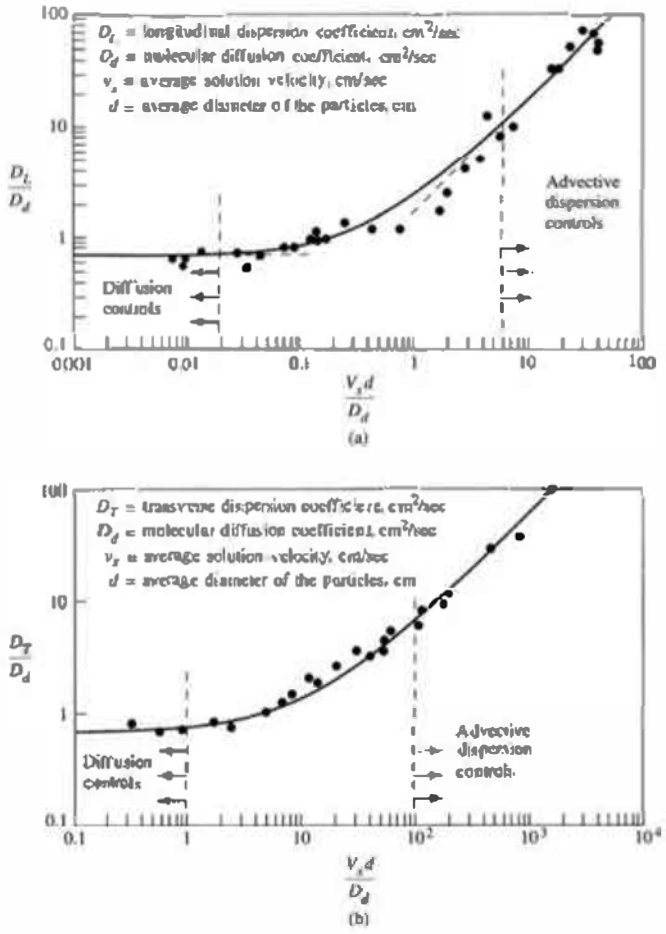
It is possible to evaluate the relative contribution of mechanical dispersion and diffusion to solute transport. A **Peclet number**, P_e, is a dimensionless number that can relate the effectiveness of mass transport by advection to the effectiveness of mass transport by either dispersion or diffusion. 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.

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_d 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_d can be replaced with $a_T v_x$ 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 field-scale 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 three-dimensional 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

R000166

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 three-dimensional 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:

$$M_{j\,k\,n} = \int_{-\infty}^{\infty}\int\int\int C x^j y^k z^n dx\, dy\, dz$$

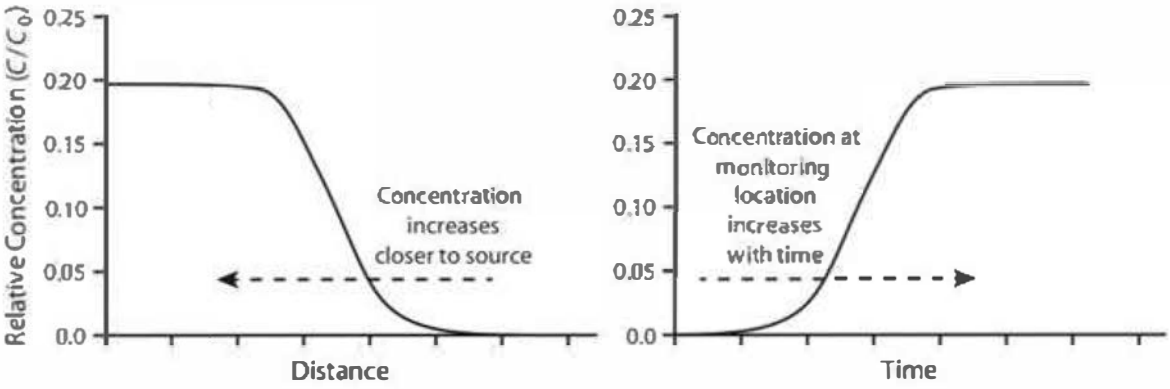
where C is the solute concentration at the spatial coordinates x, y, and z. For one-dimensional data sets, the moment analysis can be simplified to the temporal and spatial forms summarized in Table 2.2.

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	$M_t^1 = \dfrac{\int_0^{\infty} Ct\, dt}{\int_0^{\infty} C\, dt} = \dfrac{\int_0^{\infty} Ct\, dt}{M_t^0}$	$M_s^1 = \dfrac{\int_0^{\infty} Cx\, dx}{\int_0^{\infty} C\, dx} = \dfrac{\int_0^{\infty} Cx\, dx}{M_x^0}$
Adjusted First Temporal Moment	$M_{adj}^1 = \dfrac{\int_0^{x} Ct\, dt}{M_t^0} - \dfrac{1}{2}T_0$	Not defined
Second Central Moment	$M_t^2 = \dfrac{\int_0^{\infty} \left(t - M_t^1\right)^2 C\, dt}{M_t^0}$	$M_s^2 = \dfrac{\int_0^{\infty} \left(x - M_s^1\right)^2 C\, dx}{M_s^0}$
Third Central Moment	$M_t^3 = \dfrac{\int_0^{\infty} \left(t - M_t^1\right)^3 C\, dt}{M_t^0}$	$M_s^3 = \dfrac{\int_0^{\infty} \left(x - M_s^1\right)^3 C\, dx}{M_s^0}$
Fourth Central Moment	$M_t^4 = \dfrac{\int_0^{\infty} \left(t - M_t^1\right)^4 C\, dt}{M_t^0}$	$M_s^4 = \dfrac{\int_0^{\infty} \left(x - M_s^1\right)^4 C\, dx}{M_s^0}$

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).

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.

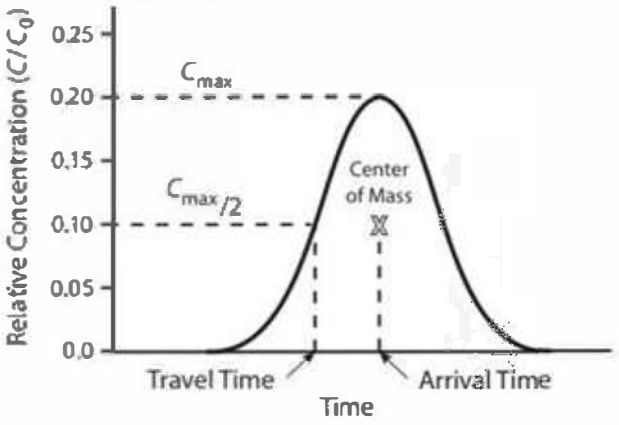
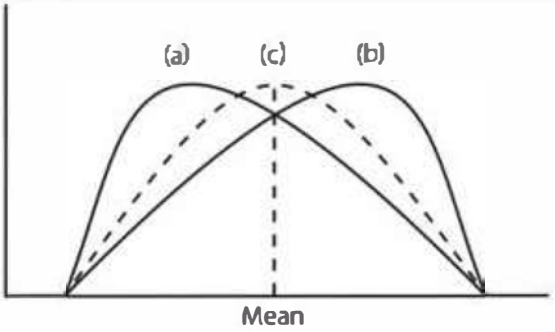


FIGURE 2.10 Skewness: (a) positive, (b) negative and (c) not skewed around the mean ($M^3 = 0$).



The second temporal moment (M_t^{r2}) 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_s^{r3}) can be used to determine the longitudinal dispersion coefficient, D_L, in either temporal or spatial coordinates:

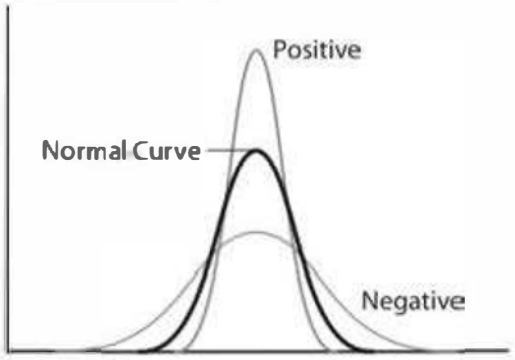
$$D_L = \frac{\sigma_L^2}{2t}$$

$$D_L = \frac{\sigma_L^2 v}{2x}$$

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.



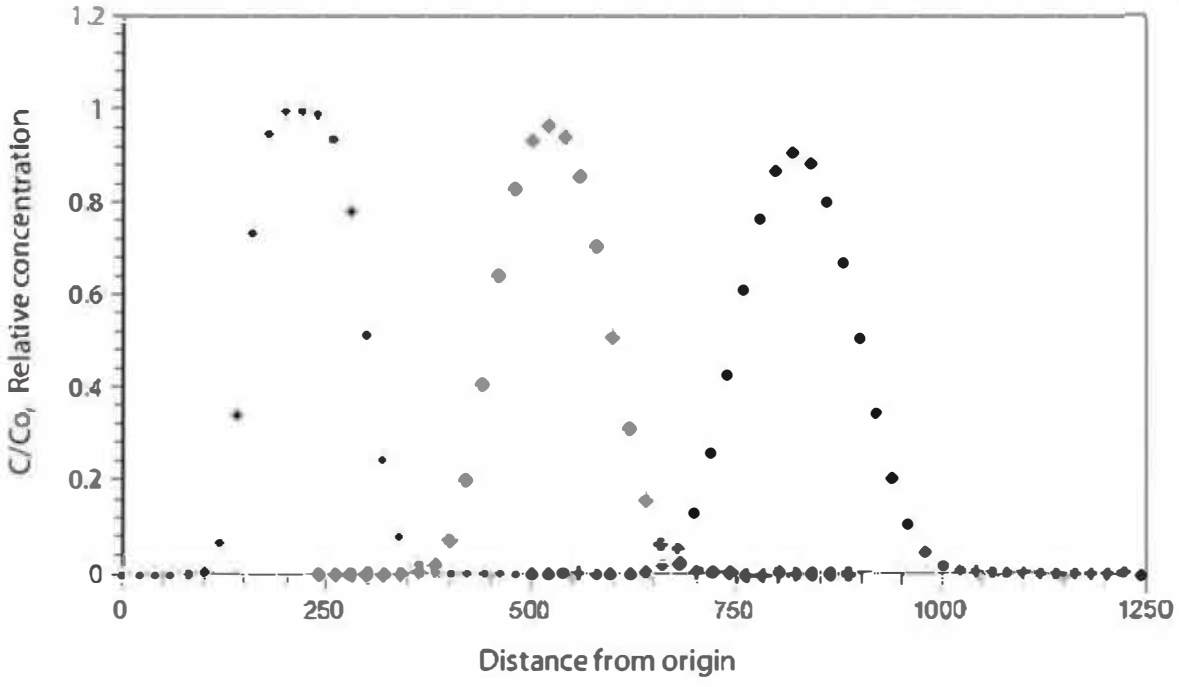
from that value indicate non-ideal transport conditions. Other applications of moment analysis are discussed in Suthersan et al. 2017.

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_o) at three observations points.

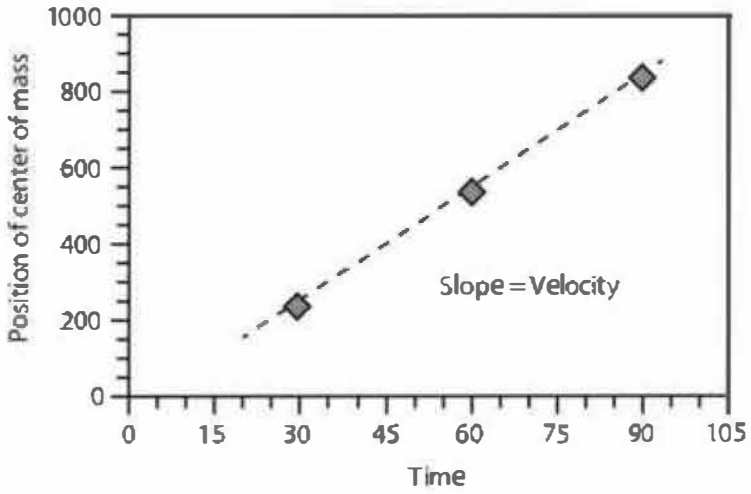
In this example, the tracer is nonreactive because the area under the curves (M^0) remains the same for all three data sets. Had the value of M^0 decreased however, it

FIGURE 2.12 The spatial position of the tracer concentrations profiles at times t_1, t_2, and t_3.



R000170

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 normaly 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 $x=\infty$).

R000172

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

$$C(0, t) = C_0 e^{-\alpha}$$

where λ = 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

$$\left.\left(-D\frac{dC}{dx} + vC\right)\right|_{x=0} = C_0$$

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.**

R000173

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 *Plume1D()* 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).

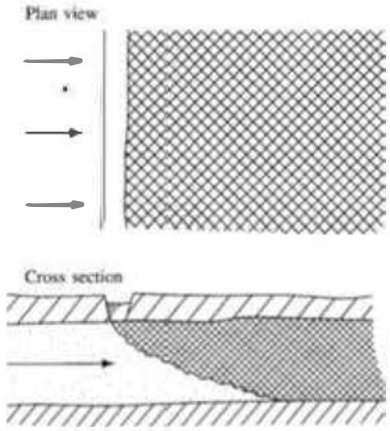
The rate of injection is considered to be constant, with the injected mass of the solute proportional to the duration of the injection. The initial concentration of the solute in the aquifer is zero, and the concentration of the solute being injected is C_0. The solute is free to disperse both up-gradient 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.



Source: J.P. Sauty, 1980. *Water Resources Research* 16:145–58. Copyright by the American Geophysical Union. Reproduced with permission.

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

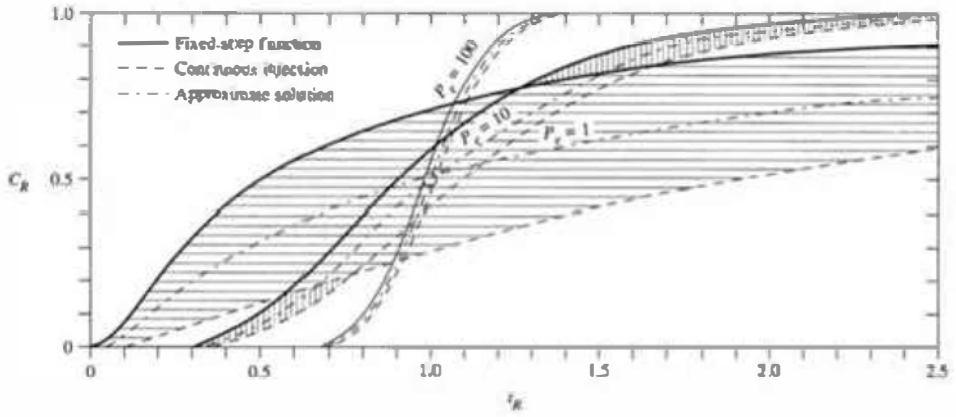
$$C = \frac{C_0}{2}\left[\operatorname{erfc}\left(\frac{L - v_x t}{2\sqrt{D_L t}}\right)\right] \tag{2.25}$$

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 Peelet number defines the rate of transport by advection to the rate of transport by hydrodynamic dispersion. For Peclet number 1, the fixed-step function and the continuous-injection function give quite different results, whereas for Pecler number 100 they are almost identical. The approximate solution lies midway between the other two. This figure suggests that for Peelet 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 Peeler 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.



Source: J.P. Sauty. 1980. *Water Resources Research* 16:145–158. Copyright by the American Geophysical Union. Reproduced with permission.

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^{-4} ms^{-1}

Hydraulic gradient = 0.00678

Effective porosity = 0.259

R000176

The estimated effective diffusion coefficient for chloride is 2×10^{-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.

$$\alpha_L = 0.83(\log L)^{2.414}$$

$$\alpha_L = 0.83(\log 125)^{2.414}\ m$$

$$\alpha_L = 4.96\ m$$

   b. The next step is to calculate D_L.

$$D_L = 4.96m \times 7.67\times10^{-6} ms^{-1} + 2\times10^{-9} m^2s^{-1}$$

$$D_L = 3.80\times10^{-5} m^2s^{-1} + 2\times10^{-9} m^{2-1}$$

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.

$$C_0 = 1575\ mgL^{-1}$$

$$v_x = 7.67 \times 10^{-6} ms^{-1}$$

$$L = 125m$$

$$D_L = 3.80 \times 10^{-5} m^2s^{-1}$$

$$t = 1.578 \times 10^7 s$$

$$C = \frac{1575\text{mgL}^{-1}}{2}\text{erfc}\left(\frac{125\text{m} - (7.67\times10^{-6}\text{ms}^{-1}\times1.578\times10^{7}\text{s})}{2\sqrt{3.80\times10^{-5}\text{m}^2\text{s}^{-1}\times1.578\times10^{7}\text{s}}}\right)$$

$$C = 787.5\text{erfc}\left(\frac{125\text{m}-121.0\text{m}}{2\sqrt{5.99\times10^{2}\text{m}^2}}\right)\text{mgL}^{-1}$$

$$C = 787.5\text{erfc}\left(\frac{4.0\text{m}}{2\times24.49\text{m}}\right)\text{mgL}^{-1}$$

$$C = 787.5\text{erfc}(0.0816)\ \text{mg/L}$$

$$C = 787.5\times0.908\text{mgL}^{-1} = 715\text{mgL}^{-1}$$

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:

$$C = \frac{C_0}{2}\left[\text{erfc}\left[\frac{L-v_x t}{2\sqrt{D_L t}}\right] + \left(\frac{v_x^2 t}{\pi D_L}\right)^{1/2}\exp\left[-\frac{(L-v_x t)^2}{4D_L t}\right]\right.$$

$$\left. -\frac{1}{2}\left(1+\frac{v_x L}{D_L}+\frac{v_x^2 t}{D_L}\right)\exp\left(\frac{v_x L}{D_L}\right)\text{erfc}\left[\frac{L-v_x t}{2\sqrt{D_L t}}\right]\right] \qquad (2.27)$$

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:

$$C_R = (t_R, P_e) = \frac{E}{(t_R)^{1/2}}\exp\left(-\frac{P_e}{4t_R}(1-t_R)^2\right) \qquad (2.28)$$

R000178

with

$$E = (t_{R\max})^{1/2} \cdot \exp\left(\frac{P_e}{4t_{R\max}}(1 - t_{R\max})^2\right) \tag{2.29}$$

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

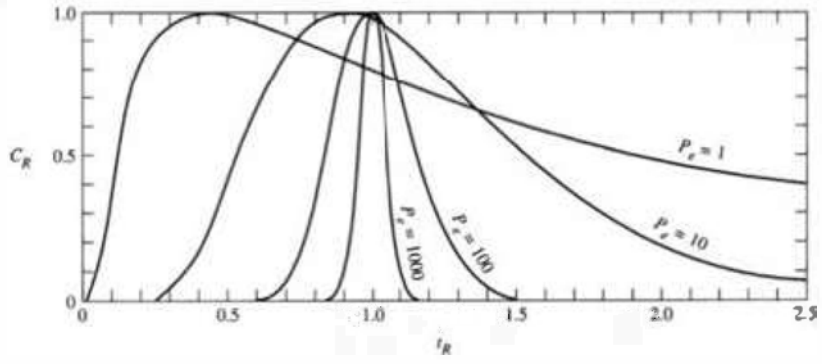
If a tracer is continuously injected into a uniform flow field from a single point that fully penetrates the aquifer, a two-dimensional plume will form that looks similar to Figure 2.16. It will spread along the axis of flow due to longitudinal dispersion and normal to the axis of flow due to transverse 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:

$$C(x,y,t) = \frac{1}{4\pi(D_L D_T)^{0.5}} \exp\left[-\frac{(x - v_x t)^2}{4D_L t} - \frac{y^2}{4D_T t}\right]$$

FIGURE 2.16 Dimensionless-type curve for the injection of a slug of a tracer into a one-dimensional flow field.



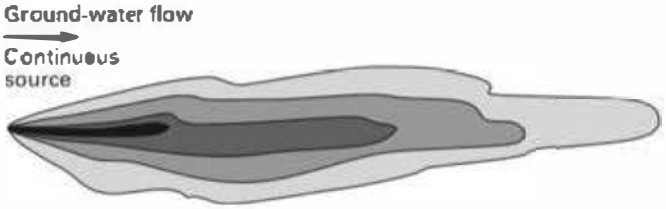
Source: J. P. Sauty, 1980, *Water Resources Research* 16:145–158. Copyright by the American Geophysical Union. Reproduced with permission.

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

R000180

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

   $Q = 3.66$ m³/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.

R000181

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:

$$C(x,y,t)=\frac{C_0(Q/b)}{4\pi(D_L D_T)^{1/2}}\exp\left(\frac{v_x x}{2D_L}\right)\int_{t_{D=0}}^{t_{D=t}}\exp\left[-t_D-\frac{B^2}{4t_D}\right]\frac{dt_D}{t_D}$$

with

$$B^2=\frac{{v_x}^2x^2}{4{D_L}^2}+\frac{{v_x}^2y^2}{4D_L D_T}$$

The integral in the above equation was solved by Hantush (1956). This solution is

$$C(x,y,t)=\frac{C_0(Q/b)}{4\pi(D_L D_T)^{1/2}}\exp\left(\frac{v_x x}{2D_L}\right)\left[W(0,B)-W(t_D,B)\right] \qquad \textbf{(2.31)}$$

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 100m. 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.

$$D_L = \alpha_L v_X = 12\text{ m} \times 0.235\text{ m/day} = 2.82\text{ m}^2\text{/day}$$

$$D_T = \alpha_T v_X = 1.2\text{ m} \times 0.235\text{ m/day} = 0.282\text{ m}^2\text{/day}$$

R000182

2. The value of B must be calculated.

$$B = \left[\frac{(v_x x)^2}{4D_L^2} + \frac{(v_x y)^2}{4D_L D_T} \right]^{\frac{1}{2}}$$

$$B = \left[\frac{(0.235\text{m/da} \times 123.5\text{m})^2}{4 \times (2.8\text{m}^2/\text{da})^2} + \frac{(0.235/\text{da} \times 7.2\text{m})^2}{4 \times 2.8\text{m}^2/\text{da} \times 0.28\text{m}^2/\text{da}} \right]^{\frac{1}{2}}$$

$$B = \left[\frac{842\text{m}^4/\text{da}^2}{31.4\text{m}^4/\text{da}^2} + \frac{2.86\text{m}^4/\text{da}^2}{3.14\text{m}^4/\text{da}^2} \right]^{\frac{1}{2}}$$

$$B = \sqrt{26.8 + 0.91}$$

$$B = 5.26$$

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 1.00m.

Q = 1.93 m³/year/365 da/year = 0.0053 m³/da

$$C(x,y,t) = \frac{C_0 Q/b}{4\pi(D_L D_T)^{1/2}} \exp\left(\frac{v_x x}{2D_L}\right)\left[W(0,B) - W(t_D,B)\right]$$

$$C(x,y,t) = \frac{12{,}950\,\mu\text{g/L} \times 0.0053\text{m}^3/\text{da}/1\text{m}}{4\pi(2.82\text{m}^2/\text{da} \times 0.28\text{m}^2/\text{da})^{1/2}} \exp\left(\frac{0.236\text{m/da} \times 123.5\text{m}}{2 \times 2.82\text{m}^2/\text{da}}\right)[0.0098 - 0.0019]$$

$$C(x,y,t) = 0.0061 \exp(5.16)[0.0079]\,\mu\text{g/L}$$

$$C(x,y,t) = 0.0061 \times 174 \times 0.0079\,\mu\text{g/L}$$

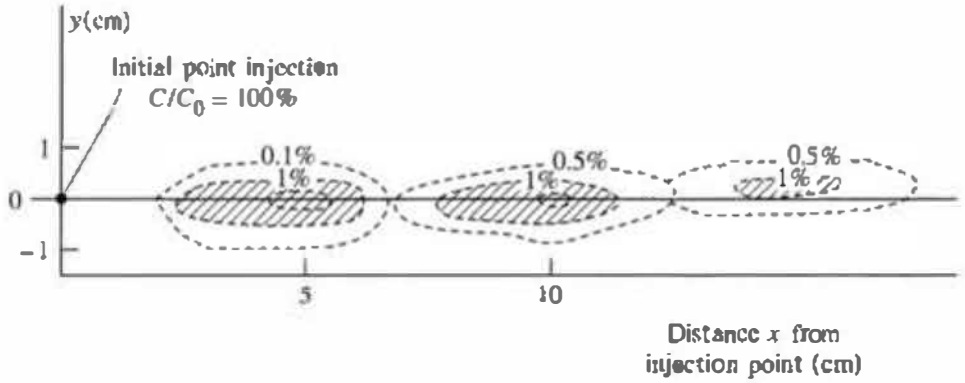
$$C(x,y,t) = 0.0084\,\mu\text{g/L}$$

R000183

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

$$C(x,y,t) = \frac{C_0 A}{4\pi t (D_L D_T)^{1/2}} \exp\left[-\frac{((x-x_0)-v_x t)^2}{4D_L t} - \frac{(y-y_0)^2}{4D_T t} \right] \qquad (2.32)$$

EXAMPLE PROBLEM

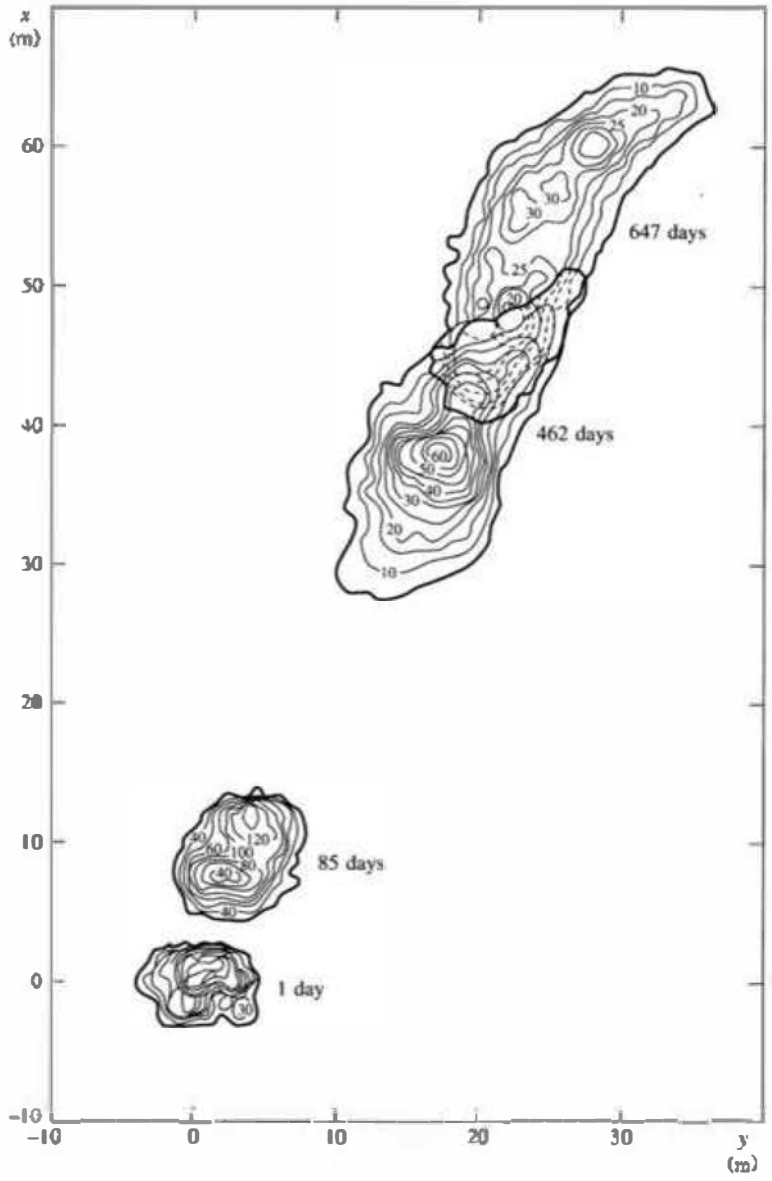
A tank truck, which is carrying water containing 1275 mg/L of dissolved benzene overturns and spills a volume of water sufficient to saturate a thin aquifer over an area of 5 m². The aquifer contains groundwater flowing with an average linear velocity of 0.45 m/day. Assume that the values of D_L and of D_T are 2.1 m²/day and 0.21 m²/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.

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.

$$C = \frac{C_0 A}{4\pi t\sqrt{D_L D_T}} \exp\left[-\frac{((x-x_0)-v_x t)^2}{4D_L t} - \frac{(y-y_0)^2}{4D_T t}\right]$$

$$C = \frac{1275\text{mgL}^{-1} \times 5\text{m}^2}{4 \times \pi \times 200\text{da} \times \sqrt{2.1\text{m}^2\text{da}^{-1} \times 0.21\text{m}^2\text{da}^{-1}}} \times$$

$$\exp\left[-\frac{((72\text{m} - 0) - (0.45\text{mda}^{-1} \times 200\text{da}))^2}{4 \times 2.1\text{md}^{-1} \times 200\text{da}} - \frac{(5.5\text{m})^2}{4 \times 0.21\text{m}^2\text{da}^{-1} \times 200\text{da}} \right]$$

$$C = \frac{6375\text{mgL}^{-1} \times \text{m}^2}{4 \times \pi \times 200\text{da} \times 0.664\text{m}^2\text{da}^{-1}} \exp\left[-\frac{(72 - 90)^2\text{m}^2}{1680\text{m}^2} - \frac{30.25\text{m}^2}{168\text{m}^2} \right]$$

$$C = 3.82\text{mgL}^{-1} \exp[-0.192 - 0.180]$$

$$C = 3.82\exp(-0.372) = 3.82 \times 0.6892 = 2.63\text{mgL}^{-1}$$

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:

$$\sigma_x = \sqrt{2D_L t} \qquad \sigma_y = \sqrt{2D_T t}$$

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

R000186

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.

$$C_{max} = \frac{2130 \text{ mgL}^{-1} \times 455 ft^2}{4 \times \pi \times 133 da \sqrt{6.96 \text{ ft}^2 da^{-1} \times 0.696 \text{ ft}^2 da^{-1}}}$$

$$C_{max} = 263 mgL^{-1}$$

3. The size of the plume can be determined from the standard deviations.

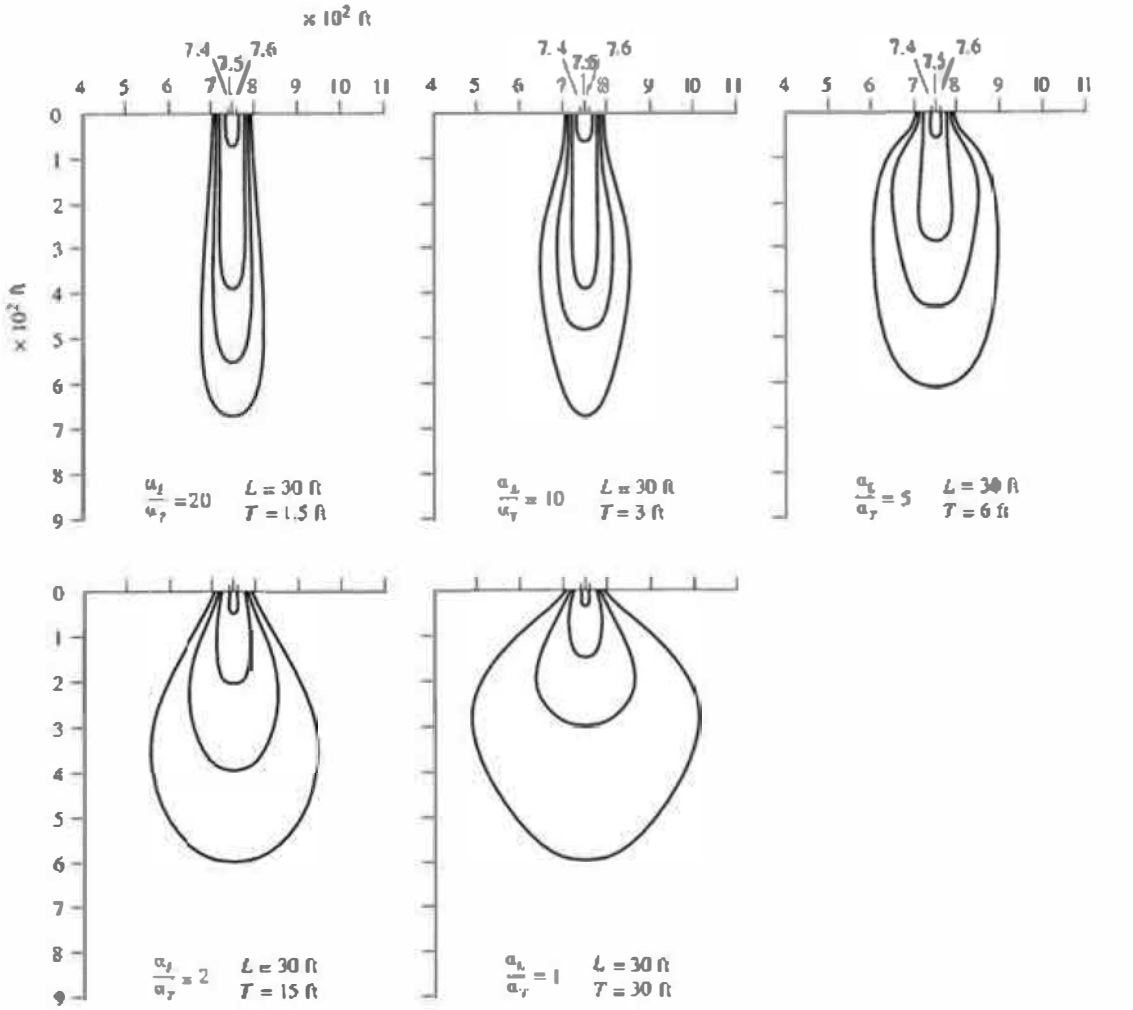
$$\sigma_x = \sqrt{2D_L t} \qquad \sigma_y = \sqrt{2D_T t}$$
$$\sigma_x = \sqrt{2 \times 6.96 \text{ ft}^2\text{da}^{-1} \times 133 \text{ da}} \qquad \sigma_y = \sqrt{2 \times 6.96 \text{ ft}^2\text{da}^{-1} \times 133 \text{ da}}$$
$$\sigma_x = 43.0 \text{ ft} \qquad \sigma_y = 13.6 \text{ ft}$$

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

R000188

chloride was 48 mg L^{-1} and after 4000 seconds, t_2, it was 252 mg L^{-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:

$$D_L = \left(\frac{v_x L}{8}\right)(J_{0.84} - J_{0.16})^{1/2}$$

$$D_L = (1/8) \times (1.35 \times 10^{-2}\ cms^{-1} \times 40cm) \times (0.28 - -2.01)^{1/2}$$

$$= 6.75 \times 10^{-2} \times 1.51 cm^2 s^{-1}$$

$$= 0.102\ cm^2 s^{-1}$$

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;

R000189

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 down-gradient 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

$$\frac{C}{C_0} = \frac{1}{2}\operatorname{erfc}\left(\frac{(U_p - U_i) - 1}{\left\{\frac{16}{3}(\alpha_L / R_f)[2-(1-U_p/U_i)]\right\}^{1/2}[1-(U_p/U_i)]\}^{1/2}}\right) \tag{2.38}$$

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

$$R_f = \left(\frac{Qt}{\pi bn}\right)^{1/2} \tag{2.39}$$

where

Q = rate of injection

t = total time of injection

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_f. 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.

R000191

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

R000192

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, Y, which can be found from

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i \tag{2.41}$$

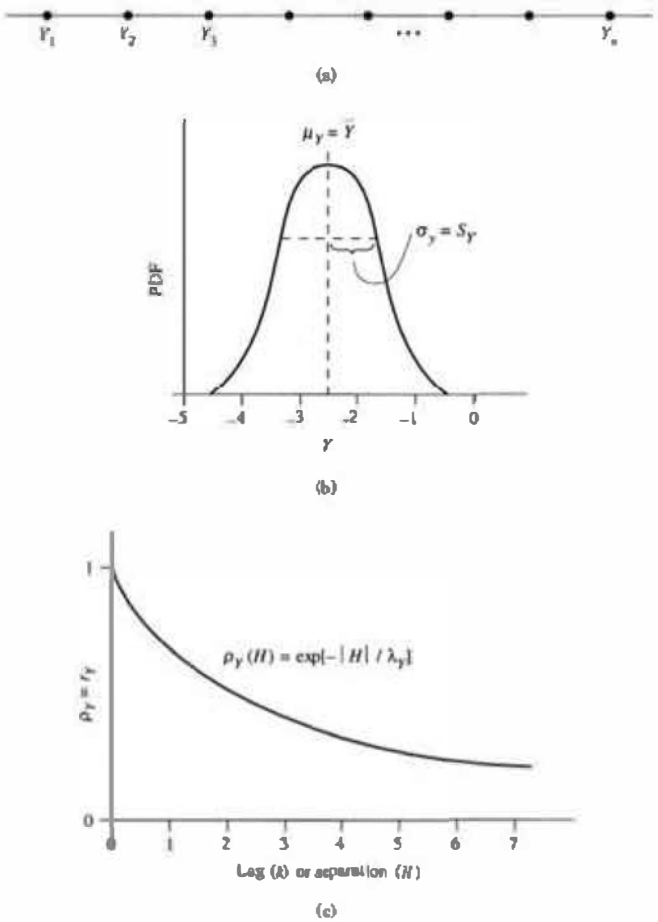
The estimate of the variance of the population is also obtained by the variance of the sampled values, S_y^2, which is found from the following equation:

$$S_Y{}^2 = \frac{1}{n-1}\sum_{i=1}^{n} (Y_i - \bar{Y})(Y_i - \bar{Y}) \tag{2.42}$$

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 $\overline{Y} - S_Y$, a 50% chance that it is greater than $\overline{Y}$, and an 84% chance that it is greater than $\overline{Y} - S_Y$. 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.

R000194

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.

$$\tau_Y(H) = \sigma_Y{}^2 \rho_Y(H) \tag{2.46}$$

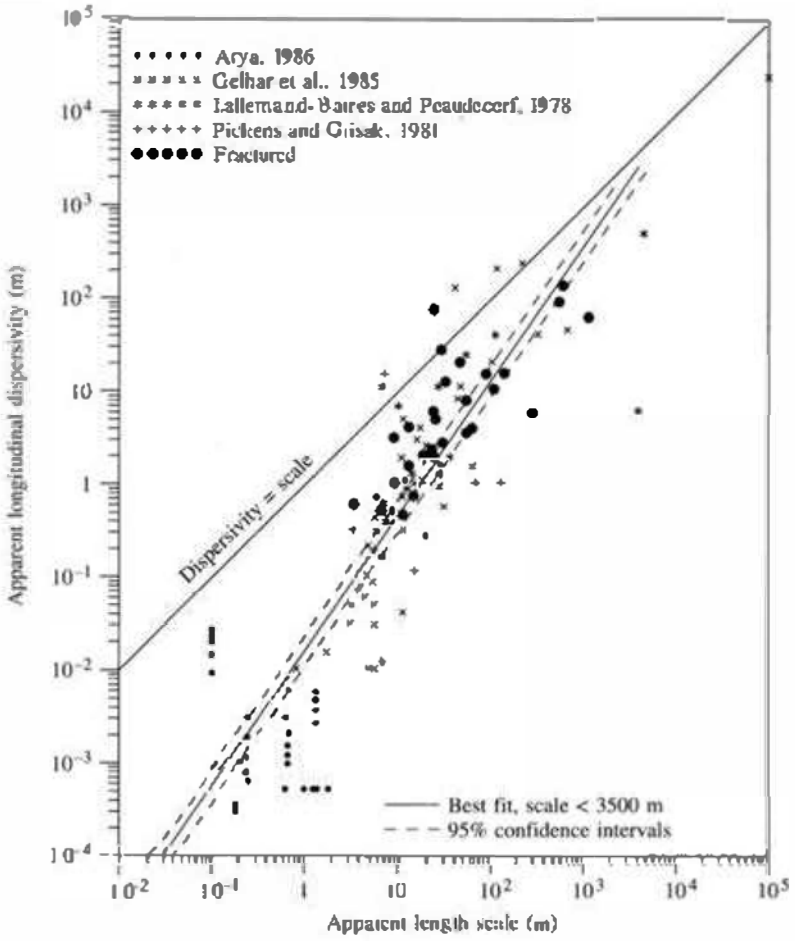
We can describe the distribution of heterogeneity of Y by the use of three stochastic functions, μ_Y, σ_Y (or $\sigma_Y{}^2$), and λ_Y. If a stochastic process is said to be stationary, the values of μ_Y, σ_Y(or $\sigma_Y{}^2$), and λ_Y do not vary in space in the region being studied. If the hydraulic 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 everywhere, 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

R000195

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_m, as a function of the travel distance, L_s, or apparent length scale

R000196

(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

$$\alpha_{ap} = 0.0175 L_s^{1.46} \tag{2.47}$$

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 0.0113 and 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:

$$\alpha_{ap} = 0.83(\log L_s)^{2.414} \tag{2.48}$$

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

R000197

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 $\alpha_L = 1.6$ 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).

R000198

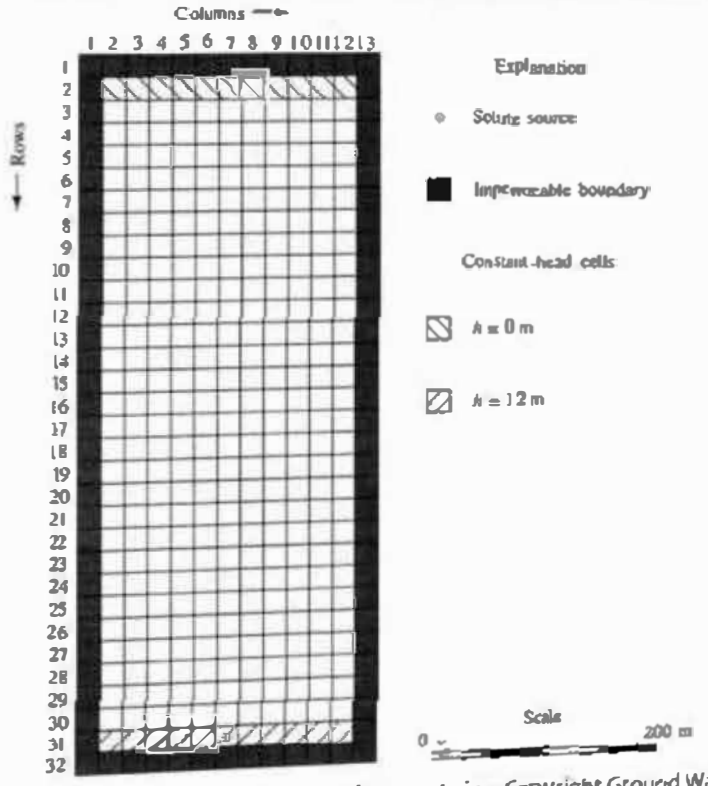
Other methods exists, such as the finite volume method (FVM) or the analytic element method (AEM), but models build around these numerical solution schemes are currently not used widely. A detailed discussion of numerical methods is beyond the scope of this textbook and the reader is referred to Peiro 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 multi-species 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 agricult ural 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 advective-dispersion 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.

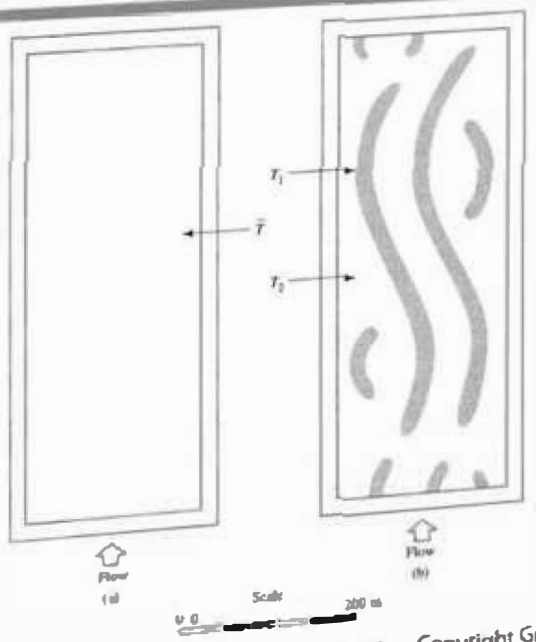
R000199

FIGURE 2.29 Finite-difference grid and boundary conditions for a deterministic model of solute transport.



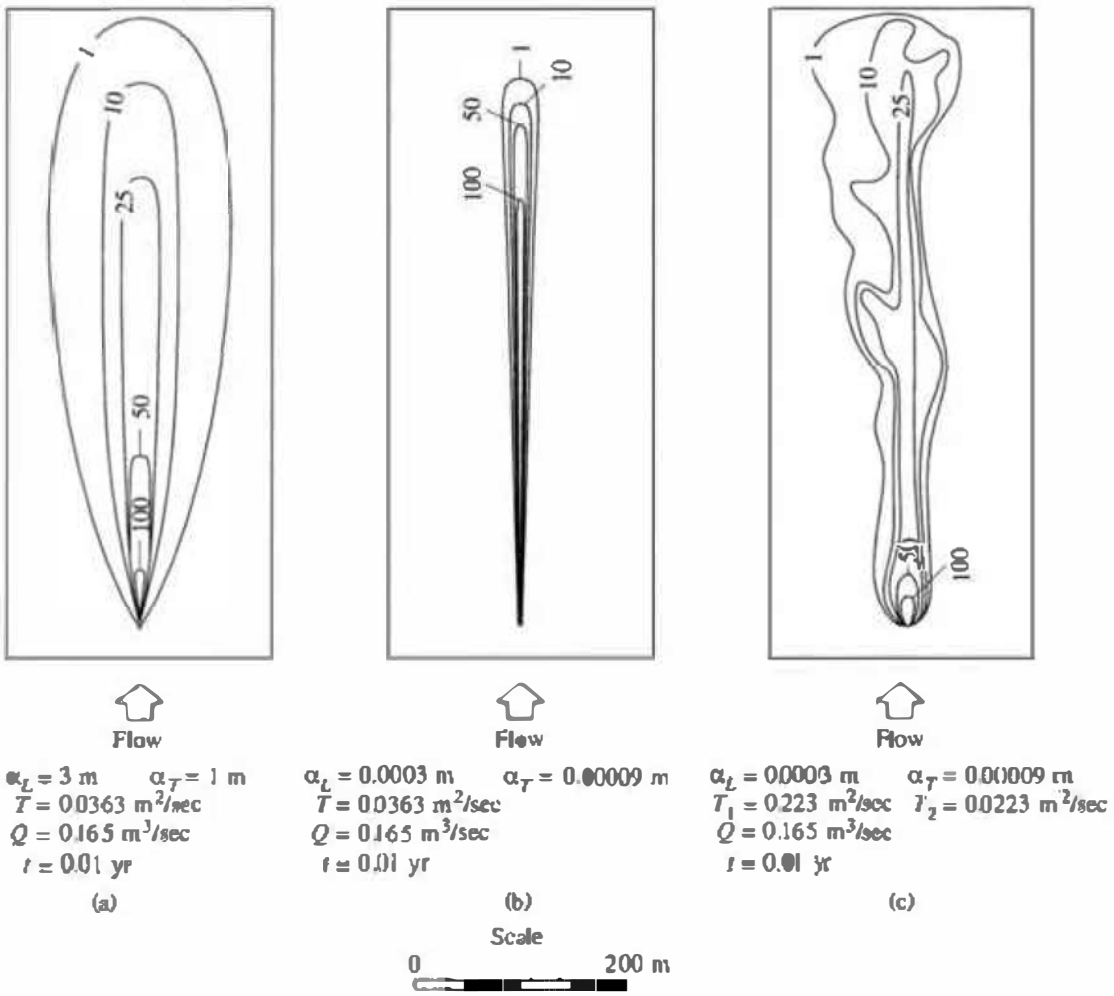
Source: A. D. Davis. 1986. *Ground Water* 24:609–615. Used with permission. Copyright Ground Water Publishing Co.

FIGURE 2.30 Model areas for finite difference solute transport model with (a) uniform transmissivity and (b) with heterogeneous transmissivity.



Source: A. D. Davis. 1986. *Ground Water* 24:609–615. Used with permission. Copyright Ground Water Publishing Co.

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.



Source: A. D. Davis. 1986. *Ground Water* 24:609-615. Used with permission. Copyright Ground Water Publishing Co.

Case Study: Borden Landfill Plume

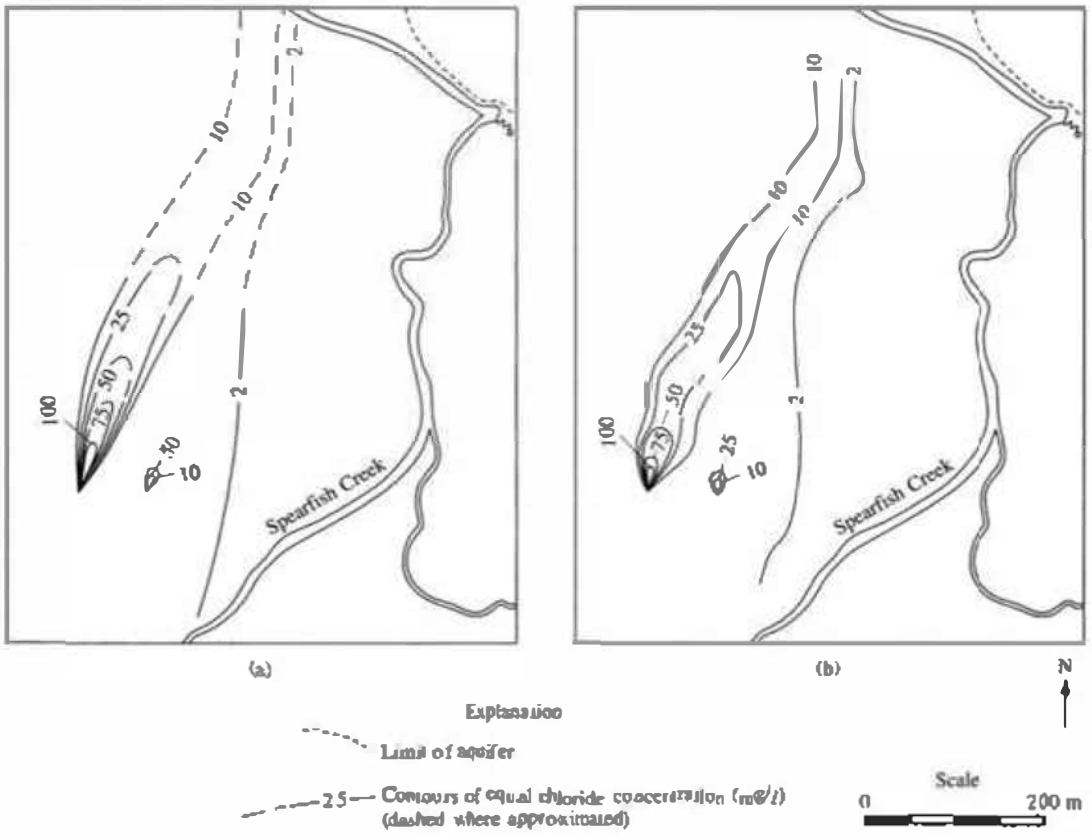
Probably the best known subsurface contaminant transport field test site is located on the Canadian Forces Base in Borden, Ontario (Sudicky and Illman 2011). An abandoned landfill in a shallow sand aquifer at Borden has been extensively studied (Cherry 1983; Macfarlane et al. 1983) and Frind and Hokkanen (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

R000201

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.



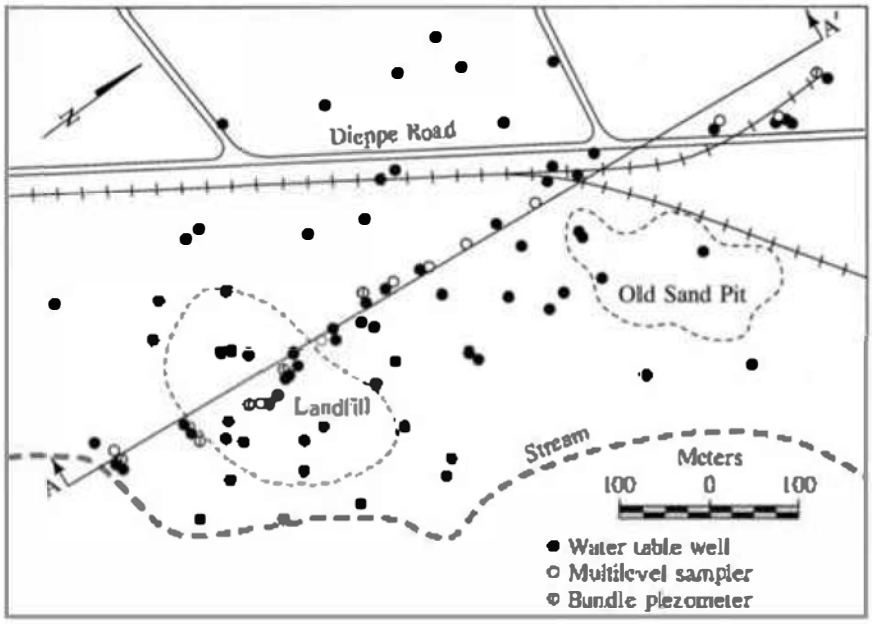
Source: A. D. Davis. 1986. *Ground Water* 24:609–615. Used with permission. Copyright Ground Water Publishing Co.

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

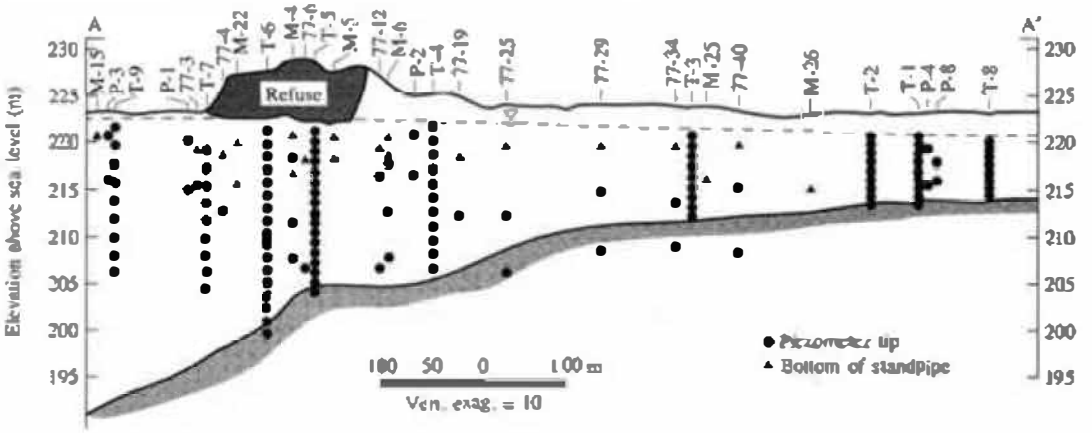
plume was not very sensitive to changes in the value of α_t over the range tested. The value of α_T was kept constant at 0.01 m (0.4 in), whereas α_t varied from 2.5 to 20 m (8 to 65 ft). This figure is slightly misleading in that there is a 10:1 vertical exaggeration, so that the vertical spreading is more obvious than the horizontal. Also, the value of α_T was varied by a factor of 200, whereas α_t 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.



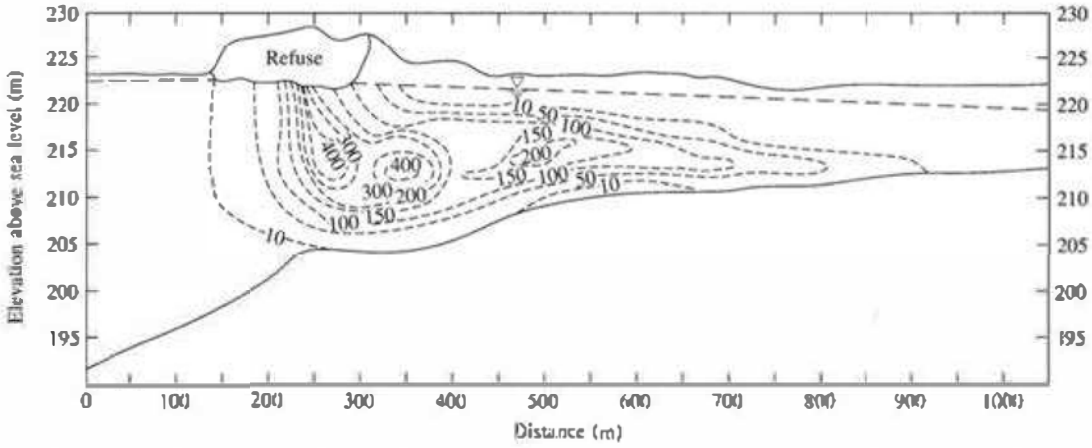
Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

FIGURE 2.34 Cross section of aquifer at the Border landfill showing the location of multilevel monitoring devices.



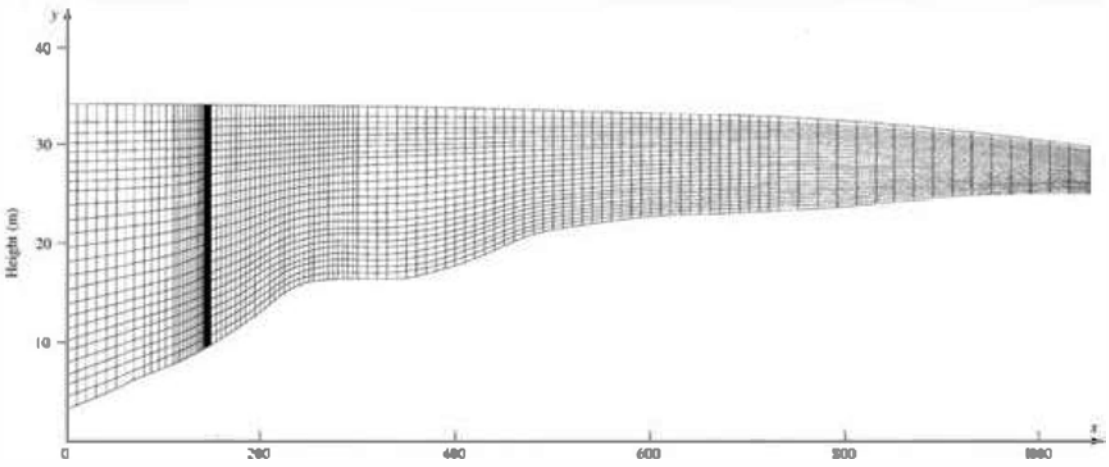
Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

FIGURE 2.35 Chloride plume along the Border landfill across section in 1979. Values are in milligrams per liter.



Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

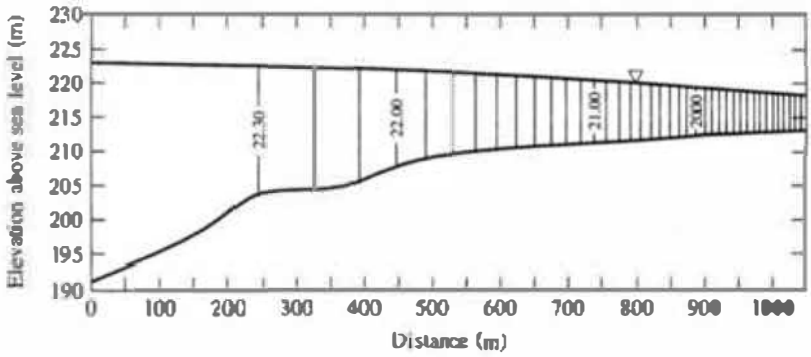
FIGURE 2.36 Finite-difference grid for Borden landfill solute transport model.



Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

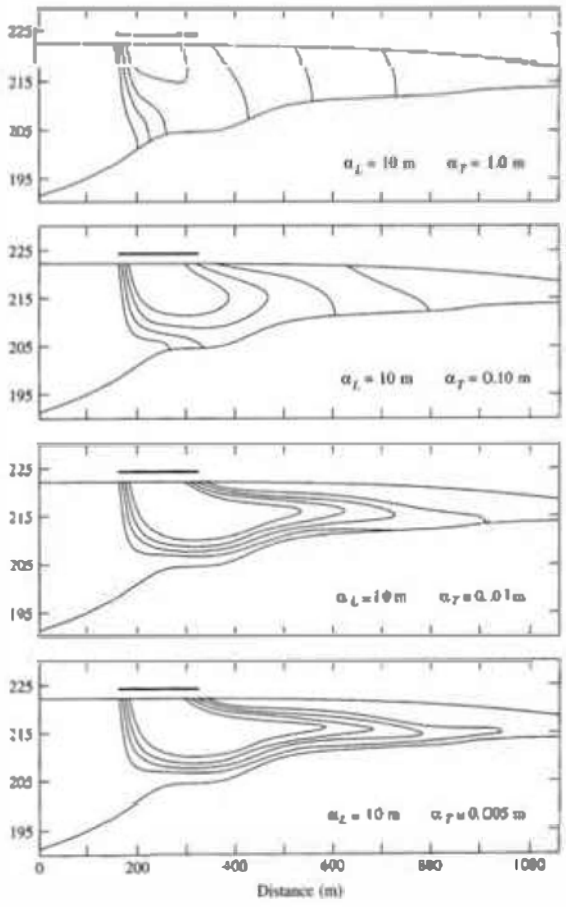
Additional sensitivity analyses were conducted with respect to the water table boundary conditions and the concentration, size, and growth pattern of the source. The authors found that in order to reproduce the observed distribution, a source history that included multiple periods of high concentration 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.



Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918-930. Copyright by the American Geophysical Union. Reproduced with permission.

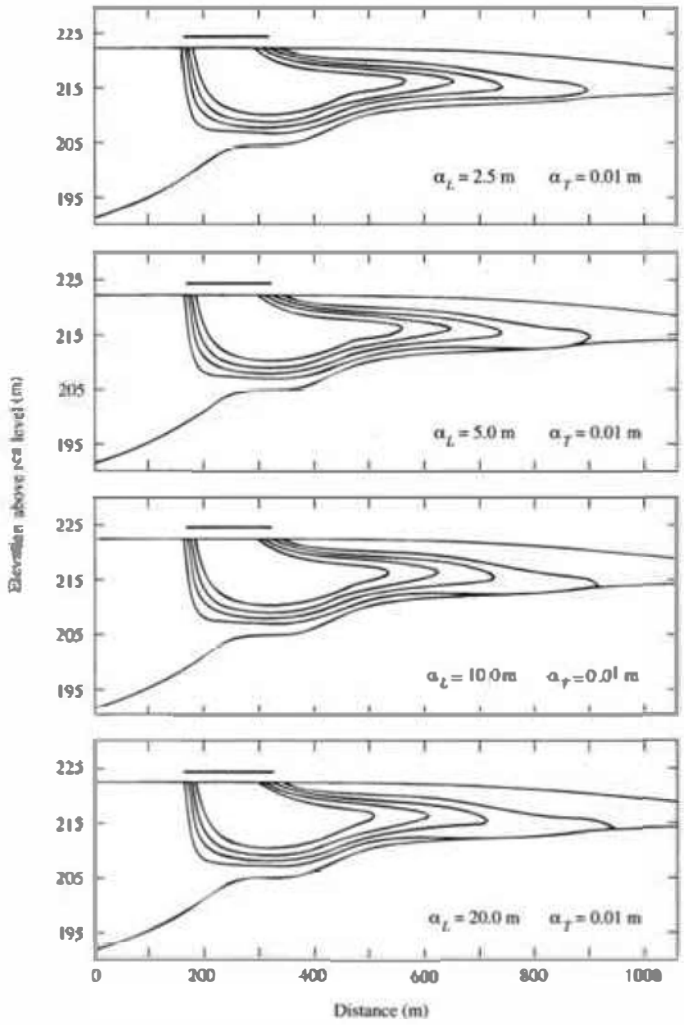
FIGURE 2.38 Sensitivity analysis of the Borden landfill solute-transport model with respect to transverse dispersivity.



Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

R000205

FIGURE 2.39 Sensitivity analysis of the Borden landfill solute-transport model with respect to longitudinal dispersivity.



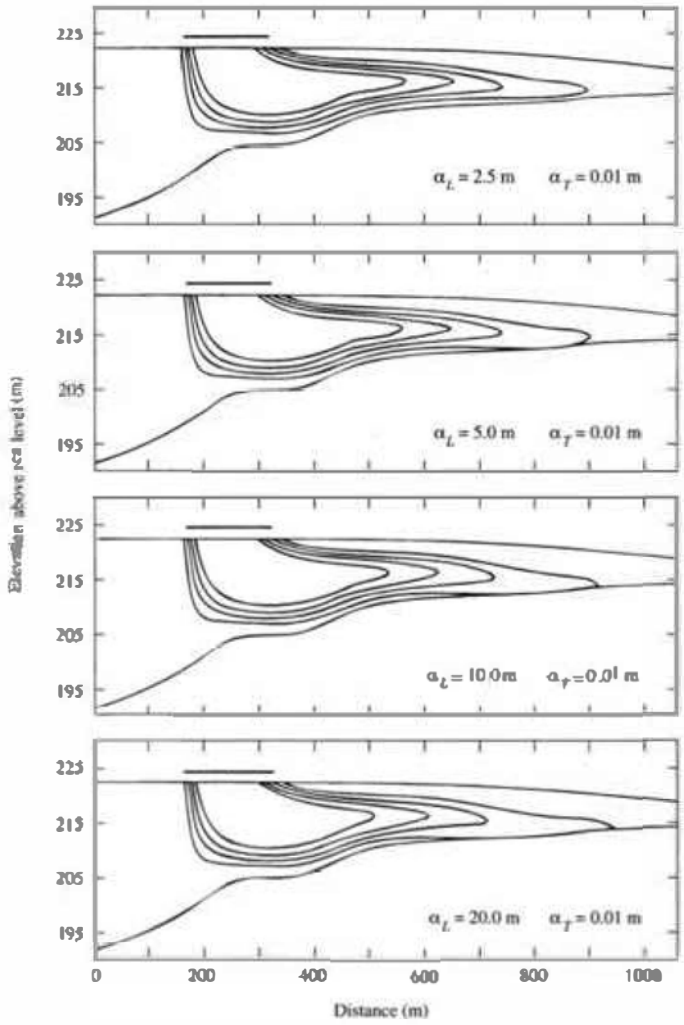
Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

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

R000206

FIGURE 2.39 Sensitivity analysis of the Borden landfill solute-transport model with respect to longitudinal dispersivity.



Source: E. O. Frind and G. E. Hokkanen. 1987. *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

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

R000207

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 non moving water into which solutes can diffuse (Raven et al. 1988).

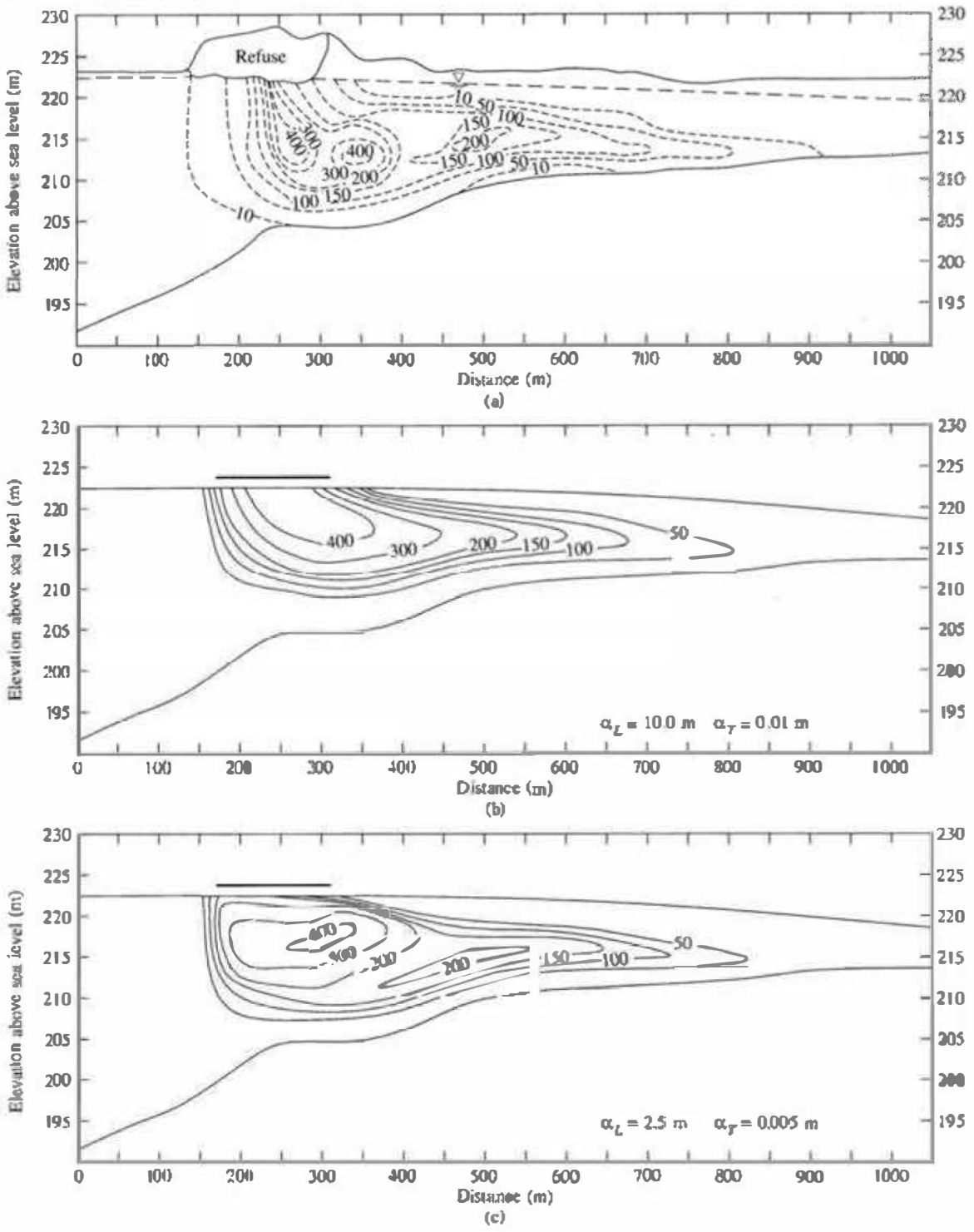
Berkowitz et al. (1988) suggested that solute transport in fractured media can be considered at a number of different scales. A very-near-field scale would be a single fracture near the source A near-field scale would include a few fractures near the source At a larger scale, the far field, the fracture 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).

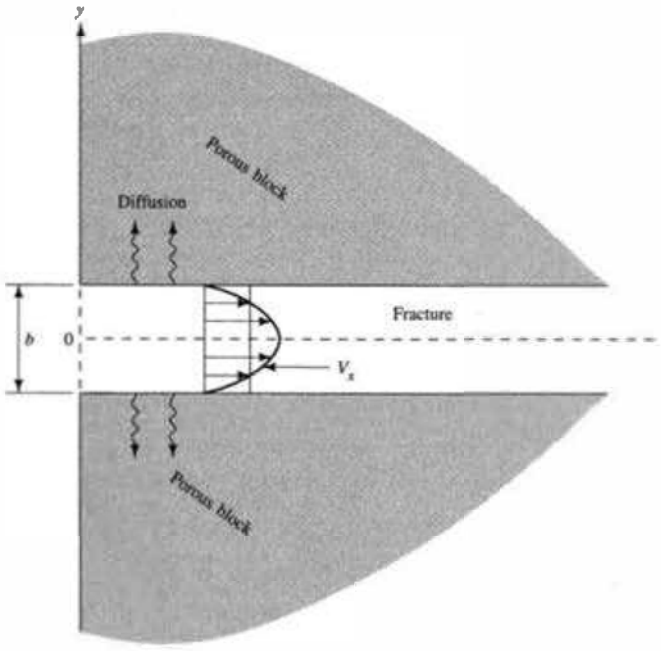
One of the first considerations in dealing with fracture flow is deciding how to treat flow in a single fracture. Some authors (e.g., Tang et al. 1981; Schwartz and Smith 1988) assume that the fluid in a fracture is all moving at a constant velocity. Conversely, Endo et al. (1984) treated flow in a fracture 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.



Source: E. O. Frind and G. E. Hokkanen, 1987, *Water Resources Research* 23:918–930. Copyright by the American Geophysical Union. Reproduced with permission.

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

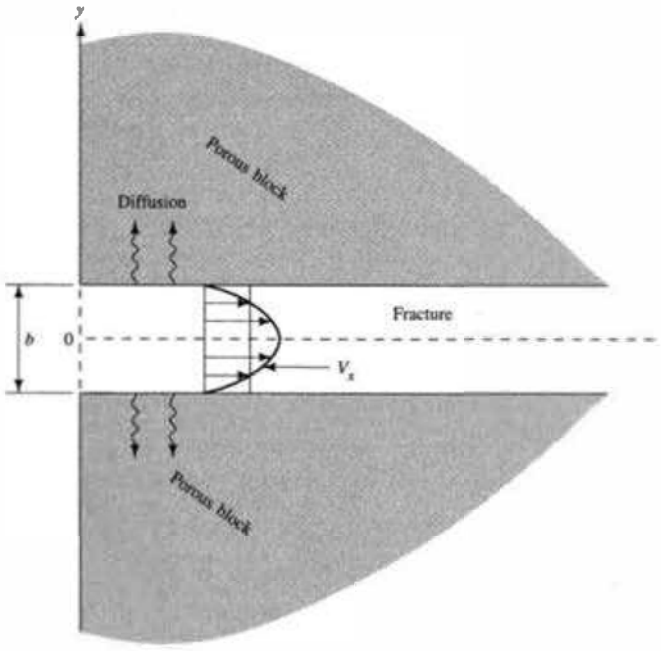
At high flow rates, advection will dominate and the concentration will follow the velocity profile of Figure 2.41. At low velocities, diffusion will be important, since the concentration gradient at the solute front will be high and the distance will be short. Under these conditions, diffusion will homogenize 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

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.

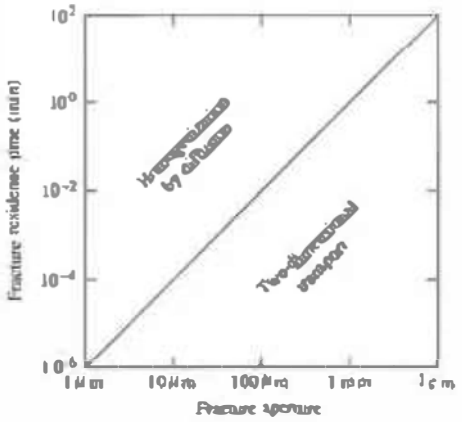
If L is the length of the fracture between cross fractures and β is the aperture of the fracture, the fracture residence time is L/V. This can be compared with $(\beta/2)^2/D$ to determine if diffusion needs to be considered (Crank 1956). If diffusion induces a change in the tracer concentration of less 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

R000211

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

$$Q = \frac{\rho g}{12\mu} Ia\beta^3 \tag{2.54}$$

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

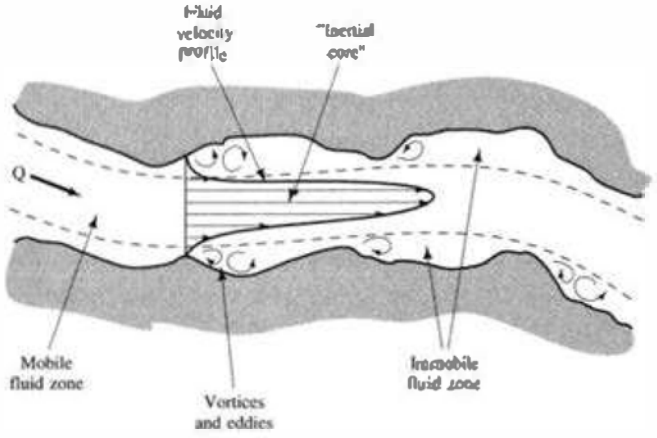
$$V_x(\zeta)=15.56\zeta-97.72\zeta^2+308\zeta^3-513\zeta^4+431\zeta^5-143.7\zeta^6 \tag{2.57}$$

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.

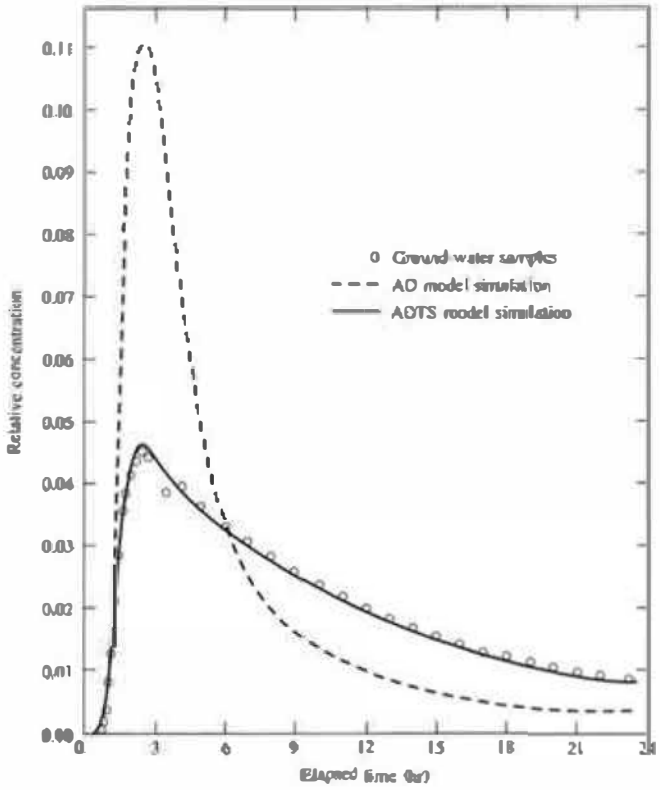
R000213

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.



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.

R000214

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 desctibed 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 dispetsion 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 $\alpha_{rm} = 0.83(\log L_s)^{2 \times 414}$.

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	Crosssectional area
a	Width of a fracture
b	Aquifer thickness
B	$[(v_x x)^2/(2D_L)^2 + (v_x y)^2/(4D_L D_T)]^{1/2}$
C	Solute concentration
C_t	Concentration at some point x and time t
C_0	Initial concentration, i.e. concentration 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

R000215

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_0	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_{ij}	Covariance
U	⟨V⟩ 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 fractal flowpath
v_x	Average linear velocity in the x direction
V	Average fluid velocity in a fracture
V	Velocity vector
⟨V⟩	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
⟨X⟩	Ensemble mean of the center of mass
$X_n(t)$	Second spatial moment of the solute mass at time t and location i, l
X_t	Total particle displacement
$\bar{Y}$	Mean of sample values of Y
Y_i	$\log K_i$
Z_α	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		

References

Anderson, M. P. 1979. Using models to simulate the movement of contaminants through groundwater flow systems. *Critical Reviews in Environmental Controls* 9:97–156.

Anderson, M. P. 1984. "Movement of contaminants in groundwater: Groundwater transport—advection and dispersion." In *Groundwater Contamination*, 37–45. Washington, DC: National Academy Press.

Anderson, M. P. 1990. Aquifer heterogeneity—a geological perspective. *Proceedings, Fifth Canadian/American Conference on Hydrogeology*. National Water Well Association, pp. 3–22.

Anderson, M. P., and W. W. Woessner. 1991. *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*. San Diego, CA: Academic Press.

Aris, R. 1956. On the dispersion of a solute in a fluid flowing through a tube. *Proceedings of The Royal Society of London* 235:67–77.

Ayra, A. 1986. Dispersion and reservoir heterogeneity. Ph.D. Dissertation. University of Texas, Austin.

Bachmat, Y., and J. Bear. 1987. On the concept and size of a representative elementary volume (REV). *Advances in Transport Phenomena in Porous Media* 128:3–20.

Bakr, A. A. 1976. Effect of spatial variations of hydraulic conductivity on groundwater flow. Ph.D. Dissertation. New Mexico Institute of Mining and Technology, Socorro.

Barker, J. A. 1982. Laplace transform solutions for solute transport in fissured aquifers. *Advances in Water Resources* 5:98–104.

Bear, J. 1961. Some experiments on dispersion. *Journal of Geophysical Research* 66:2455–2467.

Bear, J. 1972. *Dynamics of fluids in porous media*. New York: American Elsevier Publishing Company, 764 pp.

Bear, J., and A. Verruijt. 1987. *Modeling Groundwater Flow and Pollution*. Dordrecht, Netherlands: D. Reidel Publishing Company, 414 pp.

Bear, J., and A. H.-D. Cheng. 1990. "Modeling Groundwater Flow and Contaminant Transport." In *Theory and Applications of Transport in Porous Media, Volume 23*. Reprint 2010. Springer, 396 pp.

Bedient, P. B., H. S. Rifai, and C. J. Newell. 1994. *Ground Water Contamination: Transport and Remediation*. Englewood Cliffs, NJ: Prentice Hall.

Berkowitz, B., J. Bear, and C. Braester. 1988. Continuum models for contaminant transport in fractured porous formations. *Water Resources Research* 24:1225–1236.

Bierkens, M., and F. van Geer. 2014. Stochastic Hydrology. Lecture notes. Accessed October 3, 2015 at http://www.earthsurfacehydrology.nl/wp-content/uploads/2012/01/Syllabus_StochasticHydrology.pdf

Brigham, W. E. 1974. Mixing equations in short laboratory columns. *Society of Petroleum Engineers Journal* 14:91–99.

Boving, T. B., and P. Grathwohl. 2001. Tracer diffusion coefficients in sedimentary rocks: Correlation to porosity and hydraulic conductivity. *Journal of Contaminant Hydrology* 53:85–100.

Carman, P. C. 1997. Fluid flow through a granular bed. *Chemical Engineering Research and Design* 75: S32–S48.

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.

R000218

If a solution is dilute and there is no need to make density corrections, the molality can be detetmined 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

R000219

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

R000220

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

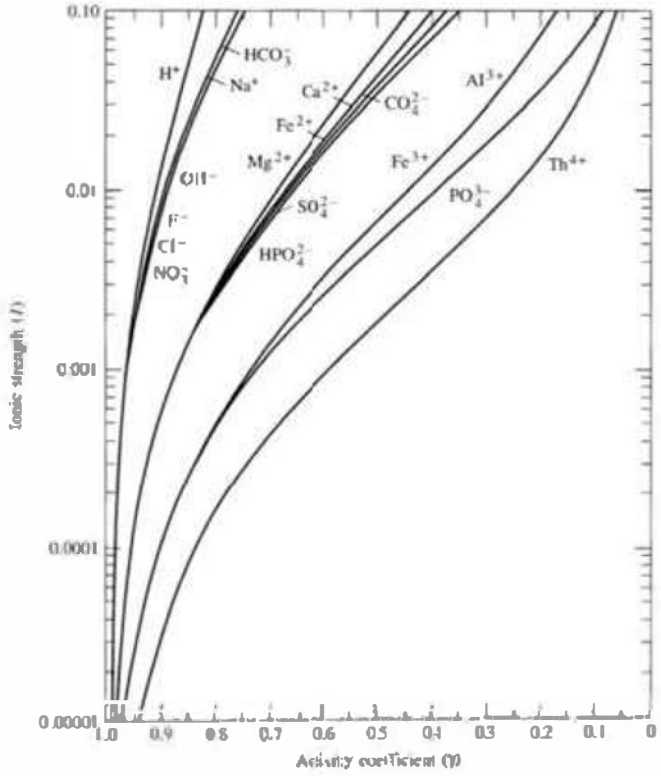
R000221

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-}, Na^+, 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

R000222

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

R000223

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
$CaCO_3$	$10^{-10.0}$	
$FeCO_3$	$10^{-10.7}$	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.

R000224

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^0 = 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

R000225

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

$$K_{eq} = \frac{[H^+][OH^-]}{[H_2O]} \tag{6.24}$$

R000226

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) (trioxide)	−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(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)	−26.8[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[h]	HVO_4^{2-} (aq)	−233.0[f]	C^{4-}(aq)	−31.37[a]
$Fe(OH)_2$(c) ppt.	−116.3[f]	VO_4^{3-} (aq)	−214.9[a]	CH_4(g)	−12.13[a]
$FeCO_3$(c) (siderite)	−159.35[b]	VO^{2+}(aq)	−106.7[a]	CH_4(aq)	−8.22[a]
FeS_2(c) (pyrite)	−39.9[b]	$V(OH)_3^0$(aq)	−212.9[a]	H^+(aq)	0.00
Fe_2O_3 (hematite)	−177.4[b]	VOH^{2+}(aq)	−111.41[h]	Cl^- (aq)	−31.38[c]
Fe^{3+}(aq)	−1.1[b]	$V(OH)_7^-$	−163.2[a]	PO_4^{3-} (aq)	−243.5[a]
$FeOH^{2+}$(aq)	−54.83[b]	$VOOH^+$	−155.65[f]	HPO_4^{2-} (aq)	−260.34[a]
$Fe(OH)_2^+$(aq)	−106.7	V^{3+}	−57.8[h]	$H_2PO_4^-$ (aq)	−270.14[h]
Fe^{2+}(aq)	−18.85[b]	**Uranium**		$H_3PO_4^0$(c)	−273.10[a]
$FeOH^+$(aq)	−62.58[f]	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	$U(OH)_4^0$(c)	−347.18[a]	NH_4^+(aq)	−18.99[c]
FeO(c)	−60.03[g]			Pb^{2+}(aq)	−5.83[a]
Fe_2S(c) (pyrite)	−38.3[g]			O_2(g)	0.00
FeS(c)	−24.22[g]				

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)

R000227

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 Thermodynamics. 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. *Radiochemica Acta* 54: 133-38.
[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 temperatures.* 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. Baily, 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 Cosmochimica Acta* 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 $[H^+][OH^-] = K_{eq} = 10^{-14}$. 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

R000228

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,

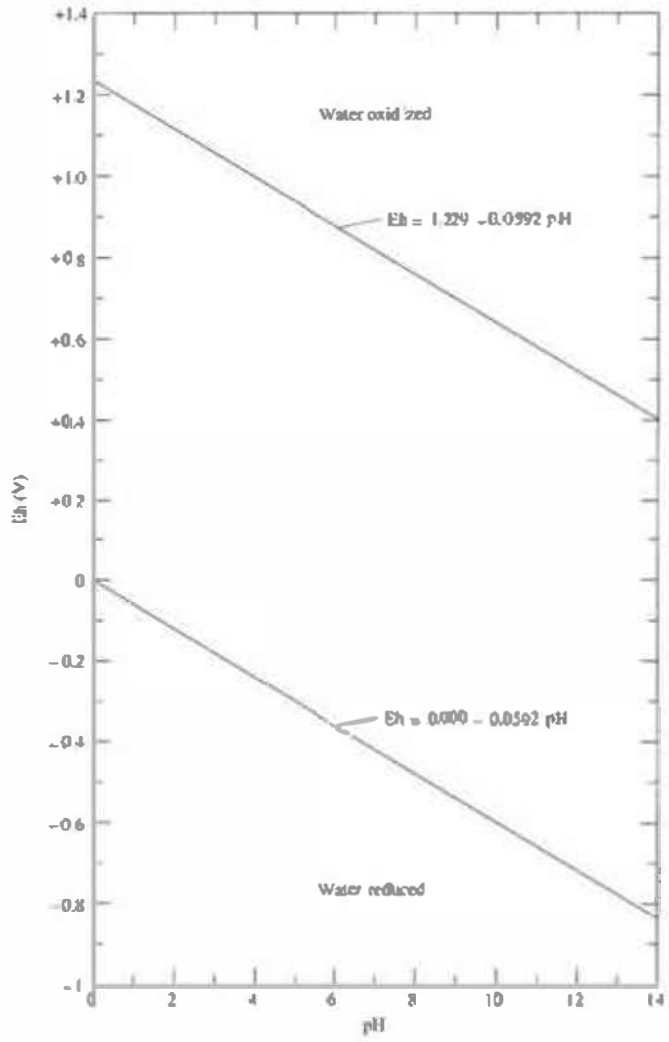
$$\Delta G^0_{H_2O(l)} = -56.69 \text{ kcal}$$

$$\Delta G^0_{O_2(g)} = 0$$

$$\Delta G^0_{H^+} = 0$$

R000229

FIGURE 6.2 Eh-pH diagram showing the stability field for water.



From Equation 6.20,

$$\Delta G_R^0 = 2\Delta G_{H_2O(l)}^0 - \Delta G_{O_2(g)}^0 - 4\Delta G_{H^+}^0$$

$$\Delta G_R^0 = 2(-56.69) - 0 - 4(0) = -113.38 \text{ kcal}$$

The value of ΔG_R^0 in kilocalories is converted to a standard potential by use of Equation 6.19:

$$E^0 = \frac{-\Delta G_R^0}{nF} = \frac{-(-113.38)}{4 \cdot 23.06} = 1.229 \text{ V}$$

The Nernst equation (Equation 6.24) can be expressed as:

$$Eh = E^0 - \frac{RT}{nF} 2.303 \log \frac{[H_2O]}{[O_2][H^+]^4}$$

R000230

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.

R000231

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

$FeO = -60.03$ kcal/mol

$Fe(OH)_2^+ = -106.7$ kcal/mol

$Fe(OH)_3 = -166$ kcal/mol

$Fe^{2+} = -18.85$ kcal/mol

$Fe(OH)_4^- = -198.4$ kcal/mol

$Fe^{3+} = -1.1$ kcal/mol

$H^+ = 0$

$H_2O = -56.69$ kcal/mol

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 ($Fe(OH)_2^+ + 2H^+ + e^- \rightleftharpoons Fe^{2+} + 2H_2O$):

$$\Delta G_R^0 = 2\Delta G_{H_2O}^0 + \Delta G_{Fe^{2+}}^0 - \Delta G_{Fe(OH)_2^+}^0 - 2\Delta G_{H^+}^0$$

$$\Delta G_R^0 = 2(-56.69) + (-18.85) - (-106.7) - 2(0)$$

$$\Delta G_R^0 = -25.53 \text{ kcal/mol}$$

$$E^0 \frac{-\Delta G_R^0}{nF} = \frac{-(-25.53)}{1 \cdot 23.06} V$$

$$E^0 = +1.107 V$$

R000232

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 $\log 1 = 0$:

$$Eh_{(volts)} = 0.898 - 0.0592\ pH \qquad (6.33)$$

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:

$$Eh_{(volts)} = 1.107 - 0.1184\ pH \qquad (6.34)$$

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:

$$Eh = 0.770\ V \qquad (6.35)$$

R000233

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.

$$\log k_{eq} = -\frac{\Delta G_R^0}{1.364} = -\frac{2.96}{1.364} = -2.17$$

$$K_{eq} = 1\,0^{-2.17}$$

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:

$$\Delta G_R^0 = \Delta G^0_{Fe(OH)_2^+} + \Delta G^0_{H+} - \Delta G^0_{FeOH^{2+}} - \Delta G^0_{H_2O}$$

$$\Delta G_R^0 = -106.7 + 0 - (-54.83) - (-56.69)$$

$$\Delta G_R^0 = +4.82 \text{ kcal/mol}$$

R000234

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 hy similar reasoning. Remember that the activity of a solid in equilibrium with dissolved species is I. 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:

$$\Delta G_R^0 = \Delta G^0_{Fe(OH)_2^+} + \Delta G^0_{H_2O} - \Delta G^0_{Fe(OH)_3} - \Delta G^0_{H^+}$$

$$\Delta G_R^0 = -106.7 + (-56.69) - (-166) - 0 = 2.61$$

$$\log K_{eq} = -\frac{\Delta G_R^0}{1.364} = -\frac{2.61}{1.364} = -1.91$$

$$K_{eq} = 10^{-1.91}$$

$$K_{eq} = \frac{\left[Fe(OH)_2^+\right]\left[H_2O\right]}{\left[Fe(OH)_3\right]\left[H^+\right]} = 10^{-1.91}$$

R000235

Since [Fe(OH)3] = land [H2O] = 1,

$$\left[H^+\right]=\frac{\left[Fe(OH)_2^+\right]}{10^{-1.91}}$$

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 $[Fe(OH)_3] = 1$, then

$$Eh_{(\text{volts})} = 0.994 - 0.0592 \log\left[Fe^{2+}\right] - 0.178\text{pH} \qquad (6.47)$$

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 $[H_2O] = 1$,

$$\left[H^+\right] = \frac{10^{-17.8}}{\left[Fe(OH)_4^-\right]} \qquad (6.48)$$

R000236

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 $n = 1$,

$$Eh = +1.375 - 0.0592\log\frac{1}{[Fe(OH)_4^-][H^+]^2}$$

R000237

This can be expressed in terms of pH as

$$Eh = 1.375 + 0.0592 \log\left[Fe(OH)_4^-\right] + 2(0.0592) \log\left[H^+\right]$$

$$Eh_{(volts)} = 1.375 + 0.0592 \log\left[Fe(OH)_4^-\right] - 0.118pH \qquad (6.50)$$

Reaction6.45 ($FeO + 2H^+ \rightleftharpoons Fe^{2+} + H_2O$) issolvedasan equilibriumreaction:

$$\Delta G^0{}_R = \Delta G^0{}_{Fe^{2+}} + \Delta G^0{}_{H_2O} - \Delta G^0{}_{FeO} - 2\Delta G^0{}_{H^+}$$

$$\Delta G^0{}_R = -18.85 + (-56.69) - (-60.03) - 2(0)$$

$$\Delta G^0{}_R = -15.51 \text{ kcal/mol}$$

$$\log k_{eq} = \frac{-\Delta G^0{}_R}{1.364} = 11.36$$

$$k_{eq} = 10^{11.36}$$

$$k_{eq} = \frac{[Fe^{2+}][H_2O]}{[FeO][H^+]^2}$$

Since $[H_2O]$ and $[FeO] = 1$,

$$[H^+]^2 = \frac{[Fe^{2+}]}{10^{11.36}}$$

$$[H^+] = \sqrt{\frac{[Fe^{2+}]}{10^{11.36}}} \qquad (6.51)$$

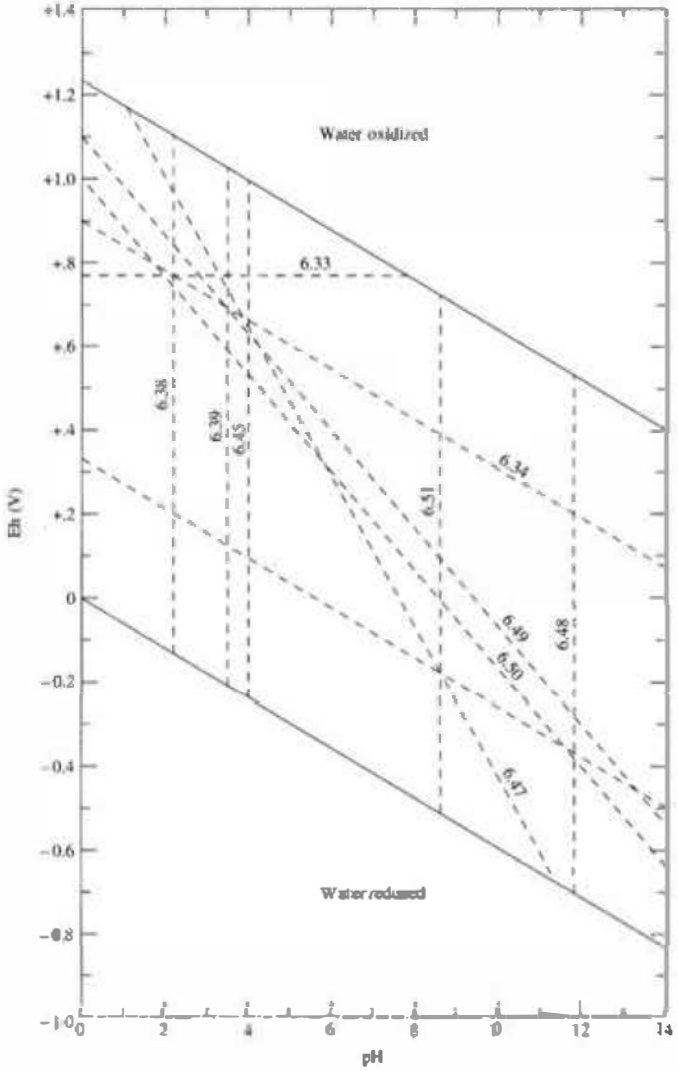
Several of the equations, including Equations 6.46, 6.47, 6.48, 6.50, and 6.51, depend upon the activity of the dissolved iron.

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	$Eh_{(volts)} = 0.322 - 0.0592pH$

R000238

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.)

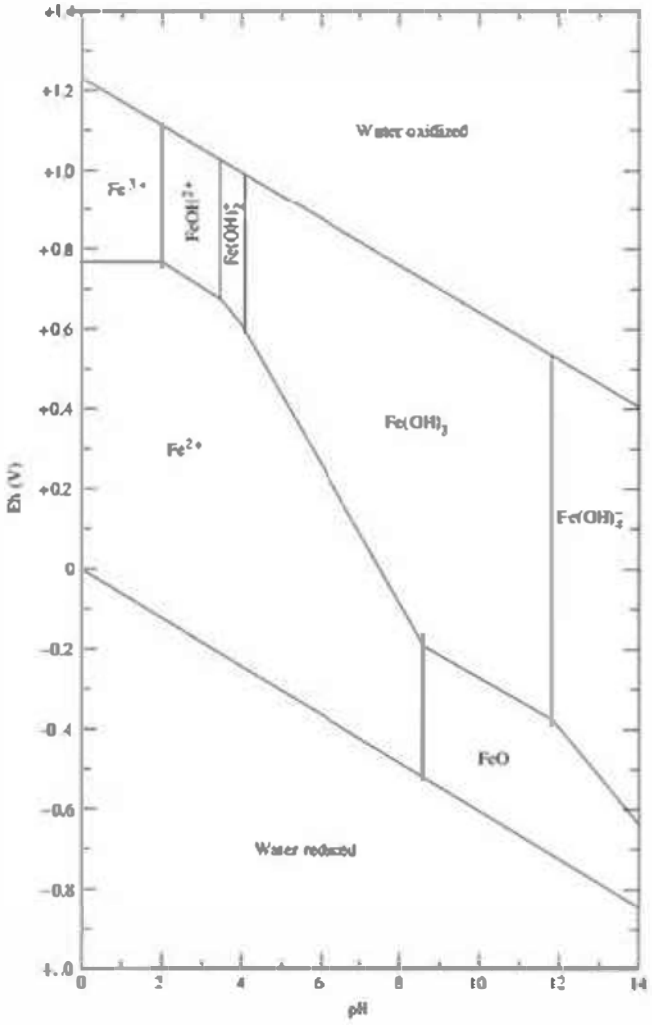


The iron Eh-pH diagram of Figure 6.4 is for a system that contains only dissolved iron. If other elements are present, such as sulfur, then additional iron compounds are possible. Figure 6.5 shows an Eh-pH diagram for a system with an iron activity of 56 µg/L (10^{-6} mol), sulfur of 96 mg/L as SO_4^{2-}, 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.

R000239

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).

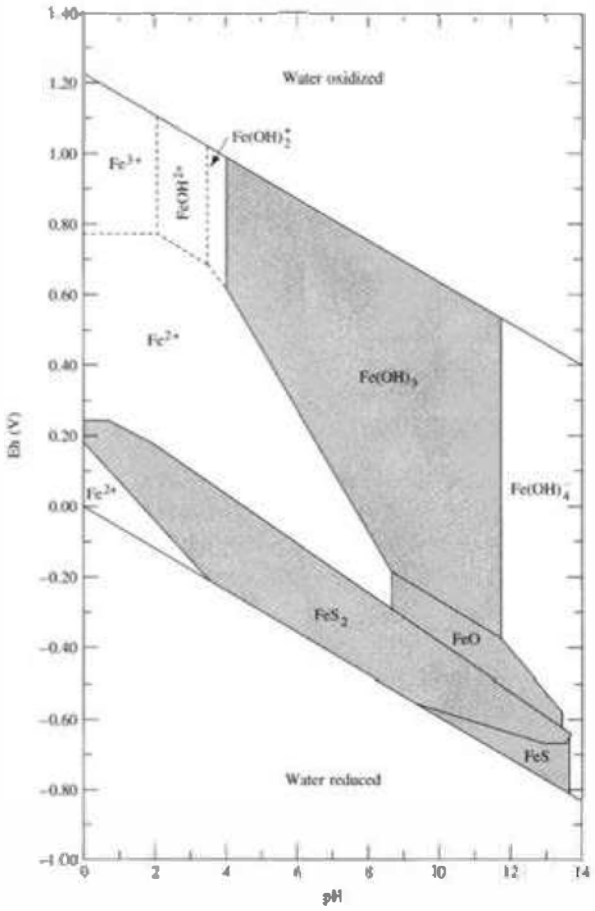
6.6 Metal Complexes and Facilitated Particle Transport

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

R000240

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^-.



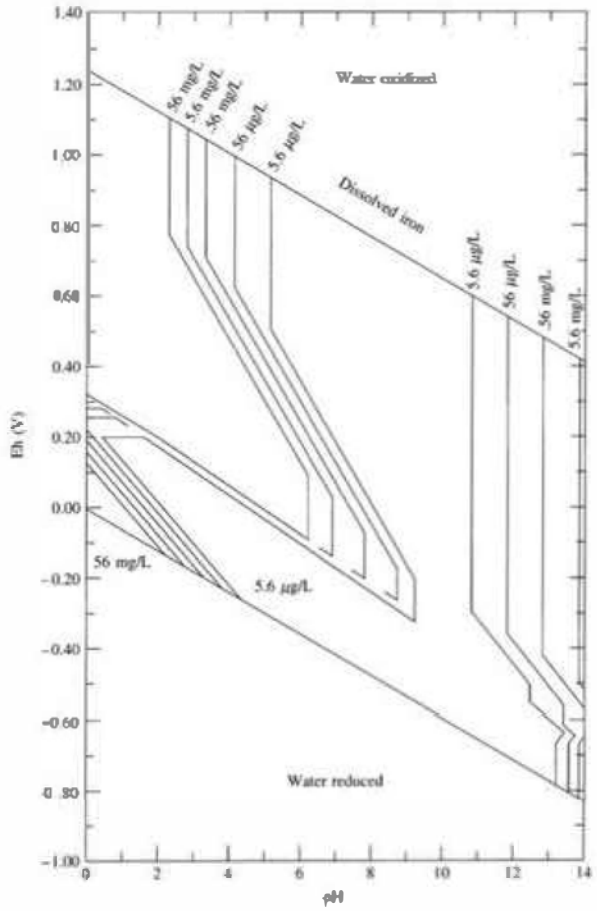
Source: J. D. Hem. 1985. *Study and interpretation of the chemical characteristics of natural waters*. Water Supply Paper 2254, U.S. Geological Survey.

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

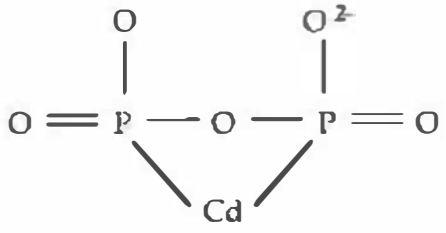
FIGURE 6.6 Equilibrium activity of dissolved iron as a function of Eh and pH under standard conditions, sulfur activity of 96 mg/L as SO_4^{2-} and activity of carbon dioxide of 61 mg/L as HCO_3^-.



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.

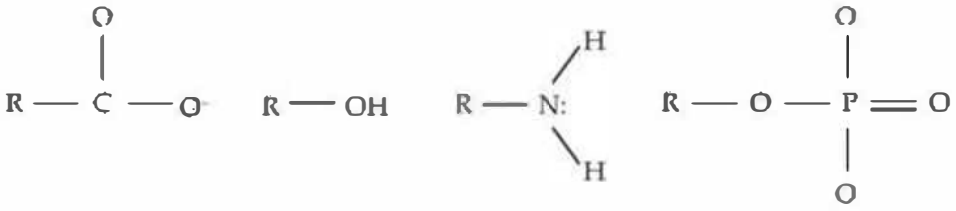
In the case of monovalent ions, there is only one site where the ligand bonds to the metal ion and the ligand is called monodentate (literally, "one tooth"). If the ligand has more than one site that can bond (polydentate), then it forms what is known as a chelating agent. For example, the pyrophosphate ion, $P_2O_7^{4-}$, can bond to a metal ion, such as cadmium, at two locations:



R000242

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.

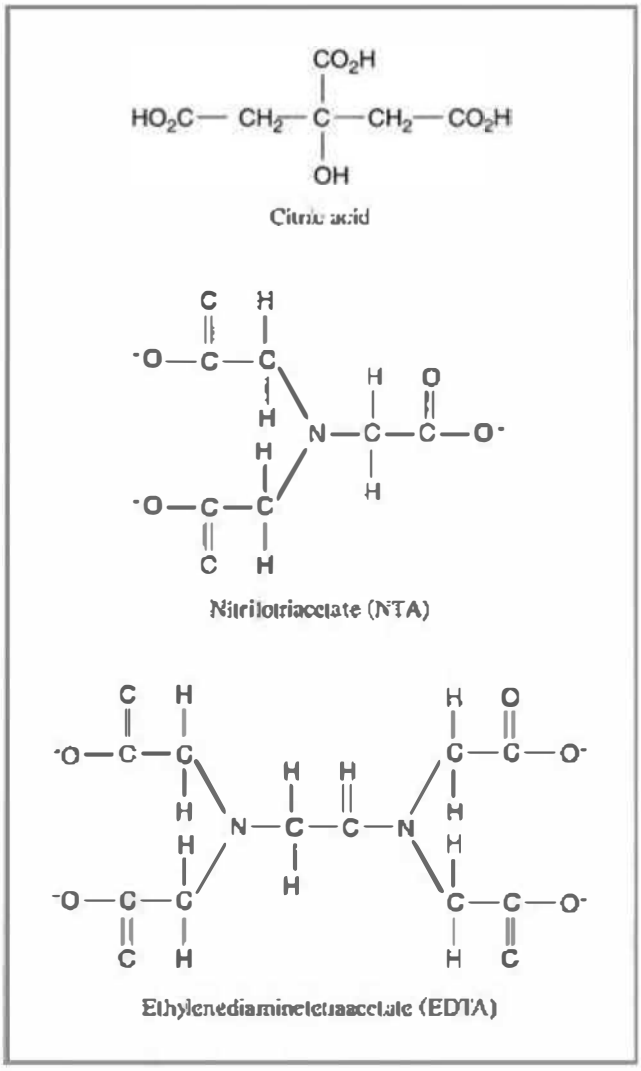
EDTA in wastewater can vastly increase the mobility of associated metals in the subsurface. Monitoring wells near radioactive waste disposal trenches at the Oak Ridge (Tennessee) National Laboratory contained significant levels of sodium EDTA, which was used as a cleaning agent. The same wells also contained 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

R000243

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.

R000244

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

R000245

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

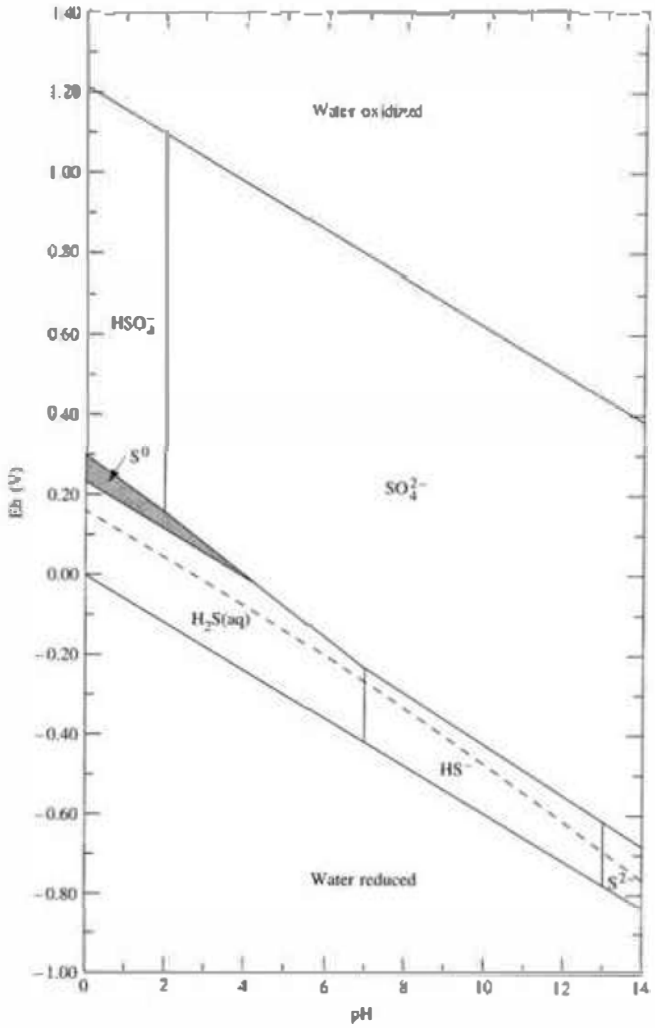
Sulfur is naturally released to the environment by the weathering of minerals containing the element. Rock containing pyrite can be oxidized to release sulfur, with microorganisms acting as a catalyst and mediating the oxidation. This is the source

R000246

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, HSO_4^- 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.

R000247

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

R000248

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 4.09, 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

R000249

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.

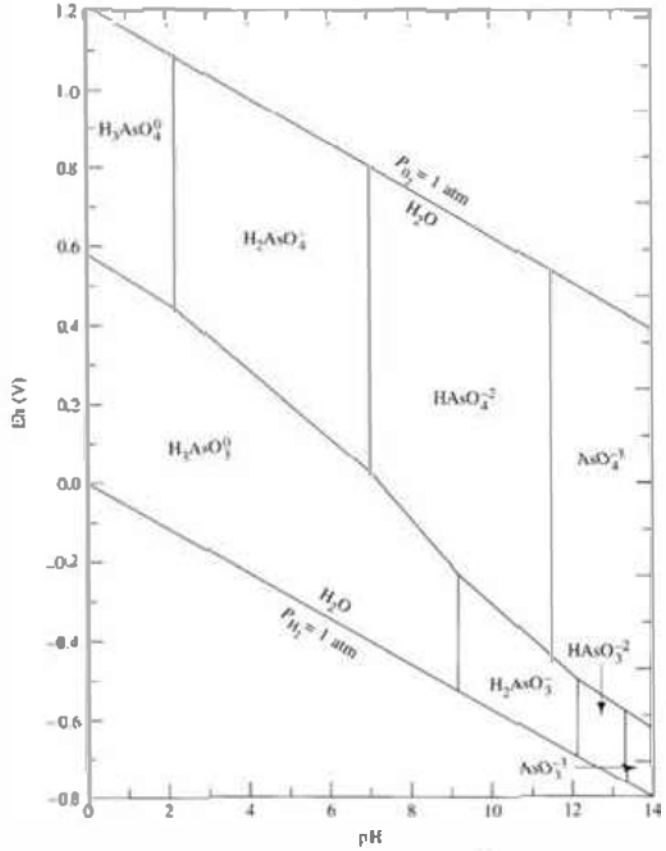
In small concentrations selenium is an essential nutrient, but in large amounts it is harmful to humans, fish, and wildlife (Coefield 2009). High selenium in groundwater-dependent ecosystems can wipe out entire species and cause massive

R000250

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.

R000251

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 typically 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 1mg/L.

R000252

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).

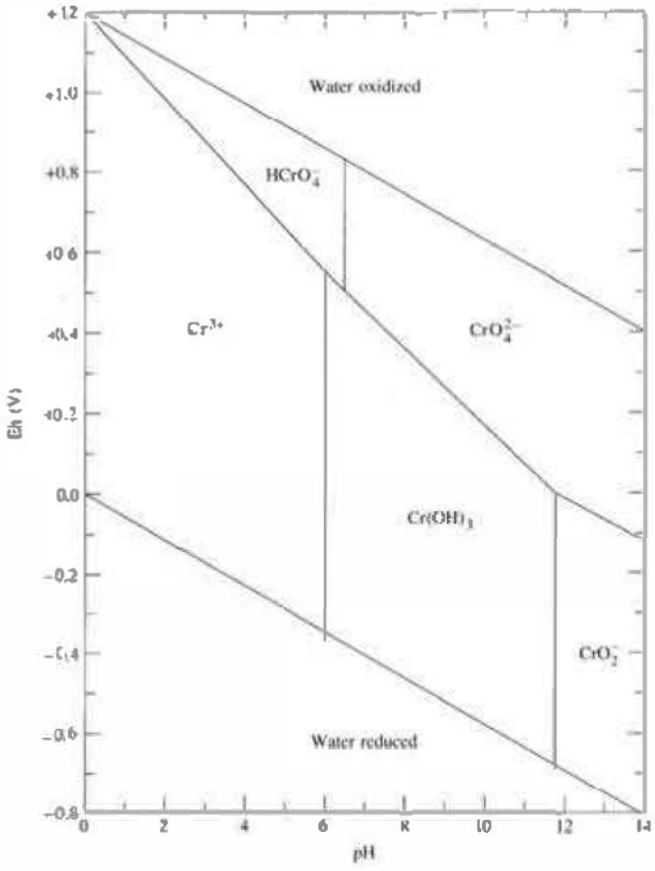
$$CrO_4^{2-} + 3Fe^{2+} + 8H_2O \rightleftharpoons 3Fe(OH)_3 + Cr(OH)_3 + 4H^+$$

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 metal-plating 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 waste-discharge 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.

R000254

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

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

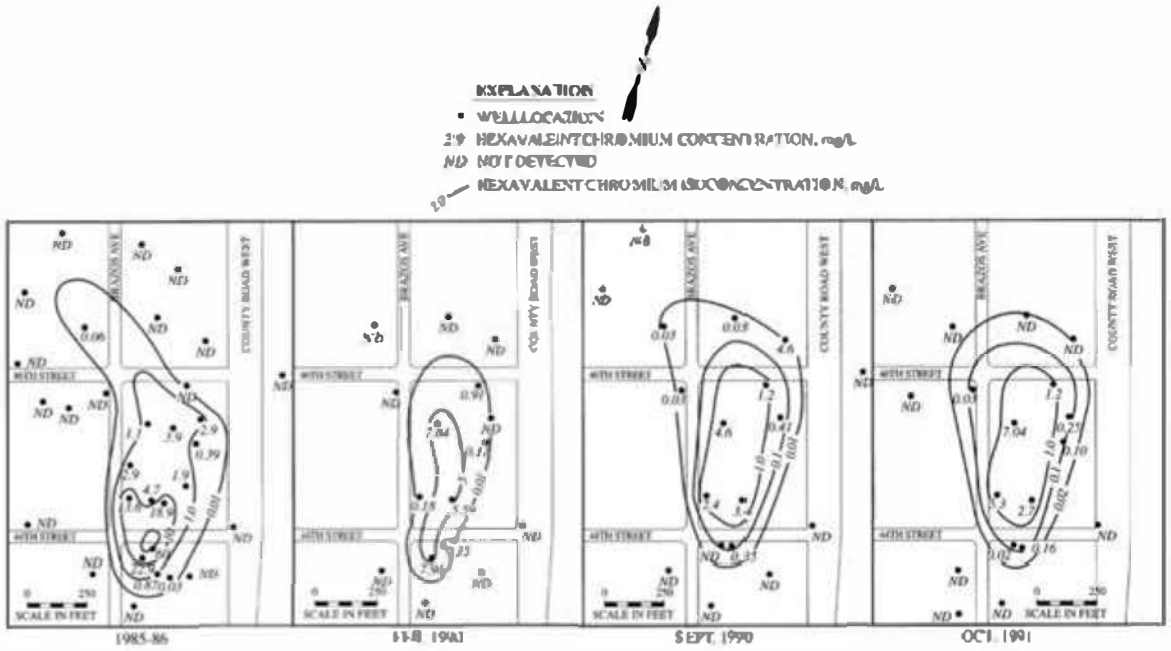
Zinc is a fairly common metal and is extensively used in metallurgy and as a pigment, zinc oxide, which is often worn on the noses of lifeguards and other people in the sun. It occurs in the +2 valence state. Zinc carbonate has a rather low equilibrium constant, 10^{-10}, which would limit the solubility 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.

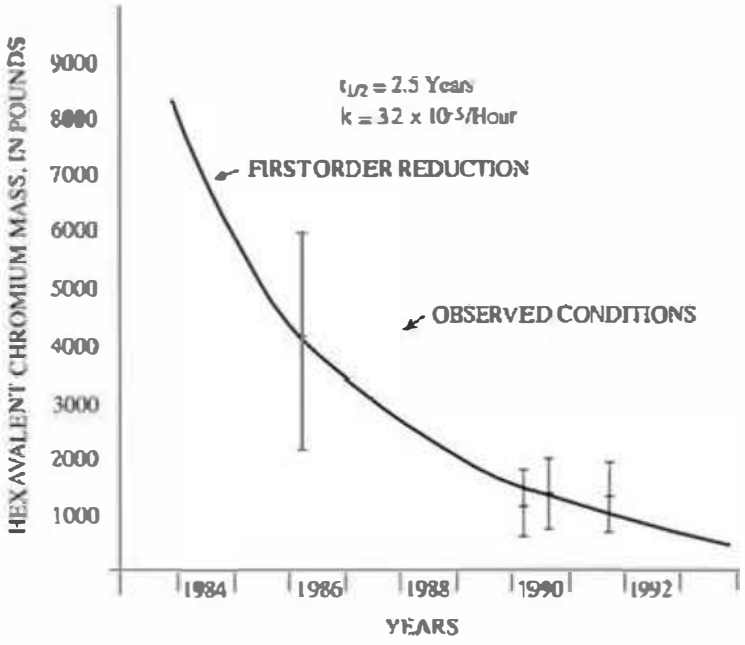
R000256

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.

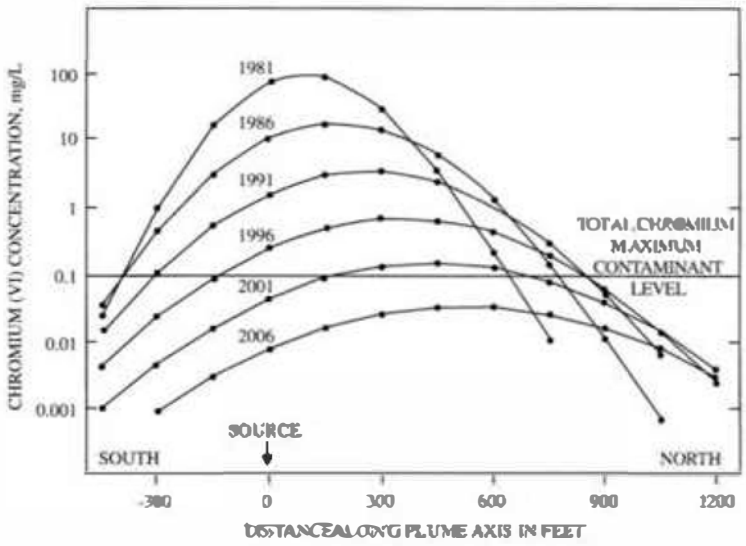
FIGURE 6.12 Reduction of the dissolved mass of Cr^{6+} with time.



Source: T. Henderson. 1994. Geochemical reduction of hexavalent chromium in the Trinity Sand aquifer. *Groundwater* 32:477-486. Used with permission.

R000257

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

R000258

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, $^{206}Pb/^{203}Pb$ (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 higher 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^*:

$$N^*_{(mol/gm)} = 2.81\times10^{-6}CEC_{(meq/100g)} + 1.07\times10^{-5}pH - 4.93\times10^{-5}$$

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

R000259

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

R000260

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—uronium, 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 1 disintegration 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, ^{114}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

R000261

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 halflife, 4.5 x 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 $PO_4^- = 0.1$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

R000262

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 to be 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 ^{224}Ra, whereas ^{235}U decays to ^{223}Ra and ^{238}U disintegrates to ^{235}Th, 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

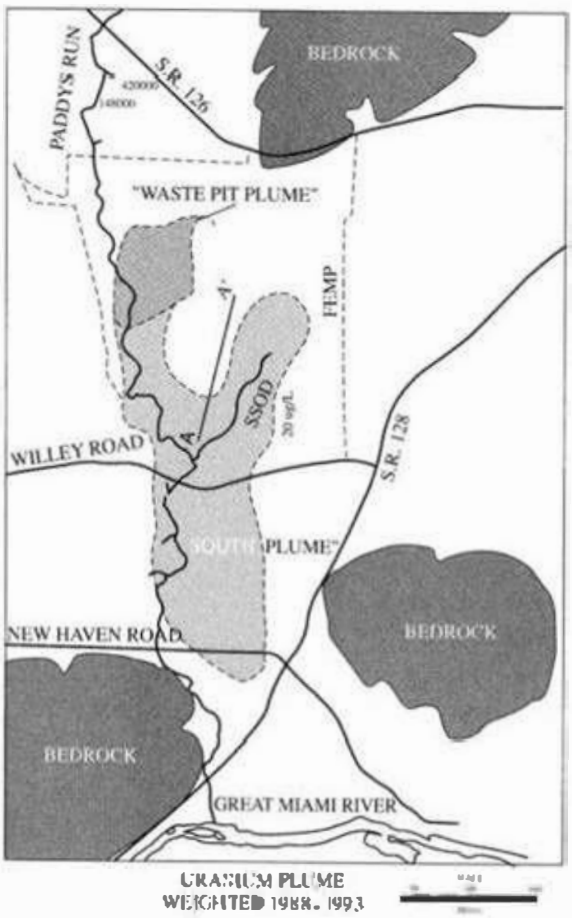
$$Sr^{2+} < Ra^{2+} < Ca^{2+} < Mg^{2+} < Cs^{2+} < Rb^{2+} < K^+ < NH_4^+ < Na^+ < Li^+$$

^{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,

R000263

FIGURE 6.17 Composite plume of total dissolved uranium >0.20 µg/L for the period 1988 to 1993.



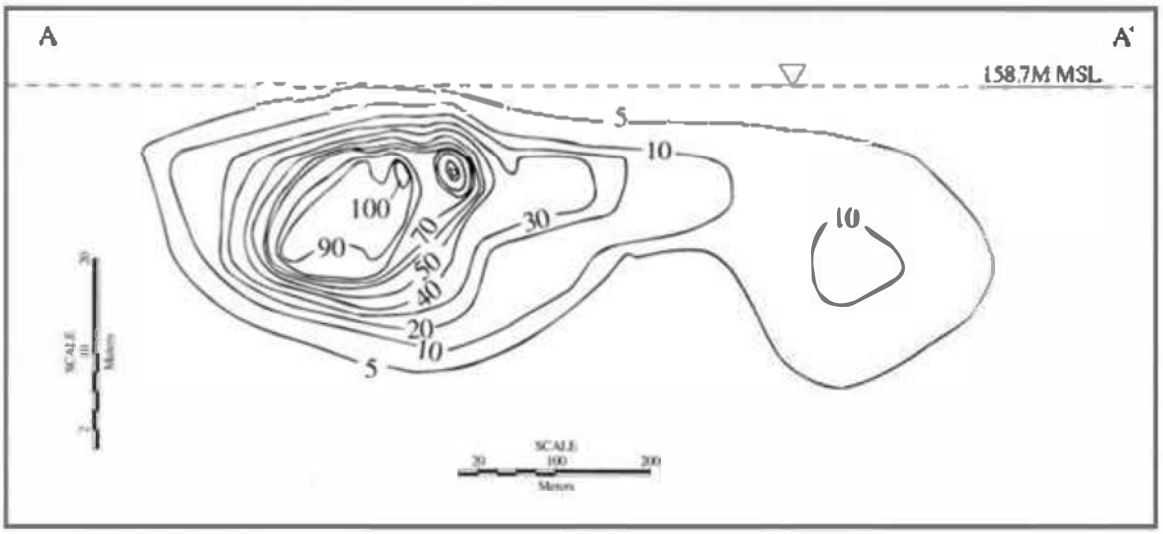
Source: W.C. Sidle and P.Y. Lee. 1996. Uranium contamination in the Great Miami Aquifer at the Fernald Environmental Management Project, Fernald Ohio. *Groundwater* 34:876–882. Used with permission.

Table 6.7 Distribution of 226Ra and 228Ra by aquifer type in the Atlantic coastal plain and Piedmont provinces.

Aquifer Type	Number of Samples	Ra–228 (pCi/L) Geometric Mean	Ra–228 (pCi/L) Range	Ra–226 (pCi/L) Geometric Mean	Ra–226 (pCi/L) 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

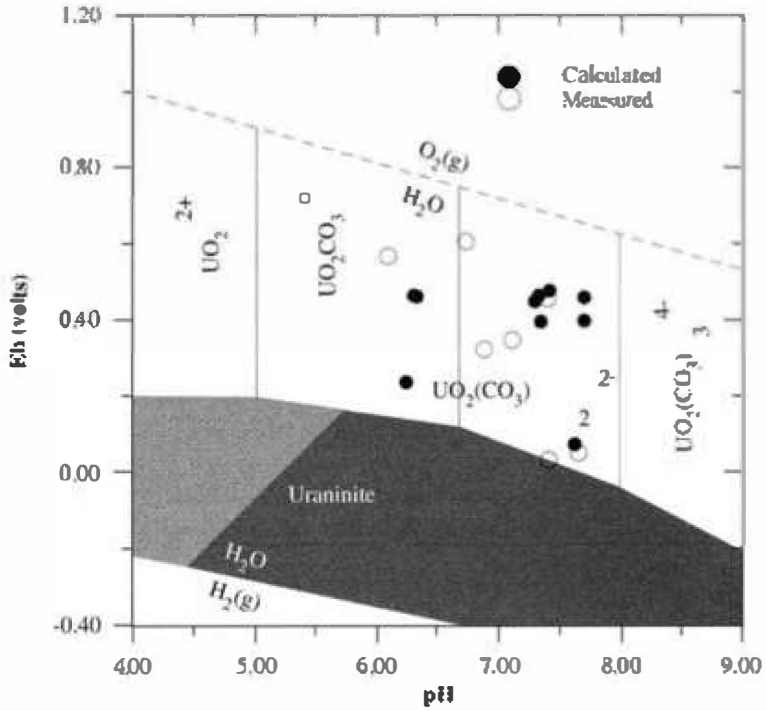
Source: C.T. Hess, J. Michel, T.R. Horton, H.M. Prichord, and W.A. Coniglio, "The occurrence of radioactivity in public water supplies in the United States," *Health Physics* 48 (1985):553–86.

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.

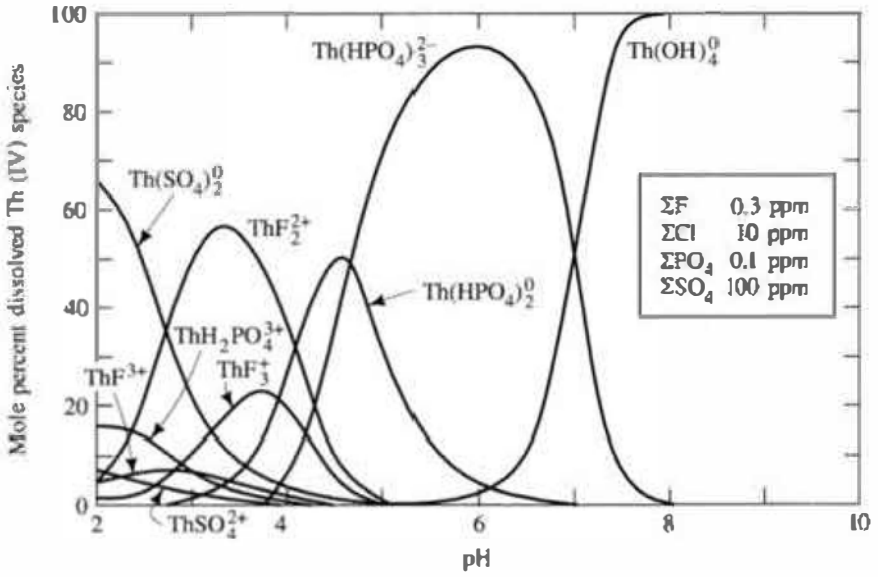
Figure 6.19 Measured and calculated redox potential for the UO_2^{2+}/U^{4+} pair plotted on the $\Sigma U = 10^{-6}$ stability field.



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.

R000265

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 radiolum inescent 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

R000267

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

R000268

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 site 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

R000269

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 nonaqueous 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.

R000270

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 electromagneric 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.

R000271

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 (eg., 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

R000272

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 phytoscreening. 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).

R000273

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 greatest 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

R000274

will develop from the soil to the porous 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.

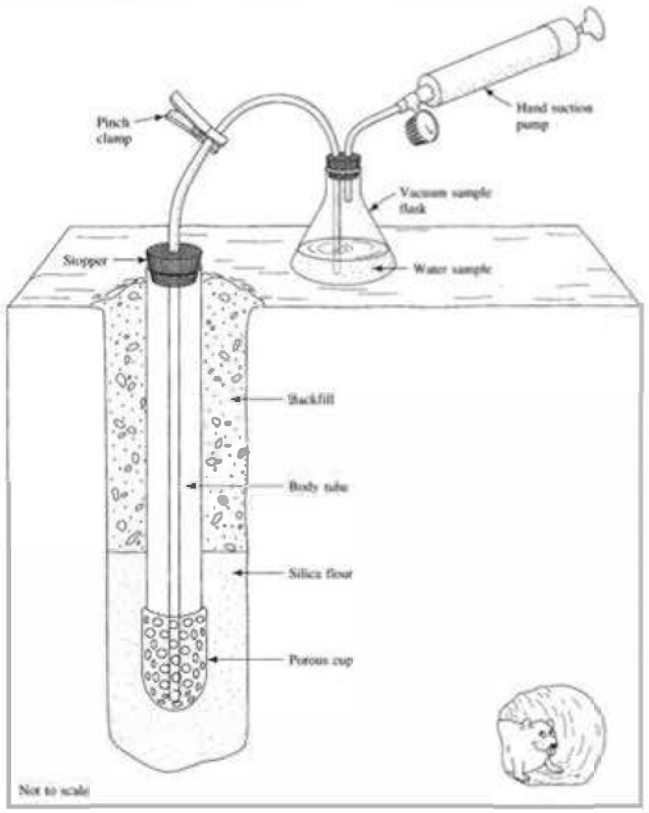
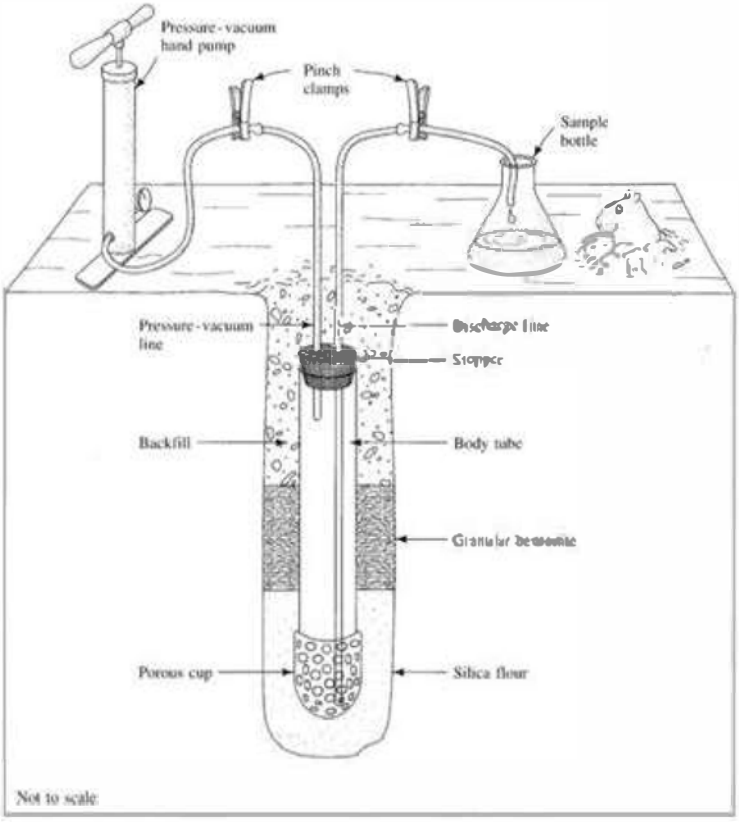


FIGURE 8.2 Operation of a pressure-vacuum lysimeter.



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

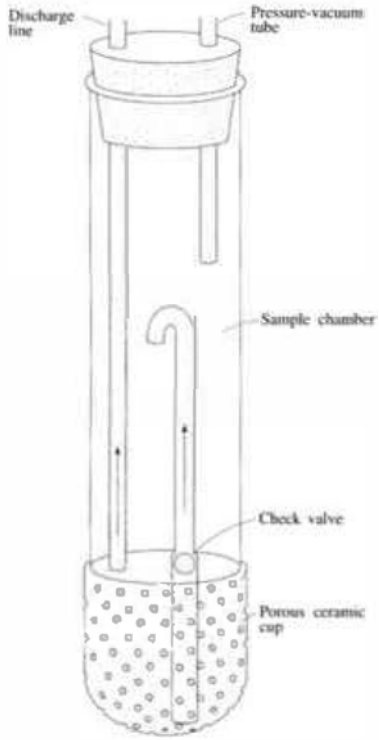
In order for suction lysimeters to work properly, they must be carefully installed (Wilson 1991). Prior to use, new porous ceramic cups should be leached with a 10% hydrochloric acid solution for 24 hours to remove dust from manufacturing. They should then be thoroughly rinsed by passing distilled water 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

R000276

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

R000277

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 water-sampling 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 multi-level 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:

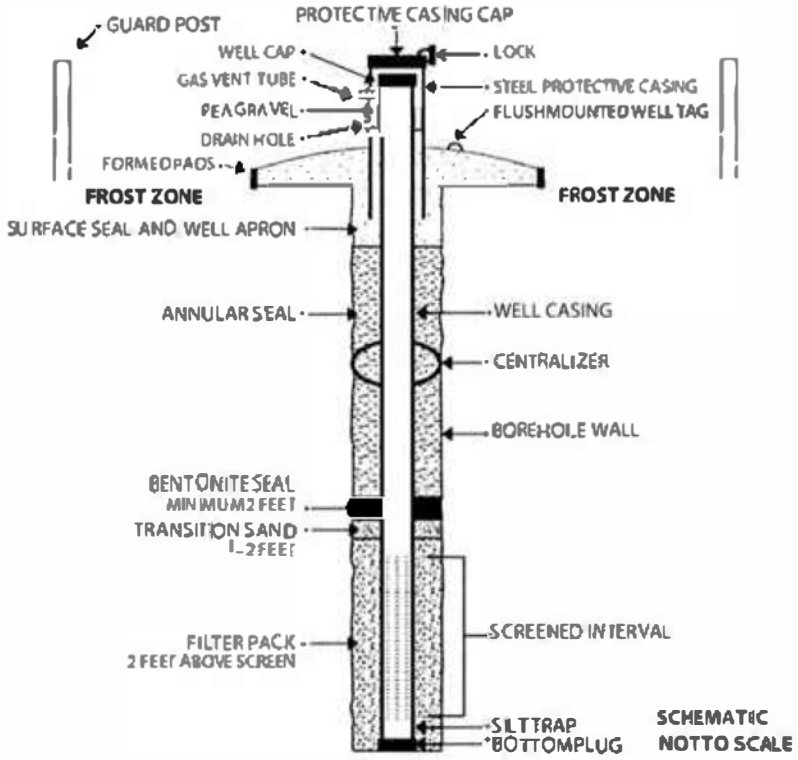
- Type of casing material.
- Diameter of the casing.
- If there will be a well screen, multiple screens, or an open borehole.
- If there is an open borehole, how deep the surface casing should be set. Cross connections between separate aquifers should be avoided.
- Length of casing.
- Depth of the well.
- Number of target sampling depths and screened intervals necessary in each well.
- Setting and length of the well screen(s).

R000278

- 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. Site 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 site 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.

R000279

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

R000280

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 (68.6–14 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:
Tetrohydrofuran, 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?

R000282

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 Parker (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

R000283

TABLE 8.3 Comparative strengths of casing materials. Note: 1 lb = 0.454 kg and 1 lb/in² = 0.07 kg/cm².

Material	Casing Tensile Strength (lb)		Casing Collapse Strength (lb/in²)	
	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.

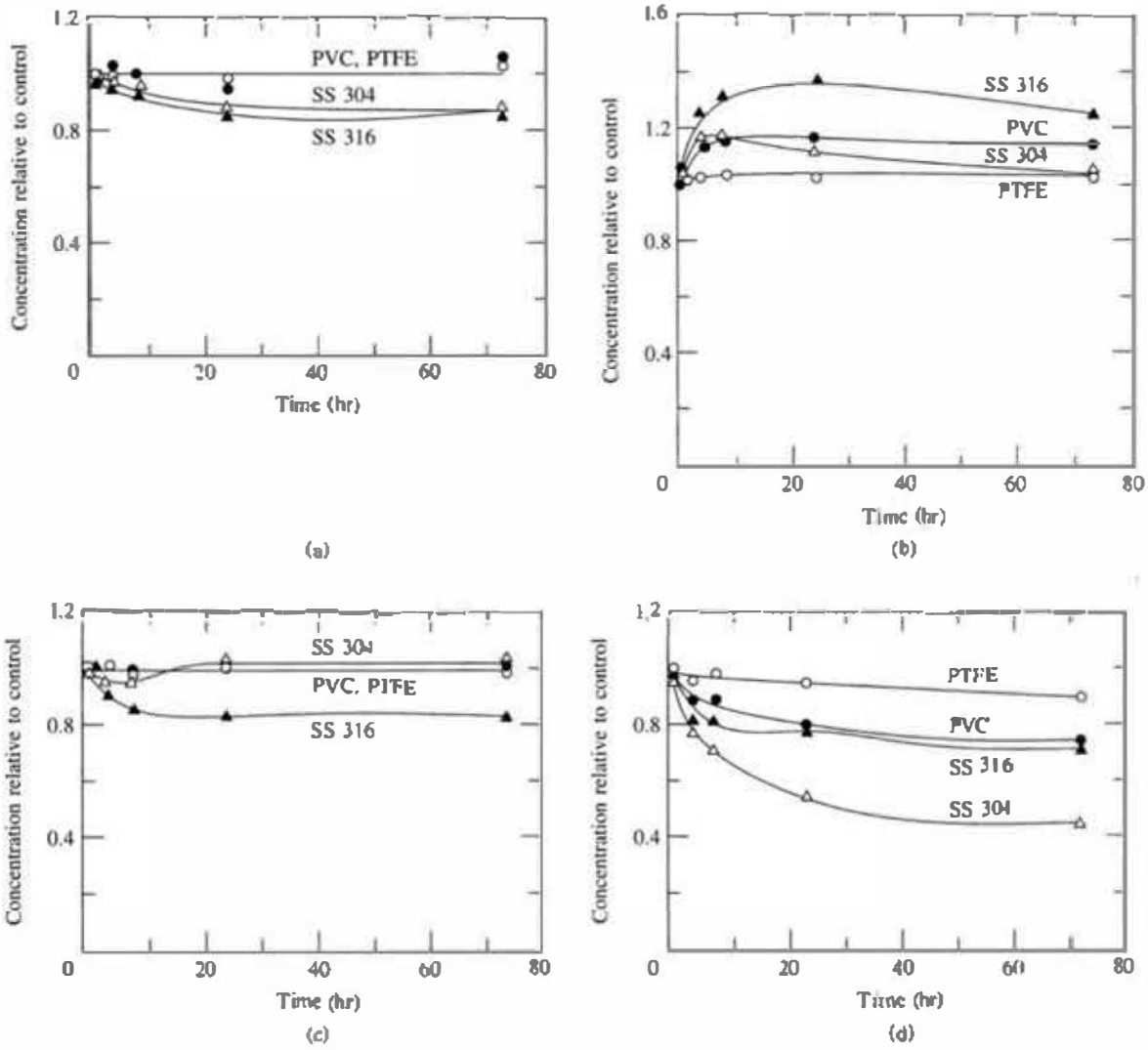
Source: E. Hughes and G. Aarons. 2014. *Well Design and Construction for Monitoring Groundwater at Contaminated Sites.* The California Environmental Protection Agency.)

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 I, I, 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 I, I, I-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.



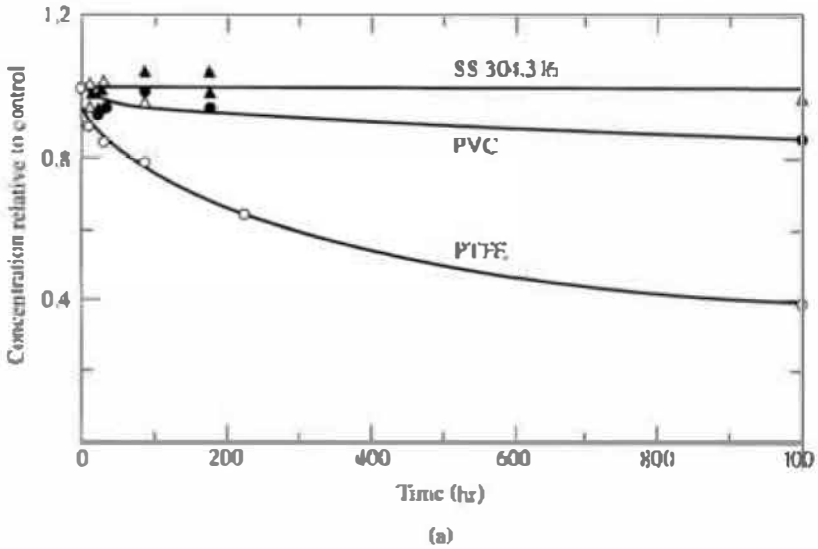
Source: L. V. Parker, A. D. Hewitt, and T. F. Jenkins. 1990. Influence of casing materials on trace level chemicals in ground water. *Groundwater Monitoring & Remediation* 10:146-156. Used with permission.

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

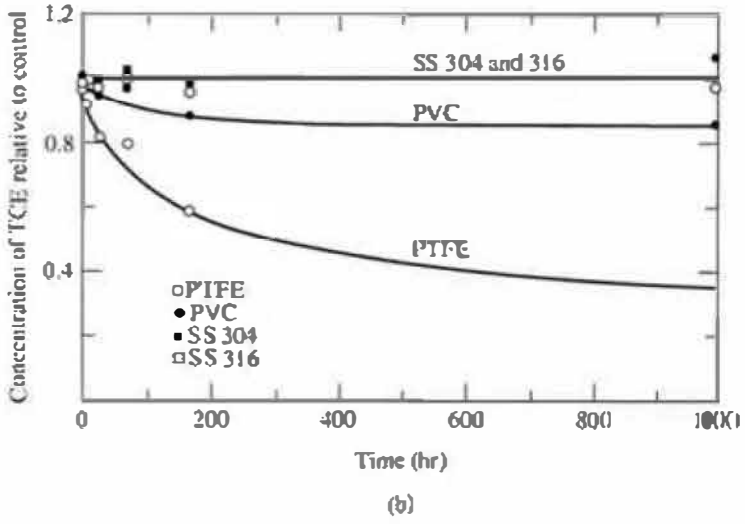
R000285

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

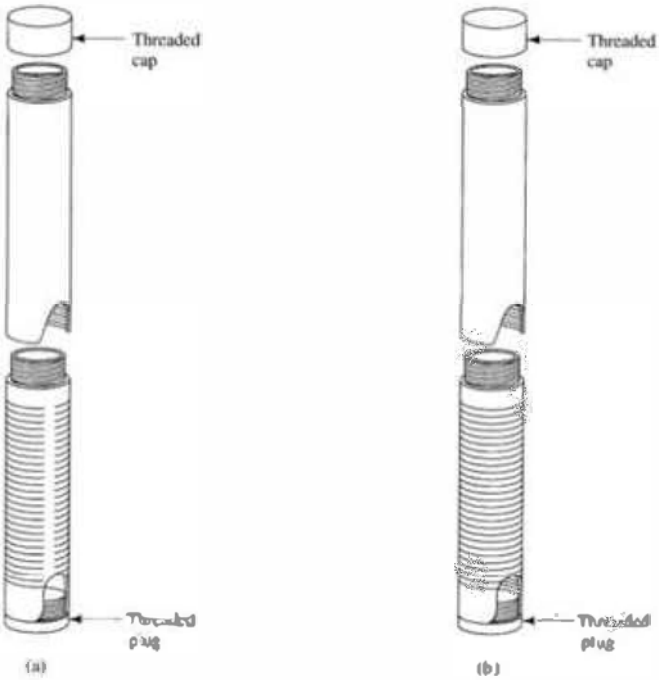
polar or ionic. Papiernik, Widmer and Spalding (1996) studied the impact of using various materials to sample agricultural contaminants, including nitrate-N, atrazine, diethylatrazine, diisopropylatrazine, cyanazine, alachlor, metolachlor and butachlor. They found that other than butachlor (which is 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 hand-cut 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.



R000287

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 smal. 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.

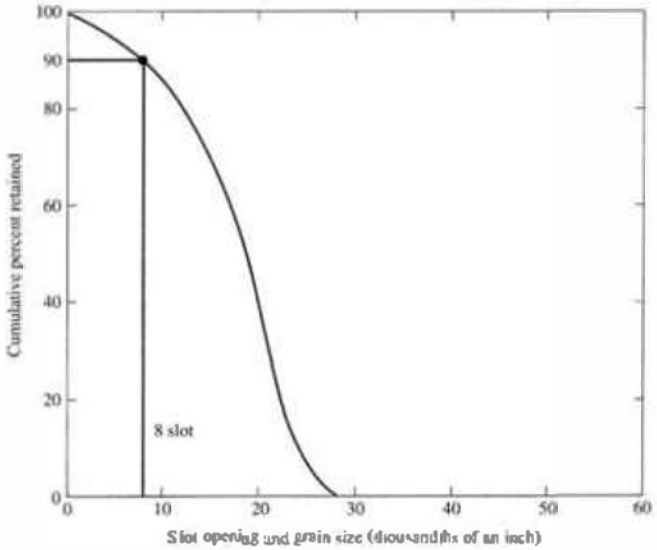
The grain size of the filter-pack material is based on the nature of the formation opposite the screen. If the formation is fine sand, then the grain-size distribution is determined. The filter pack material should have an average grain size that is twice the average grain size of the formation and have 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.



R000289

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. Bentonite-cement 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 shrink 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

R000290

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.

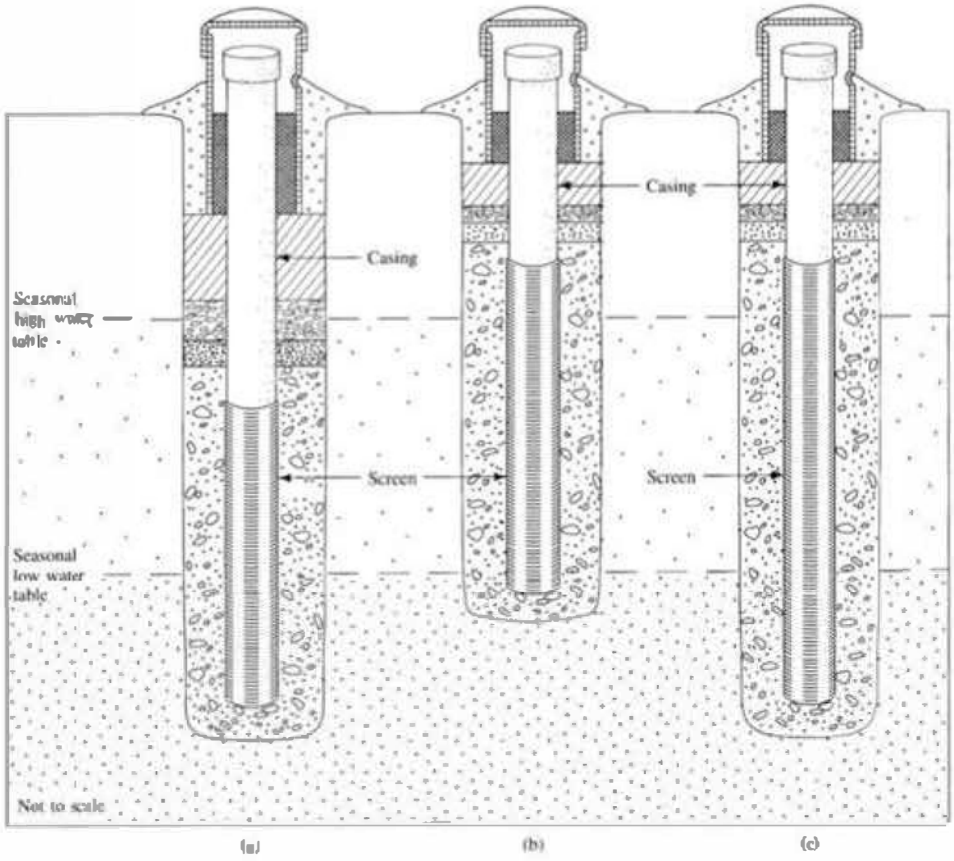
To monitor the position of the water table or to detect the presence of LNAPLs, the screen must be set so that it intersects the water table. The screen must be long enough to intersect the water table over the range of annual fluctuation. In addition, the screen must be long enough so that when the 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

R000291

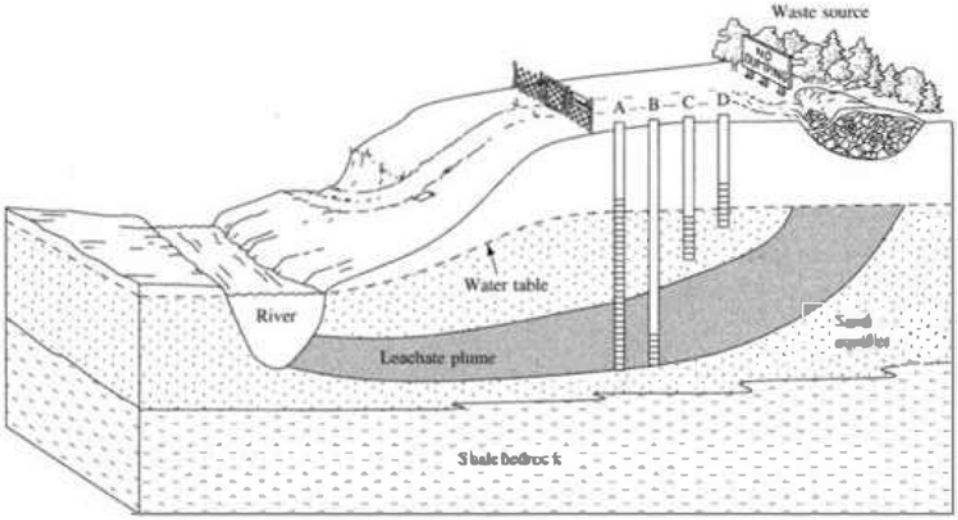
FIGURE 8.10 (a) Incorrect placement of water table–monitoring well screen. Seasonally high water table is above the top of the screen and floating, light nonaqueous phase liquids would be above the screen and not detected. (b) Incorrect placement of water table–monitoring well screen. Seasonally low 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 clusrer). Alrernatively, 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

R000293

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 watertable 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:

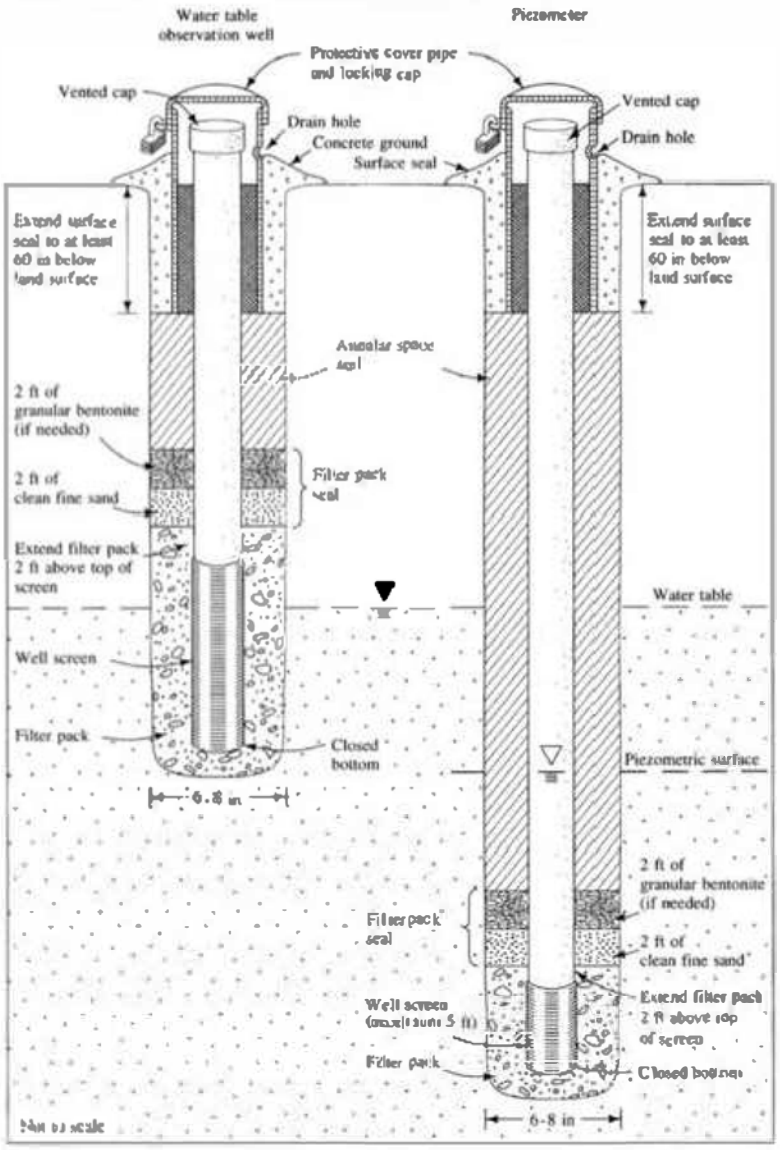
> *"Fully screened monitor wells sample the entire thickness of the aquifer. Therefore, excursions could not pass above or below the well screens. However, the concentration of the indicator parameters might be diluted and therefore may not provide timely warning that an excursion is occurring.*

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: (1) 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.



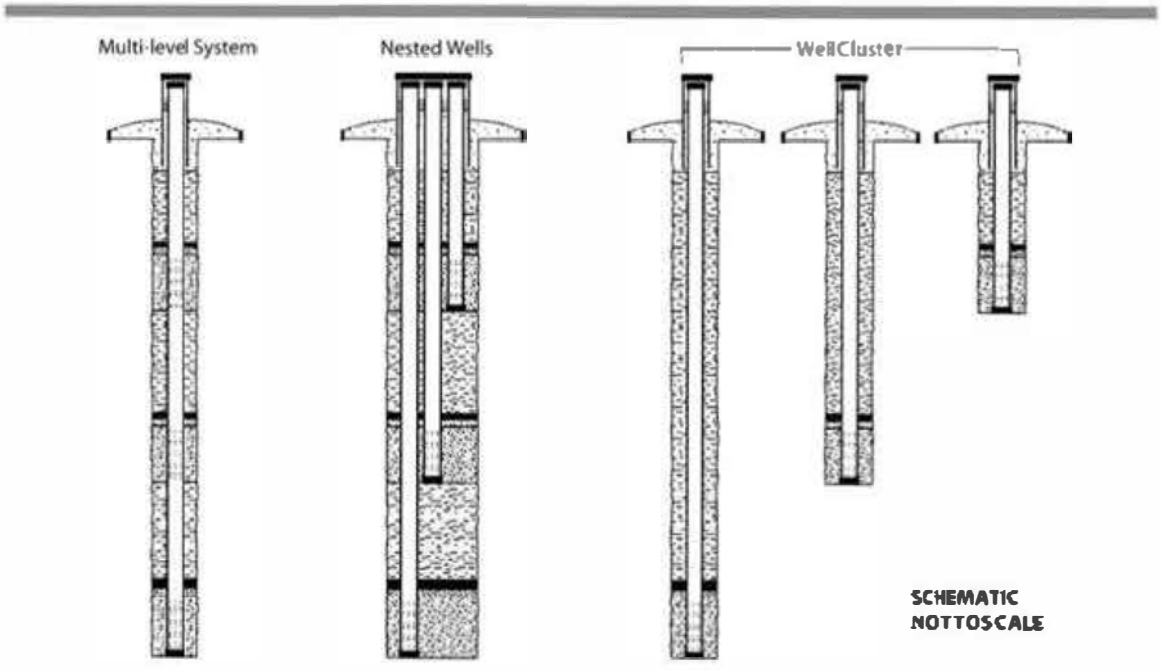
Source: Wisconsin Department of Natural Resources.

R000295

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 closespaced 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.

R000296

(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 prior 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 true 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 the 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.

R000297

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.

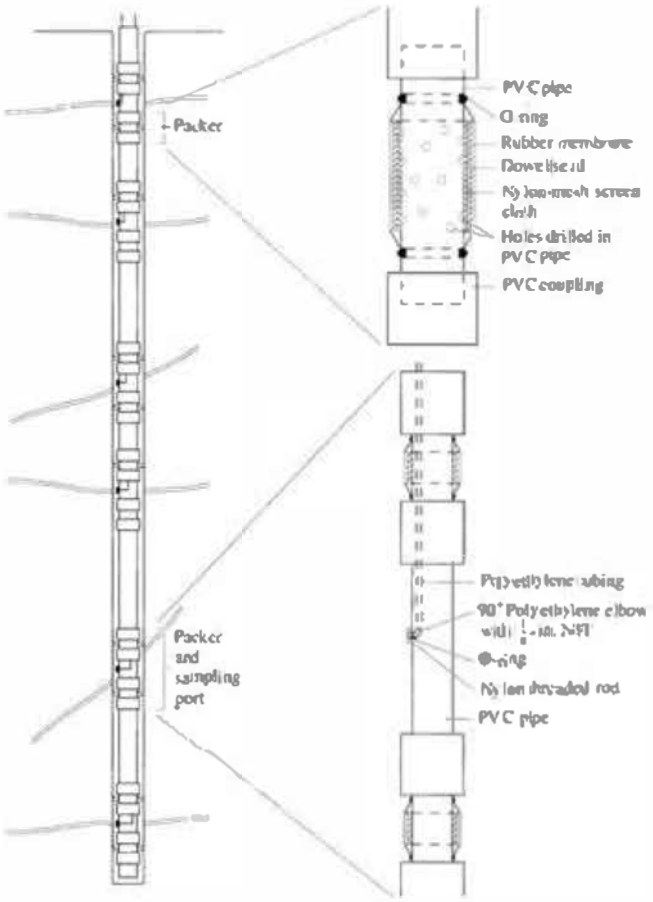
Flexible Liner Systems Another type of multilevel sampling practice employs the flexible liner system (developed by FLUTe™) and represents a significant advancement over a simple multilevel system. Similar to the simple system above, it has a series of internal tubes inside a liner which allow sampling and pressure measurement at selected intervals down hole in uncased wells. In hard rock consolidated systems, downhole 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

R000298

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

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 specificarea 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 nonaqueousphase 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

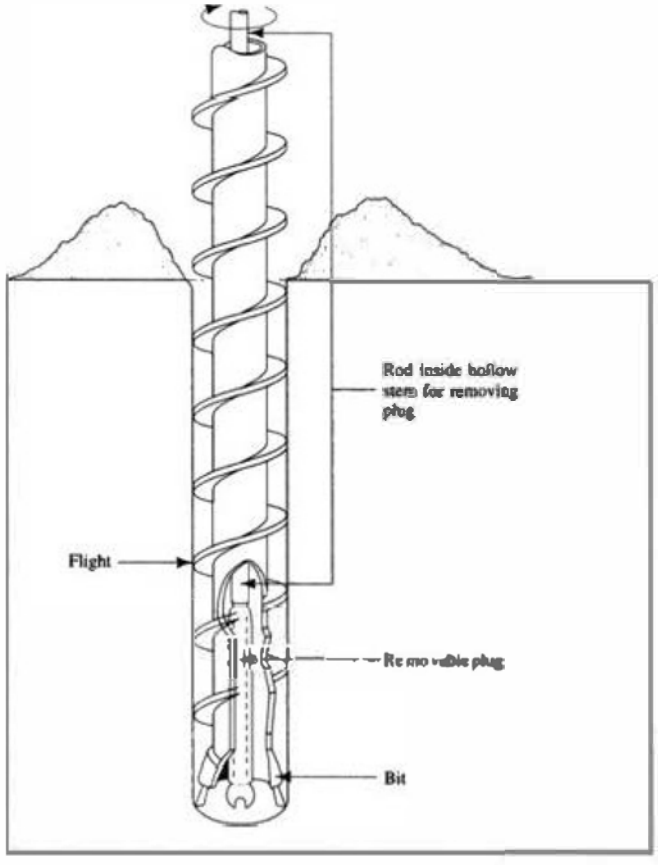
There are a number of methods of drilling that are appropriate for installation of monitoring wells. When working in shallow unconsolidated formations, hollow-stem

R000300

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 both 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.

R000301

FIGURE 8.17 Hollow-stem auger drilling rig.

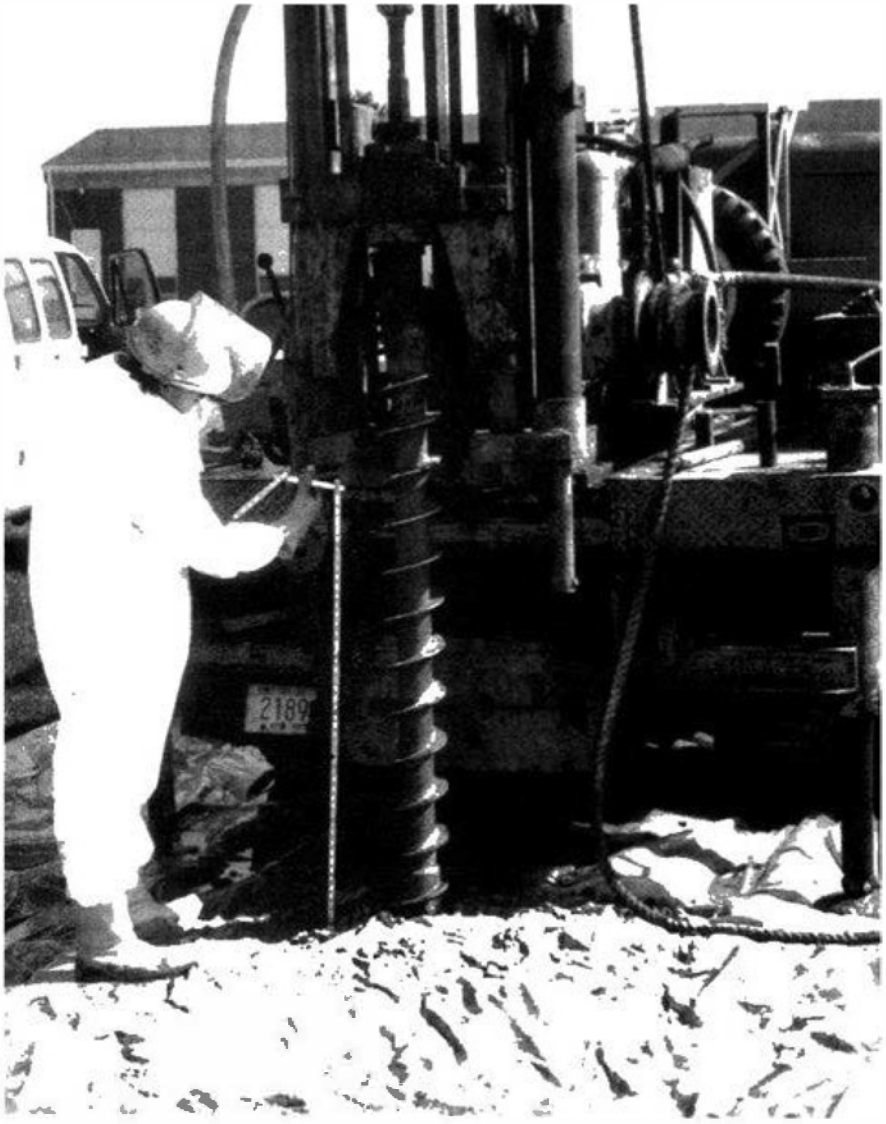


Photo credit: C.W. Fetter.

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

R000302

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.

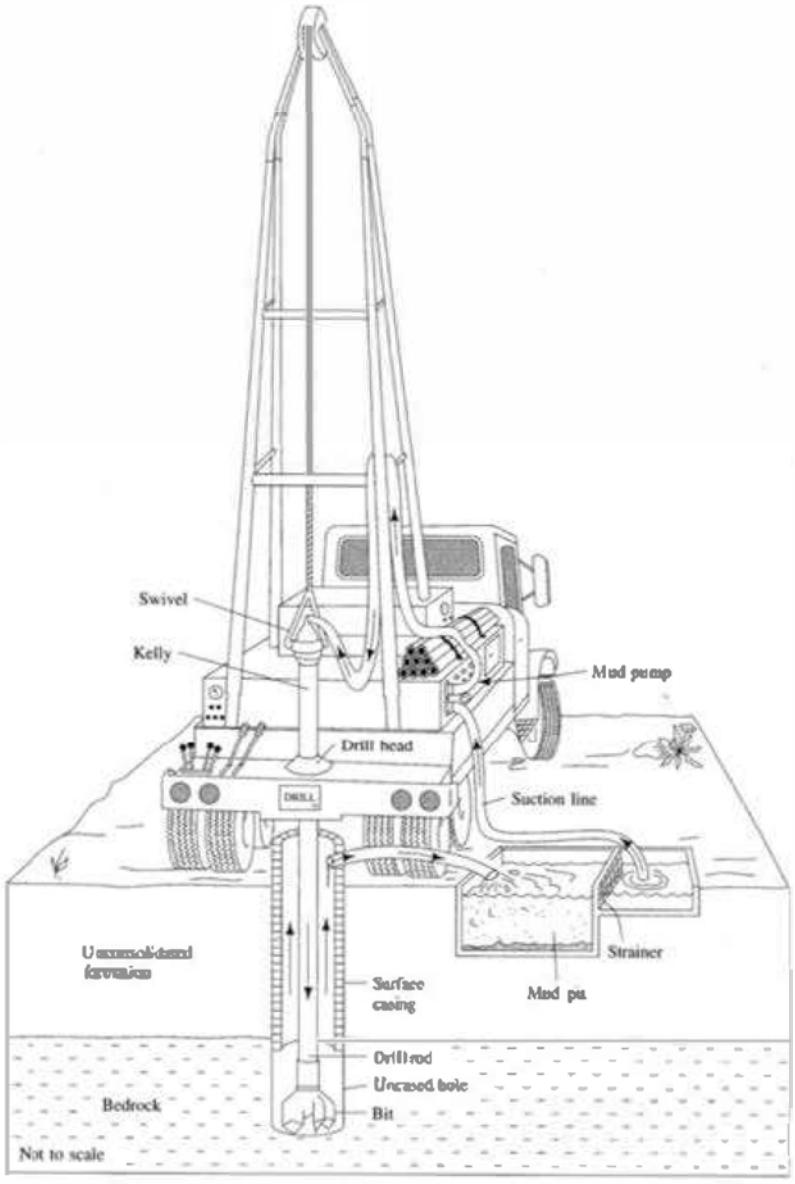
Hollow-stem auger drilling can also be used to sample water quality at various depths during drilling. At a selected horizon the plug at the end of the hollow stem is removed. A well point on the end of a rod is lowered to the bottom of the augers and then is driven ahead of the bit by hammering or hydraulic 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

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

R000304

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.

R000305

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).

R000306

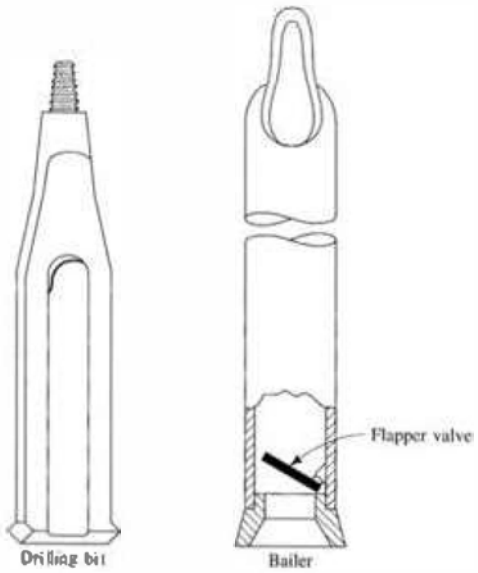
FIGURE 8.19 When drilling in difficult-to-access areas or where soggy soils prevent heavy drill equipment to reach the site, a portable drill rig can be used. Shown here is the installation of an 8-inch bedrock well with a portable air-rotary drill rig in a rice field in Goa, India. The drill rig is 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.

R000307

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

R000308

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.

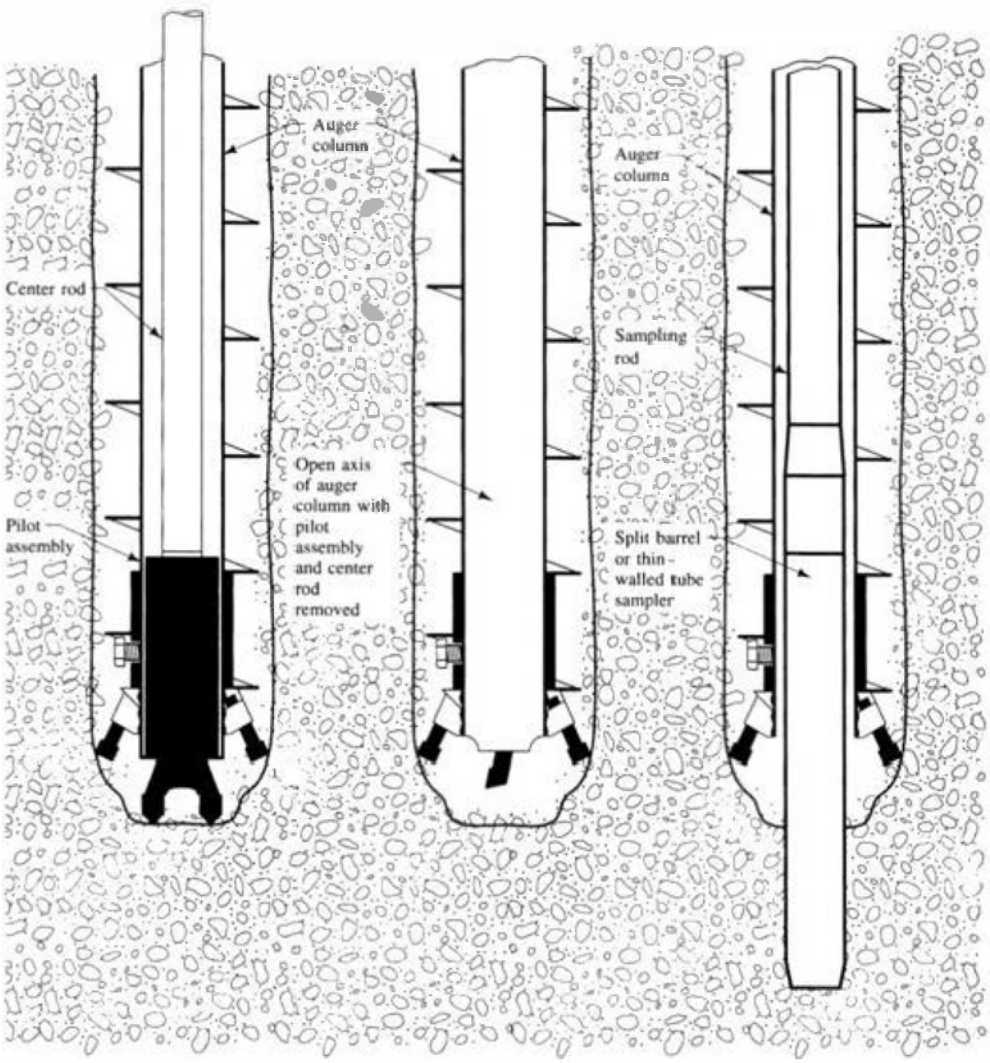
Laboratory measurement of bedrock cores can quantify contaminants in the core, simulate degradation microcosms, and provide core physical, mineralogical, and microbial measurements to determine contaminant phase and mass distribution. Typically, most groundwater flow in fractured consolidated rock occurs 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

R000309

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 microstratigraphy 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.

R000310

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.

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.

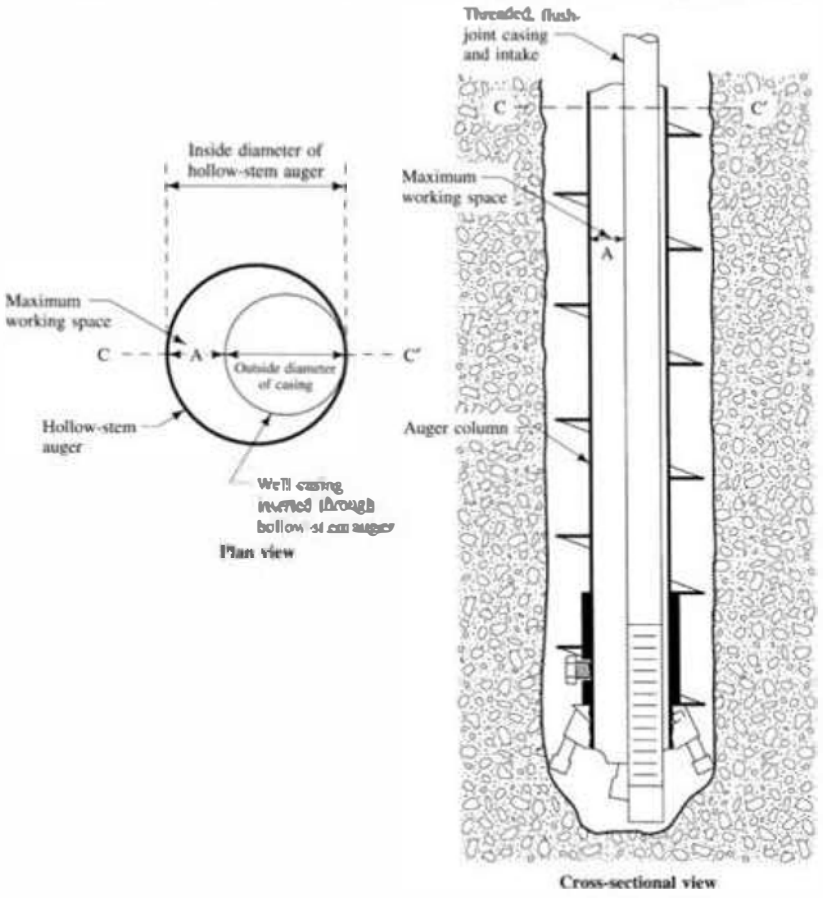
In consolidated formation a rock-core sample is collected by use of a core barrel with a diamond-studded bit. The rotating bit grinds up rock in an annular pattern, leaving an undisturbed center of rock that enters the core barrel. There is a core lifter just behind the bit to keep the core from falling 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).

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.

R000313

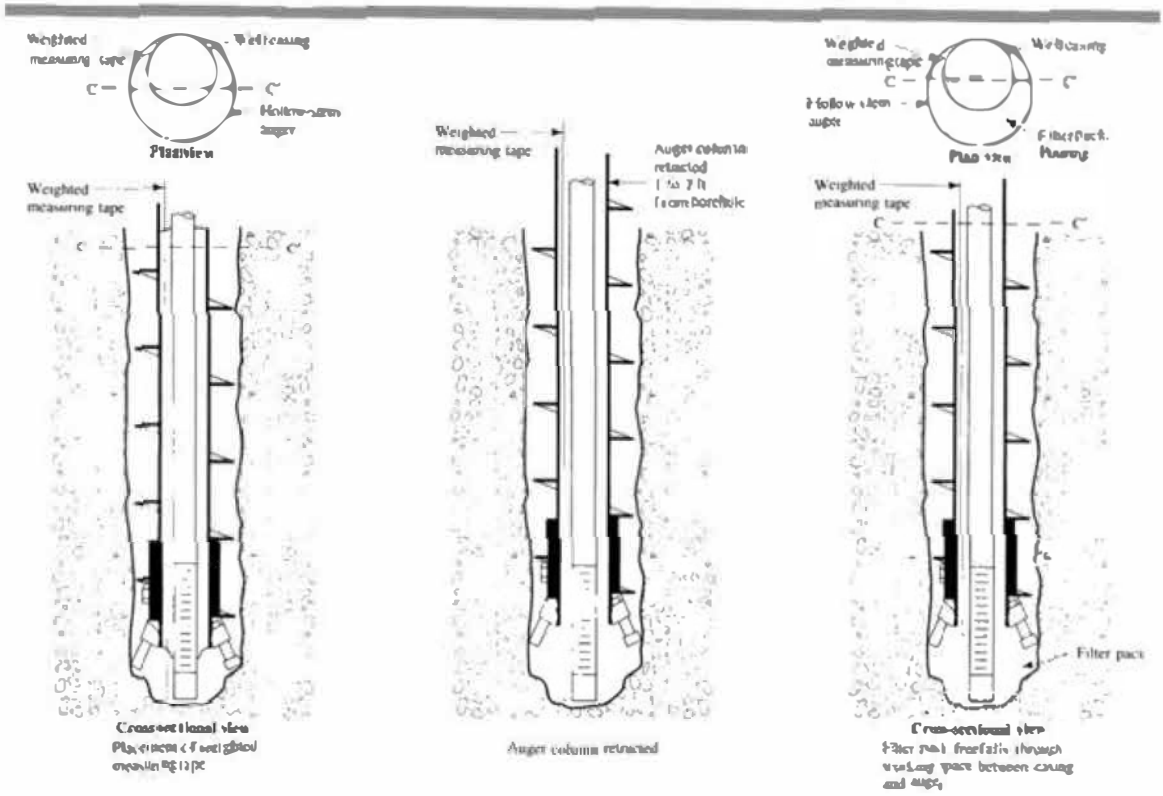
FIGURE 8.24 Lowering well screen and casing into hollow-stem augers. Note the white wrapping paper around the decontaminated casing.

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.



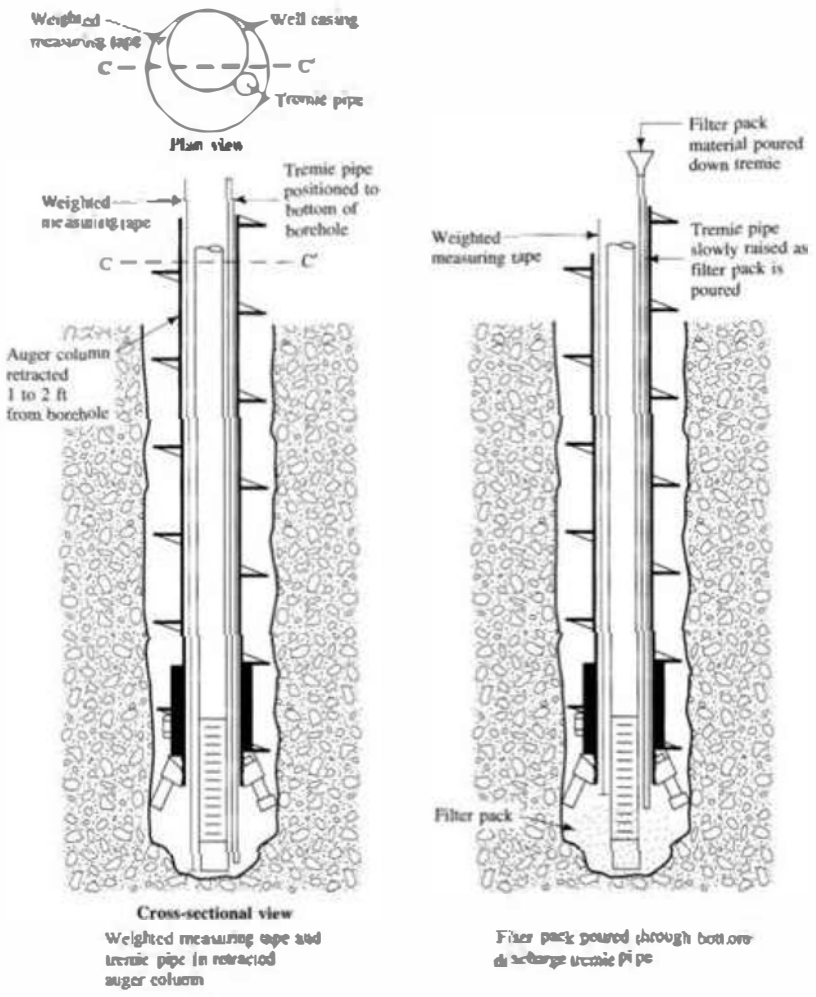
Source: G. Hackett. 1988. Drilling and constructing monitoring wells with hollow-stem augers part 2: Monitoring well installation. *Groundwater Monitoring & Remediation* 8:60-68. Used with permission.

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 filterpack 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.

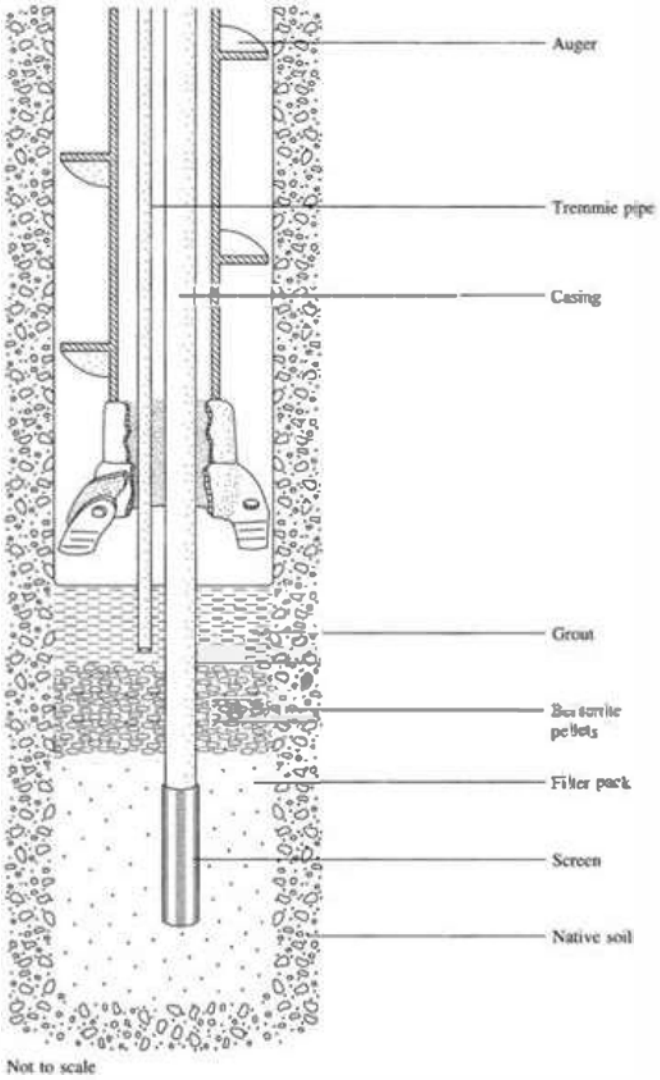


Source: G. Hacket; 1988. Drilling and constructing monitoring wells with hollow-stem augers part 2: Monitoring well installation. *Groundwater Monitoring & Remediation* 8:60-68. Used with permission.

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

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.

R000317

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.

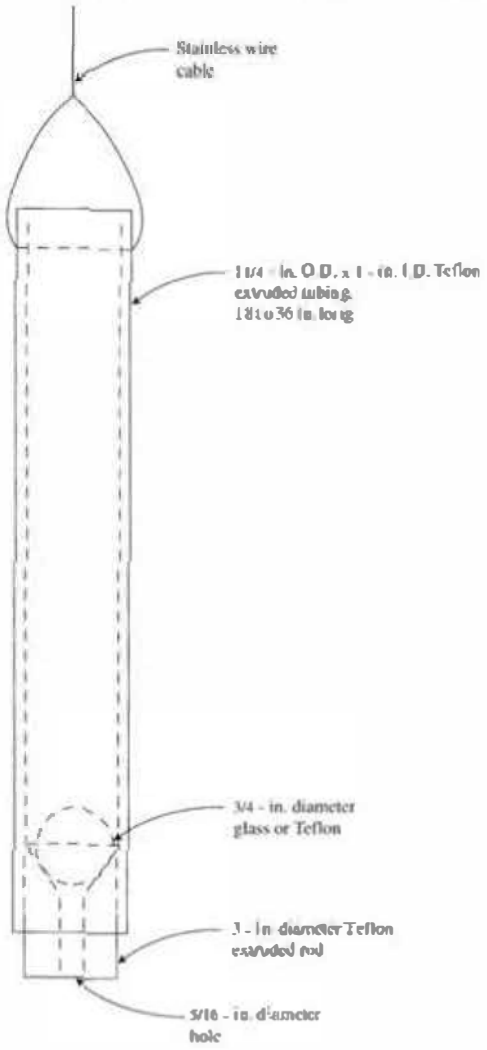
There are three procedures used for monitoring well development: bailing, surge block surging, and pumping/overpumping/backwashing. These may be used alone or in combination.

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

R000318

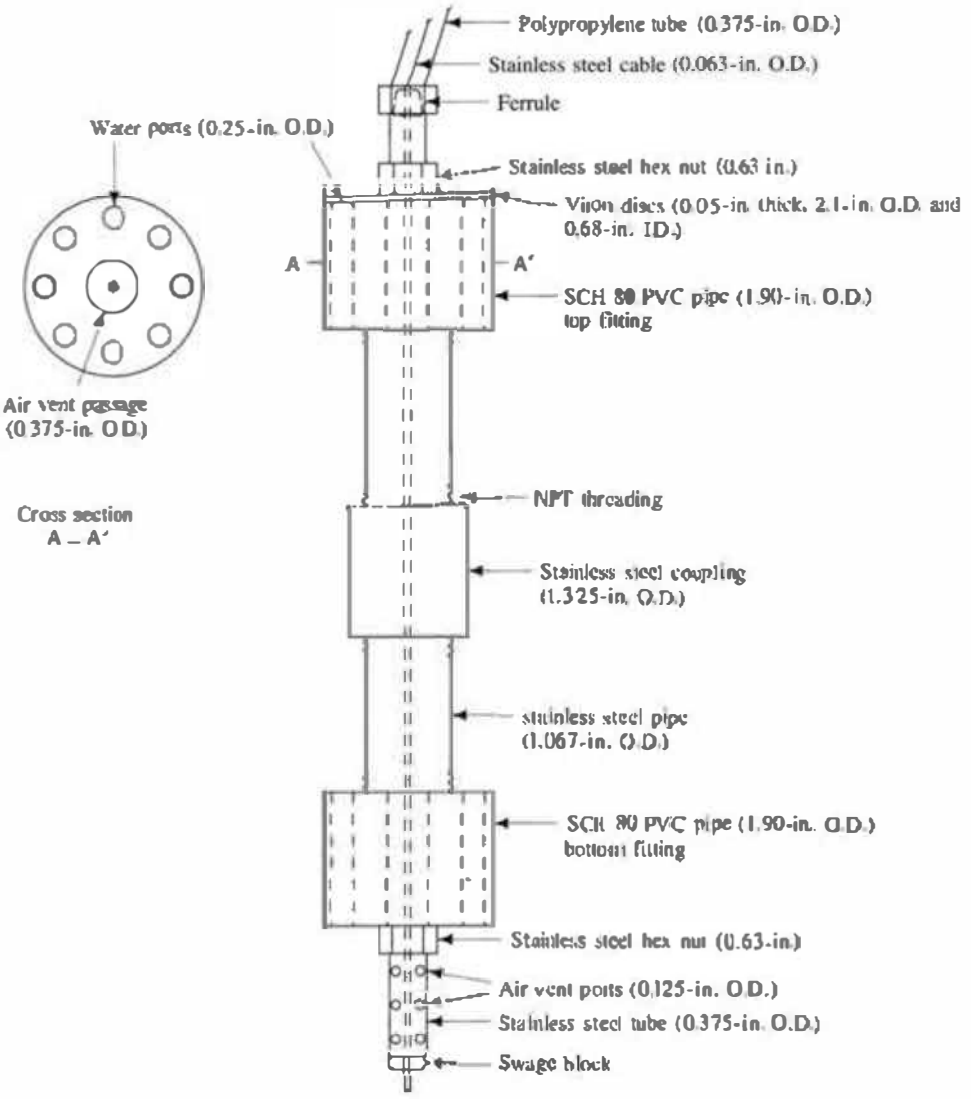
FIGURE 8.28 Diagram of a bottom-loading bailer.



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* 6:7 7–80. 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

R000320

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.

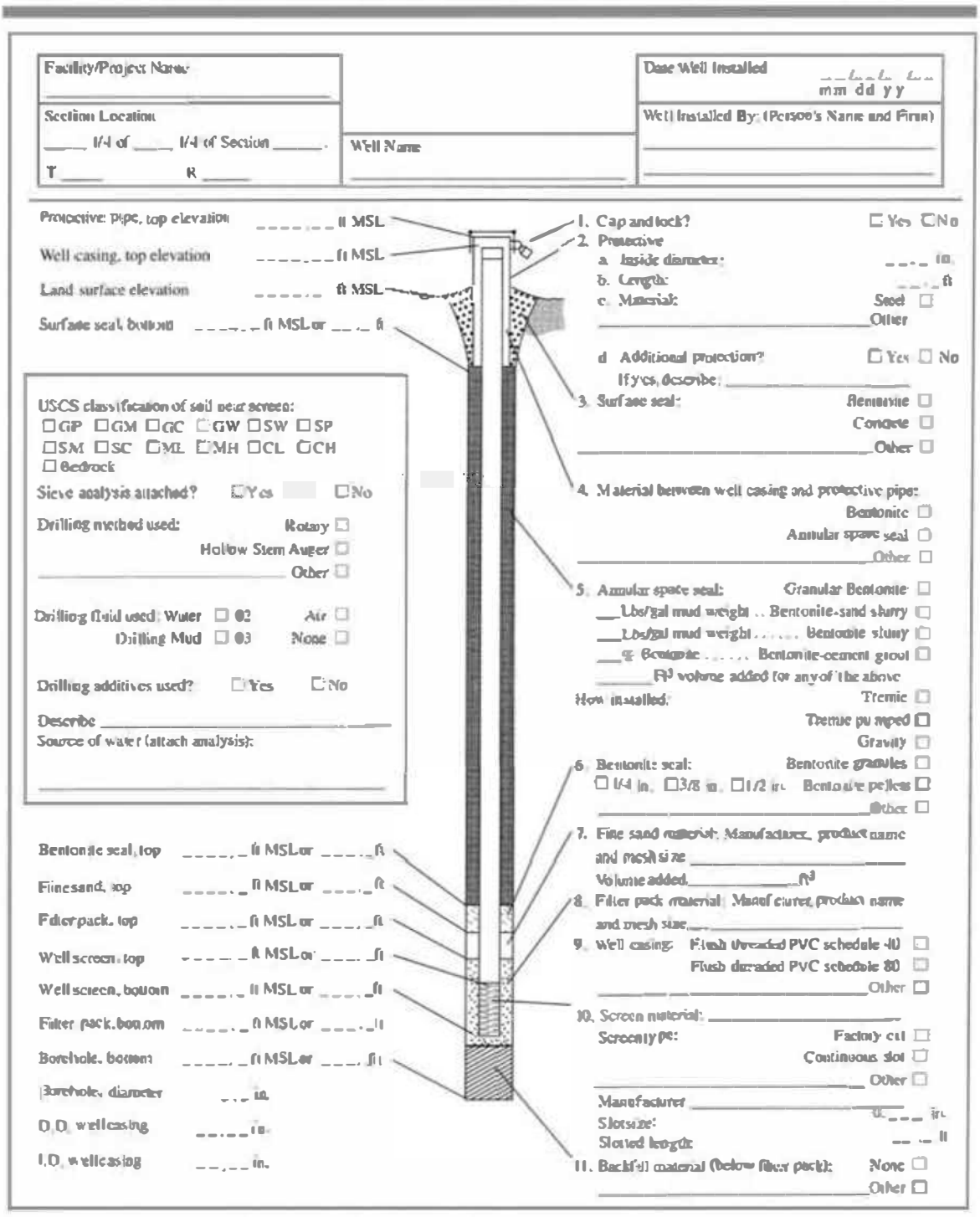
Records should also be kept of well development, including the date that it occurred, the method used, the water level at the start of development, the water level at the end of development, the time spent developing the well, and the volume of water removed. The thickness of sediment on the bottom of 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 countries 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

R000322

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.

R000323

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 filterpack 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.

R000324

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

R000325

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

FIGURE 8.31 Matrix showing applications of a number of groundwater sampling devices.

						Ground Water Parameters													
						Inorganic							Organic				Radioactive		Biol.
Portable Sampling Devices		Device	Approximate Maximum Sampling Depth	Minimum Well Diameter	Sample Delivery Rate or Volume	EC	pH	Redox	Major Ions	Trace metals	Nitrate, Fluoride	Dissolved Gases	Non-volatile	Volatile	TOC	TOX	Radium	Gross Alpha & Beta	Coliform Bacteria
	Grab	Open bailer	no limit	$\frac{1}{2}$ in.	Variable	•			•	•	•		•				•		•
		Point-source bailer	no limit	$\frac{1}{2}$ in.	Variable	•	•	•	•	•	•		•	•	•	•	•		•
		Syringe sampler	no limit	$1\frac{1}{2}$ in.	0.01–0.2 gal	•	•	•	•	•	•		•				•	•	•
	Positive displacement (submersible)	Gear-drive	200 ft	2 in.	0–0.5 g/min									•					
		Bladder pump	400 ft	$1\frac{1}{2}$ in.	0–2 g/min	•	•	•	•	•	•	•	•	•	•	•	•	•	•
		Helical rotor	160 ft	2 in.	0–1.2 g/min	•	•	•	•	•	•	•	•	•	•	•	•	•	
		Piston pump (gas-drive)	300 ft	$1\frac{1}{2}$ in.	0–0.5 g/min	•			•	•	•		•				•	•	
		Centrifugal	variable	3 in.	variable	•			•		•						•	•	
	Suction lift	Peristaltic	2–25 ft	$\frac{1}{2}$ in.	0.01–0.5 g/min	•			•		•		•				•		•
	Down contact	Centrifugal	variable	1 in.	Variable														
		Gear-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* 8:82-84. Used with permission.

R000326

R000327

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

R000328

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.

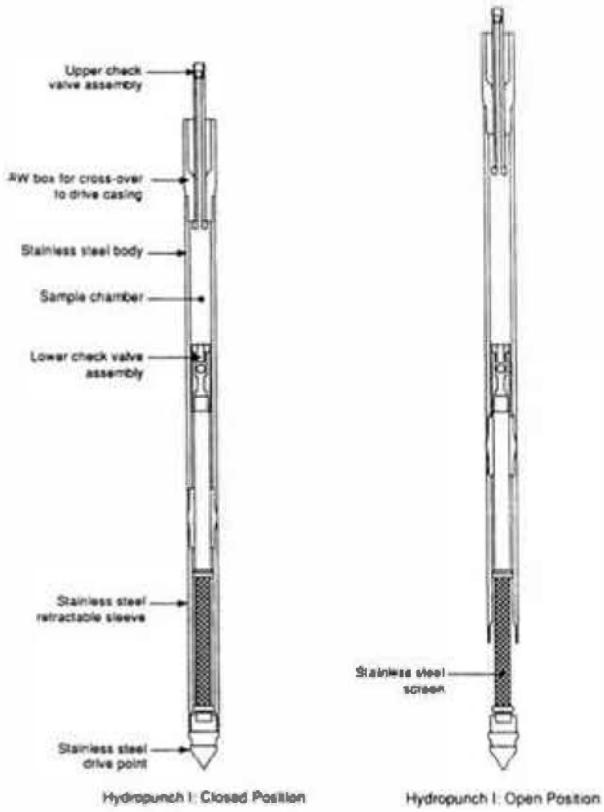
The HydroPunch™ is one such device, a direct-push sampler, that can be used to collect a groundwater sample from a discrete depth in the earth (Edge and Cordry 1989). It consists of a pointed sampling probe that is attached to a hollow drill rod. The rod is pushed into the earth by the hydraulic ram 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

R000329

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.

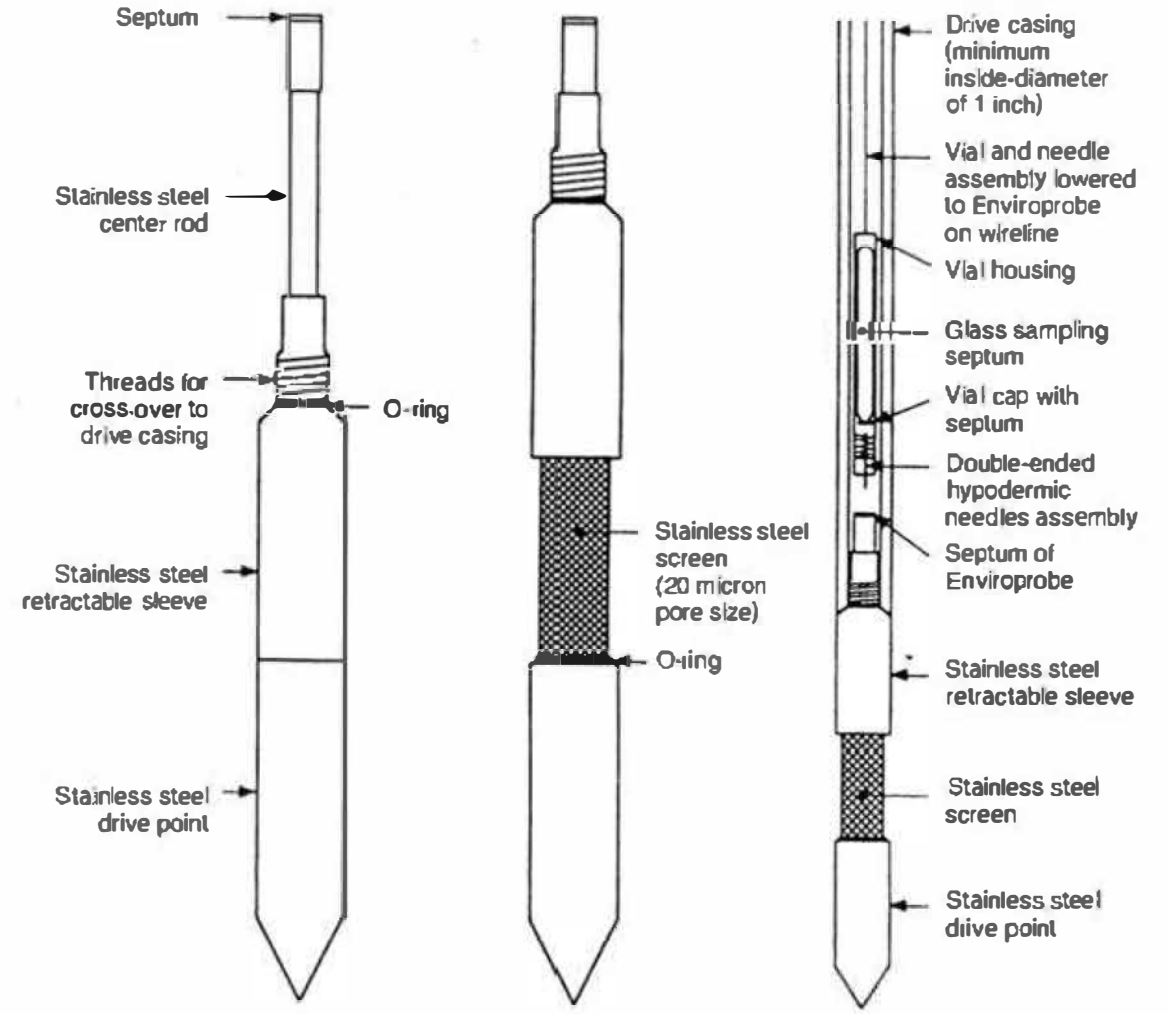
If the unconsolidated material is too coarse for the sampling probes to be pushed very far into the earth, then they can be used with a hollow-stem auger drilling rig. The drilling rig is used to install a test boring. At selected depths, either probe can be advanced within the augers and ahead of the 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

R000330

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

R000331

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

R000332

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

R000333

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

R000334

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.

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

R000336

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 re-emergence 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

R000337

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 blocking groundwater'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, but 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

R000338

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 (*Ecoli*) 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: *Ecoli*, 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

R000339

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 hexafluoride) 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

R000340

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

R000341

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

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 geochemists 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

R000343

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 et 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 concurrent 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 has 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

R000344

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

R000345

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

R000347

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 I 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.itrcweborg/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/scmtools.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://wwwnap.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

R000348

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, costeffective, 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

R000349

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 period, 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.

R000350

FIGURE 9.1 The NFPA 704 chemical hazard label. Each quadrant is labeled with its respective color and hazard.

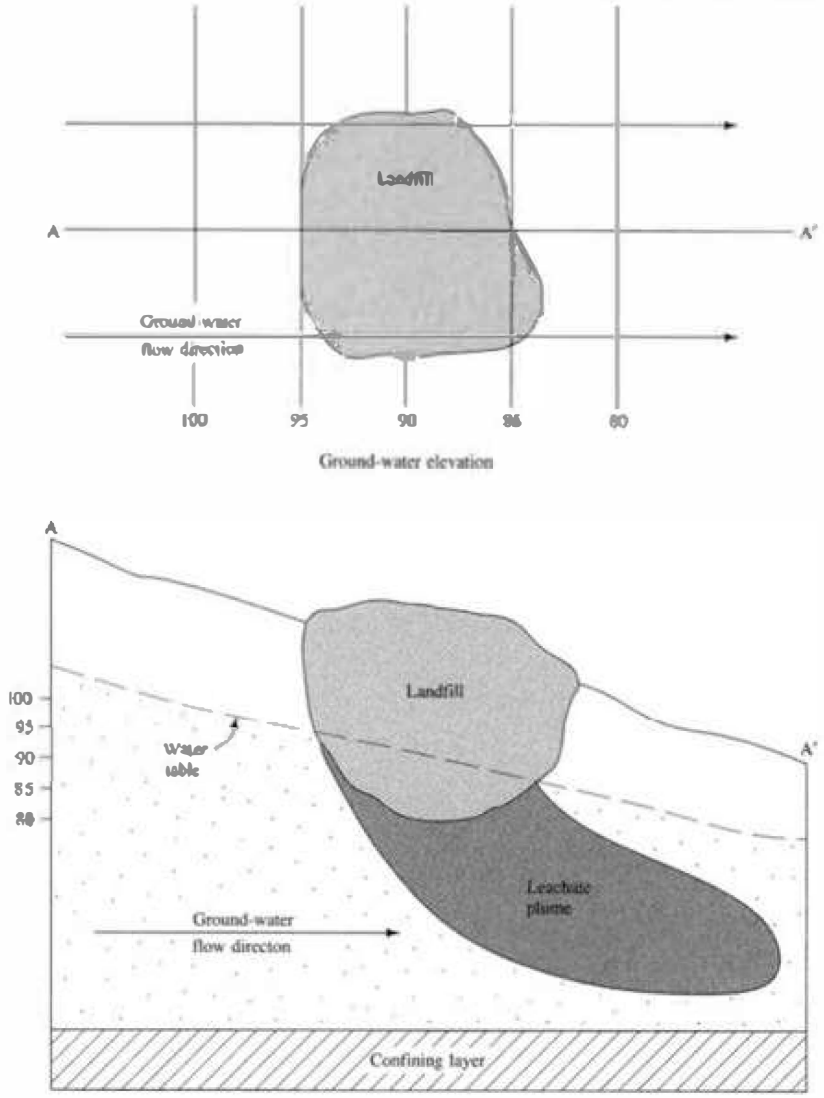
Soil contaminated with organic compounds may be remediated by excavation and incineration. This is a technique that has been proposed for highly refractory organic compounds, such as PCBs and some pesticides. The organic matter of the soil is incinerated while a supplemental fuel is burned in the incinerator. 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.



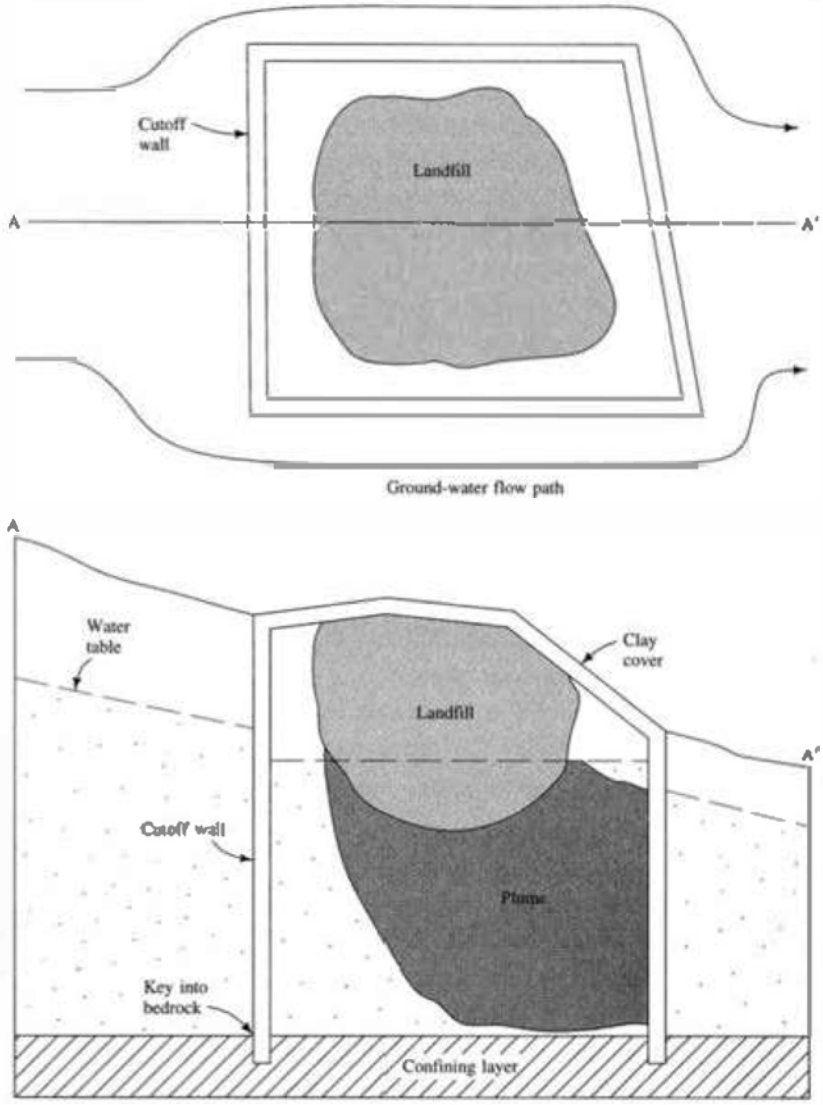
wall and fall on the downgradient wall. If there is no recharge or flow through the cutoff walls, the water table within the cutoff walls will be flat. However, there is generally leakage through the cover or cutoff walls, so some extraction wells will be needed for added hydraulic control within the 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

R000352

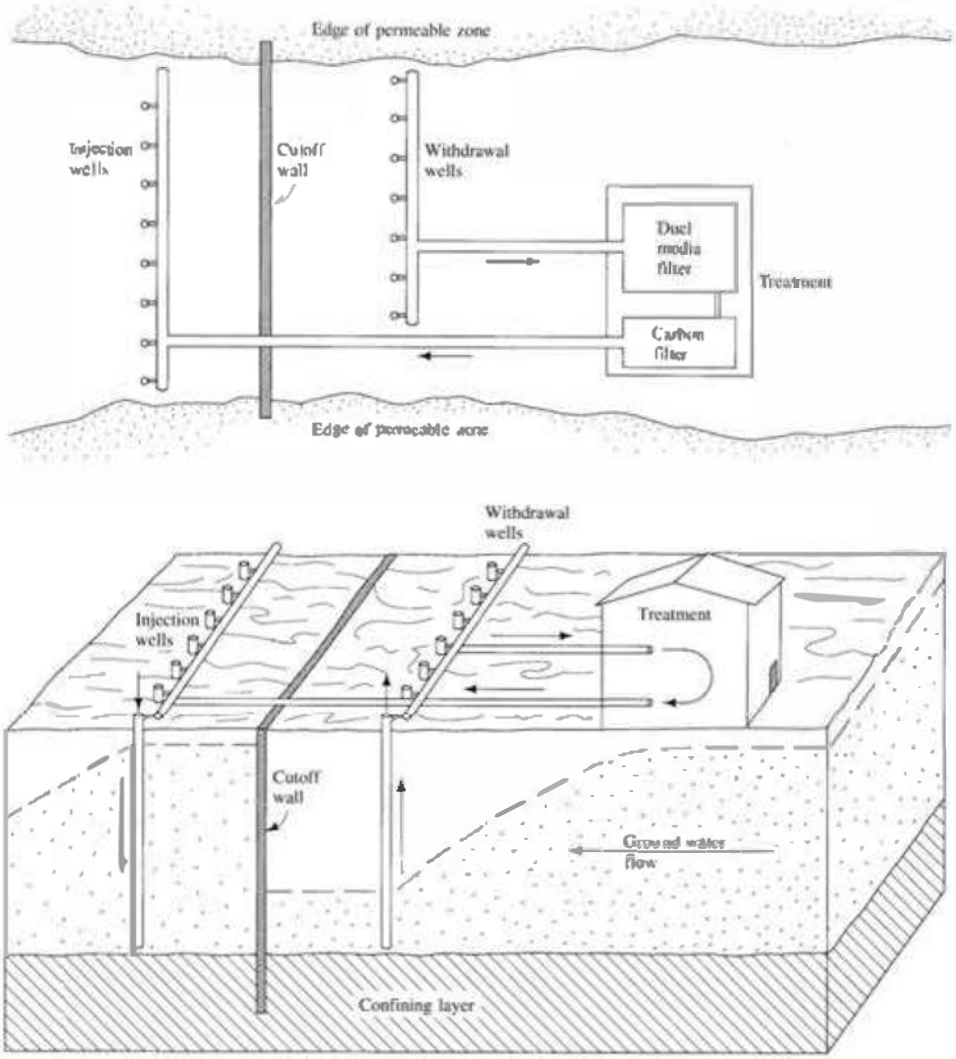
FIGURE 9.2b Top and side view of a cutoff wall that completely surrounds the landfill in (a), opposite page. Cutoff wall is keyed into underlying low-permeability formation.



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 I 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

R000354

steel-sheet 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.

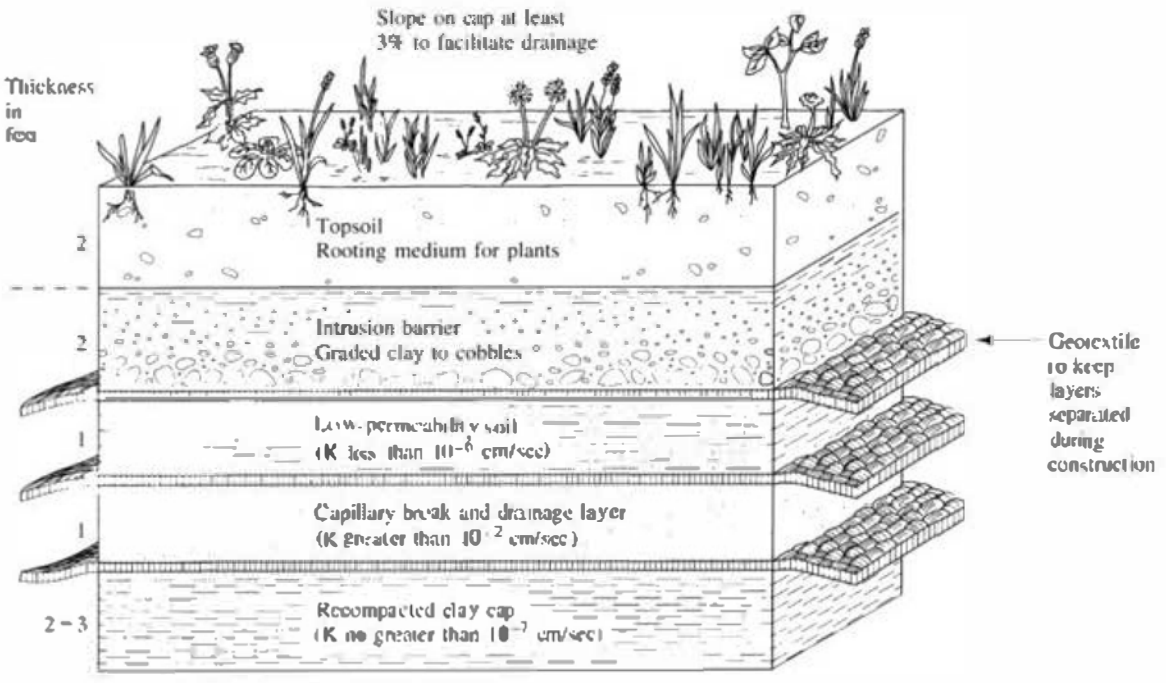
If contaminated material can be immobilized or its solubility reduced through a chemical reaction, this process is called stabilization. Similarly, if the contaminated material can be encapsulated to form a solid and to restrict its migration by decreasing the surface area exposed to leaching, that process 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.



R000355

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 (I ft) thick low-permeability zone to separate the cobble layer from the next-lower zone; (4) a 0.3 m (I 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 I 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,

R000356

FIGURE 9.5 Plume-stabilization well used to isolate plume of contaminated groundwater.

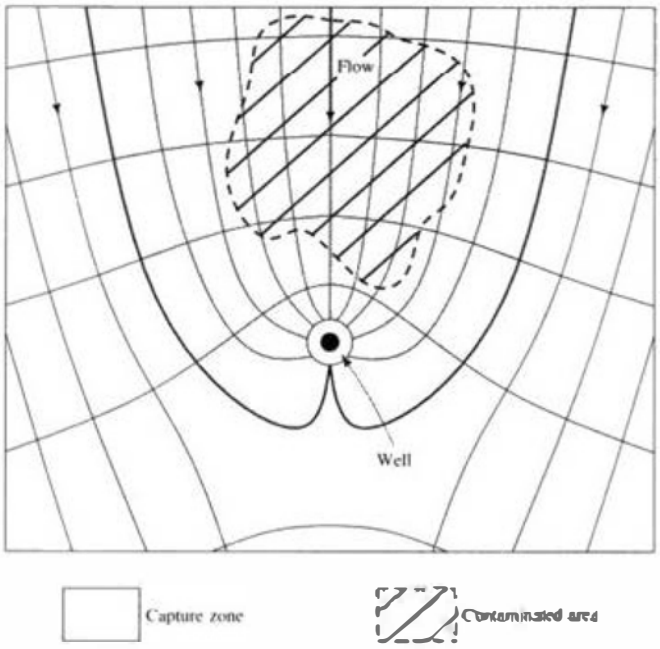
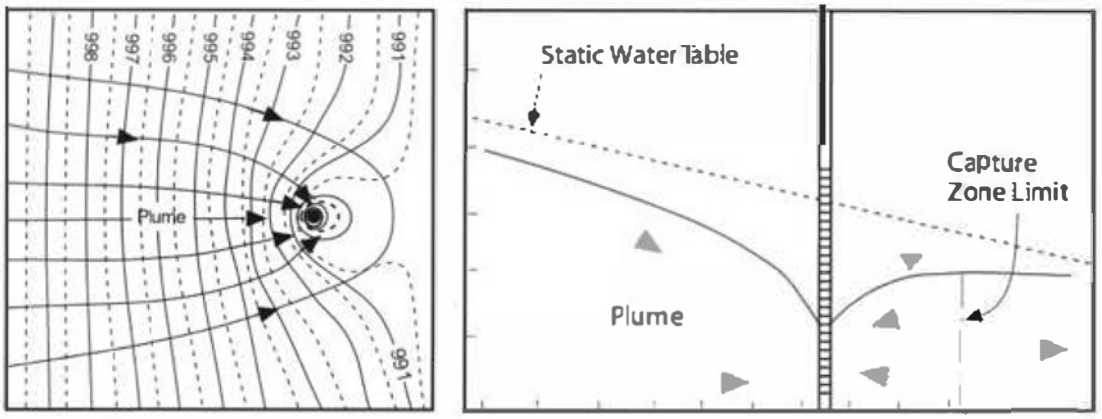


FIGURE 9.6 Example of plume stabilization by a well which is used to hydraulically contain a plume of contaminated groundwater. Shown are plan view and cross sections.

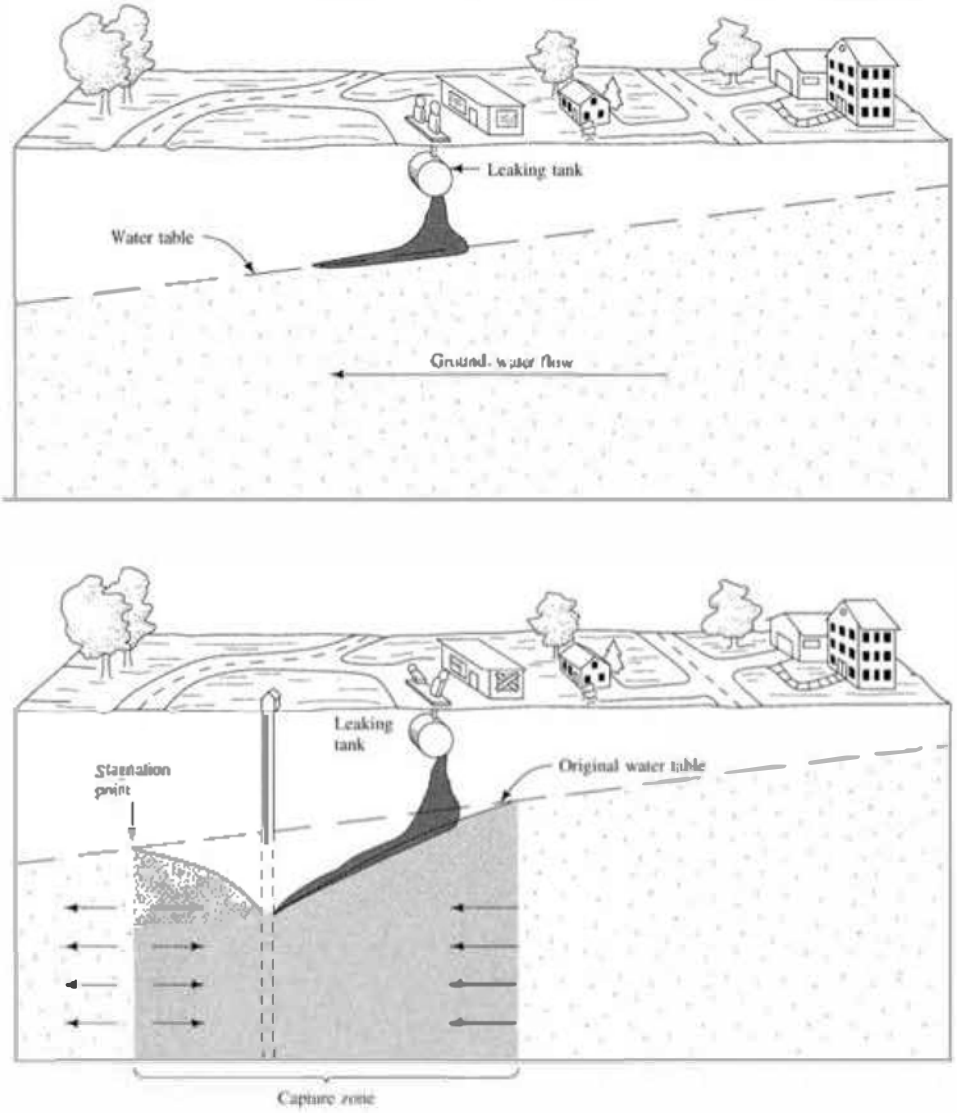


Source: After Cohen et al. 1993; as cited in U.S. EPA 1995, Report EPA/625/R95/005.

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.

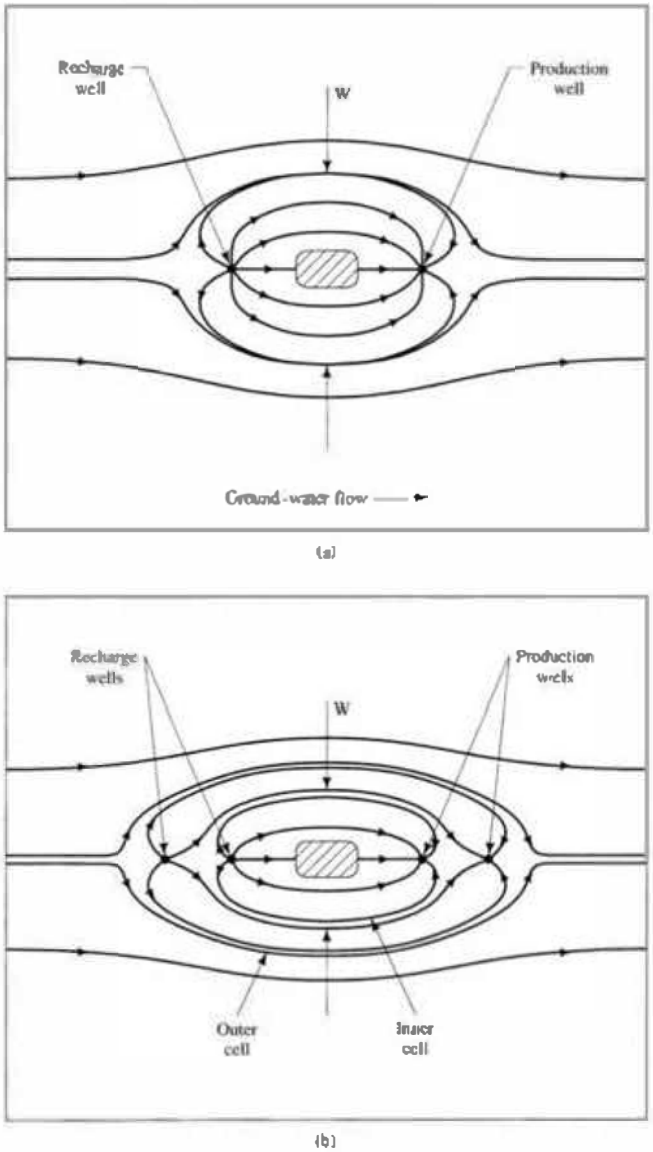
FIGURE 9.7 Cross section along the x axis showing the cone of depression for a single extraction well superimposed on the regional water table.



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.

R000358

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

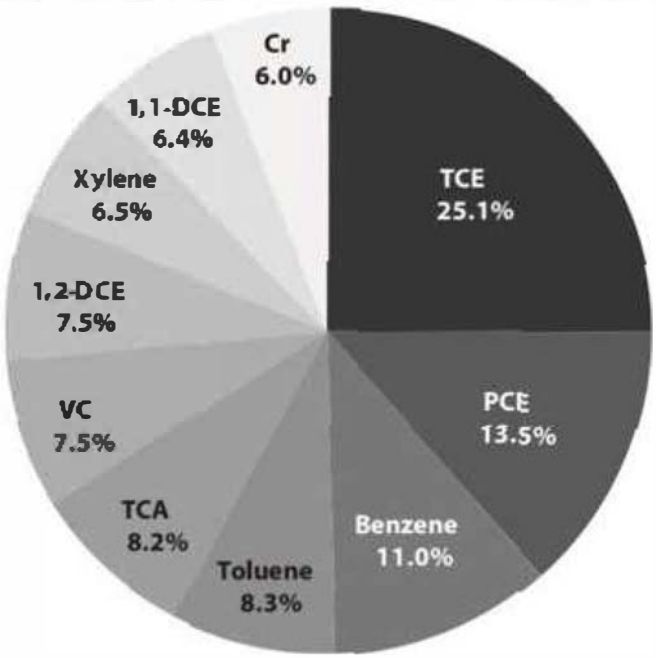
9.3.1 Overview

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) sites 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.

R000360

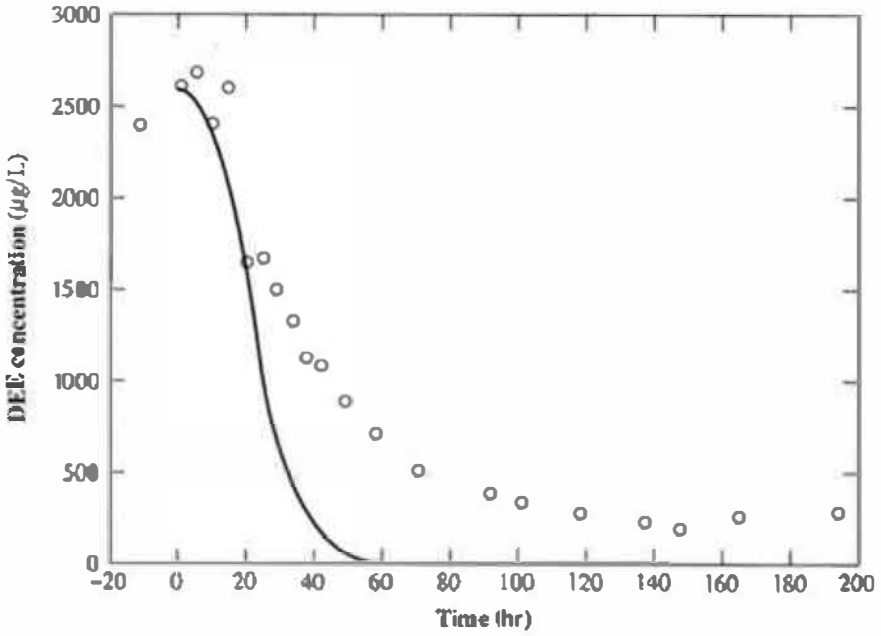
discharged to a surface-water body in the United Stares requires state permits, including a National Pollutant Discharge Elimination System (NPDES) permit. Many states provinces, and regions require a permit to inject water into the ground and there may be concentration limits specified as a part of 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.

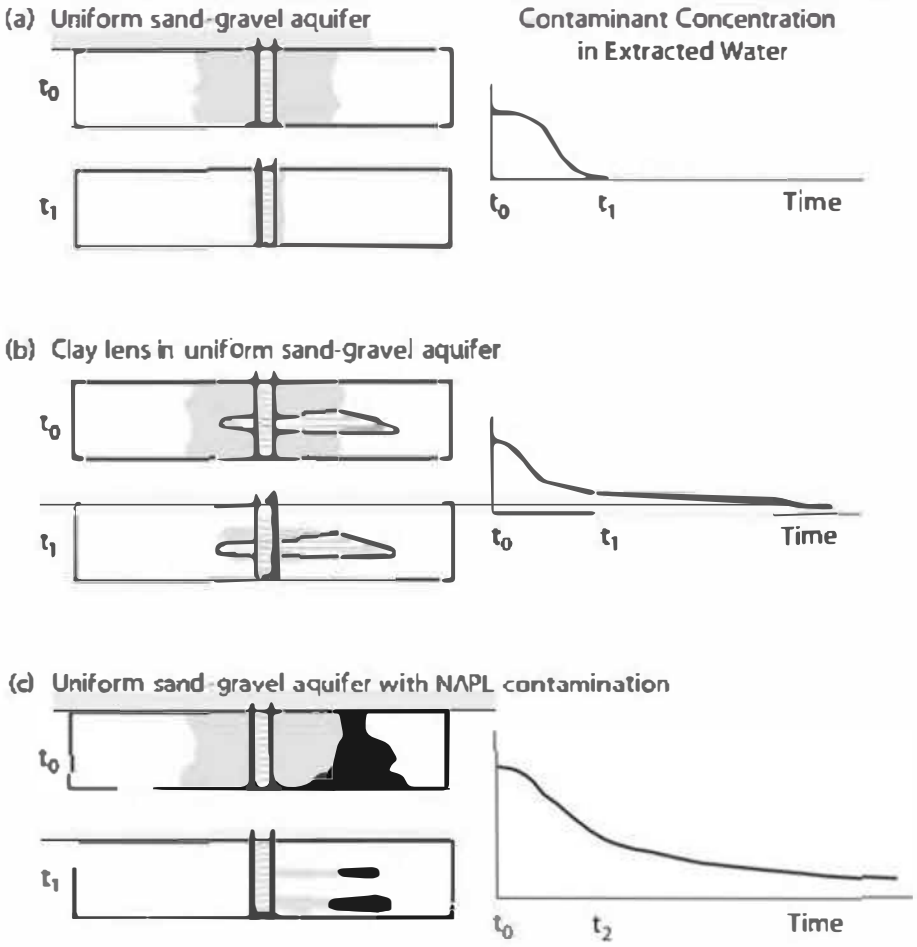
composed of uniform sand. During the time interval t_0 to t_1, the contamination is effectively flushed out. However, if the porous media is heterogeneous and the aquifer consists of sand with an interbedded clay lens, the concentration in the effluent from the extraction well is still elevated at t_1 (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 matetial are being flushed, the dtop 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 concenttation will eventually apptoach somewhat constant value, which represents a steady state condition where the rate at which the contaminants are being removed by the pump-and-treat

R000362

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.

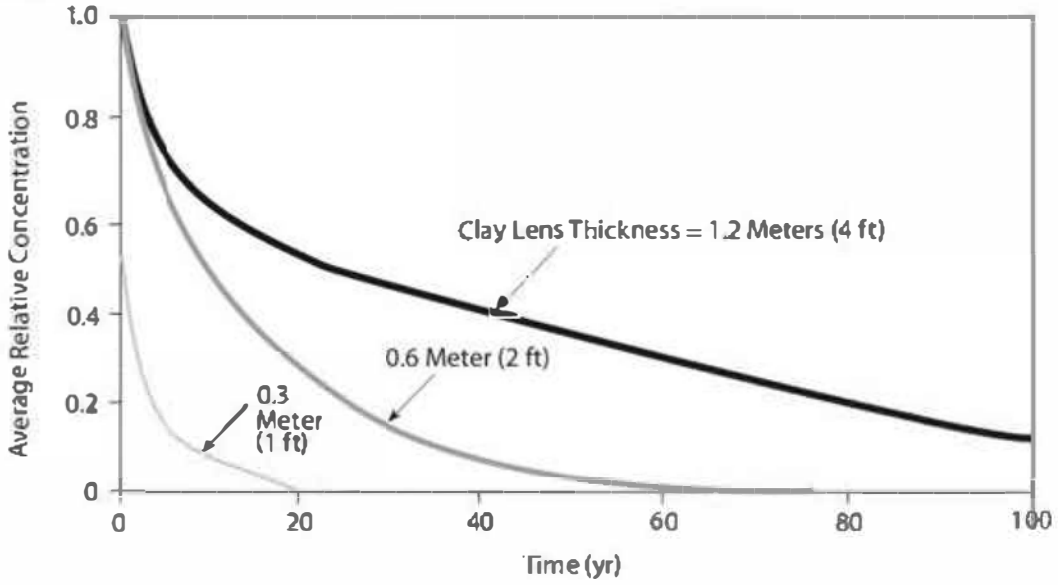


Source: Modified after Mackay and Cherry 1989.

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 9.1 lc). 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.

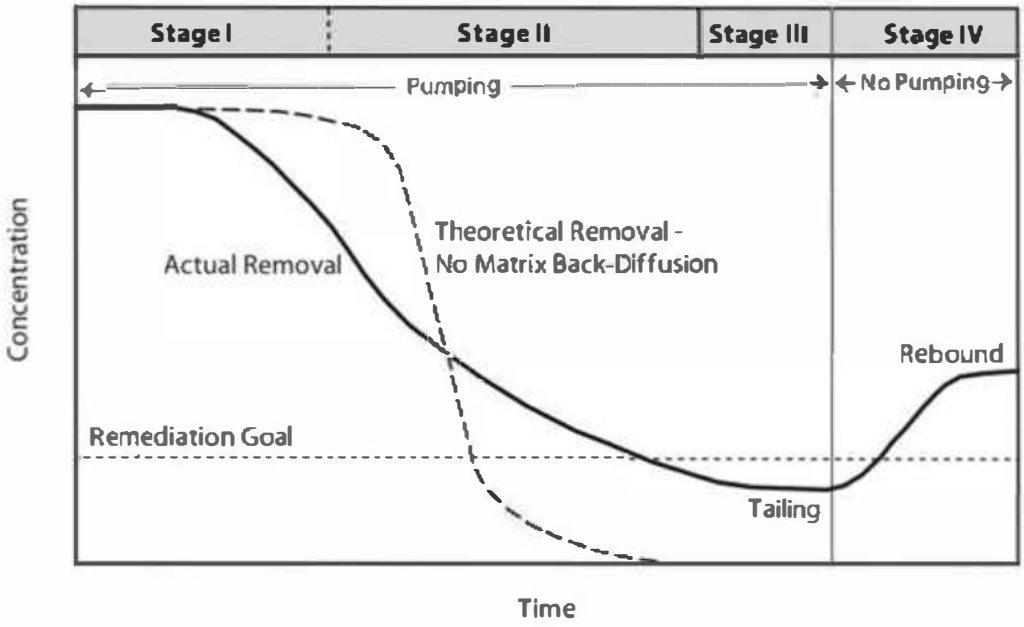
A study of pump-and-treat cleanup at 16 sites in the United States where the groundwater was contaminated with organics revealed that if the initial concentration of contamination was high (>1000 μg/L), pumping could achieve reductions of contaminant concentrations of 90 to 99% before leveling occurred. 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 concenttation 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

R000364

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 pre-determined 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.

R000365

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.

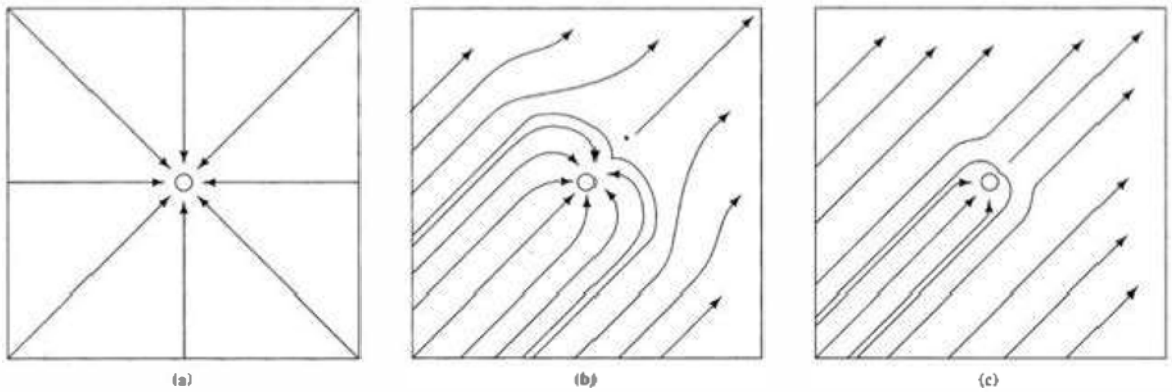
9.3.2 Capture Zones

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).



R000366

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

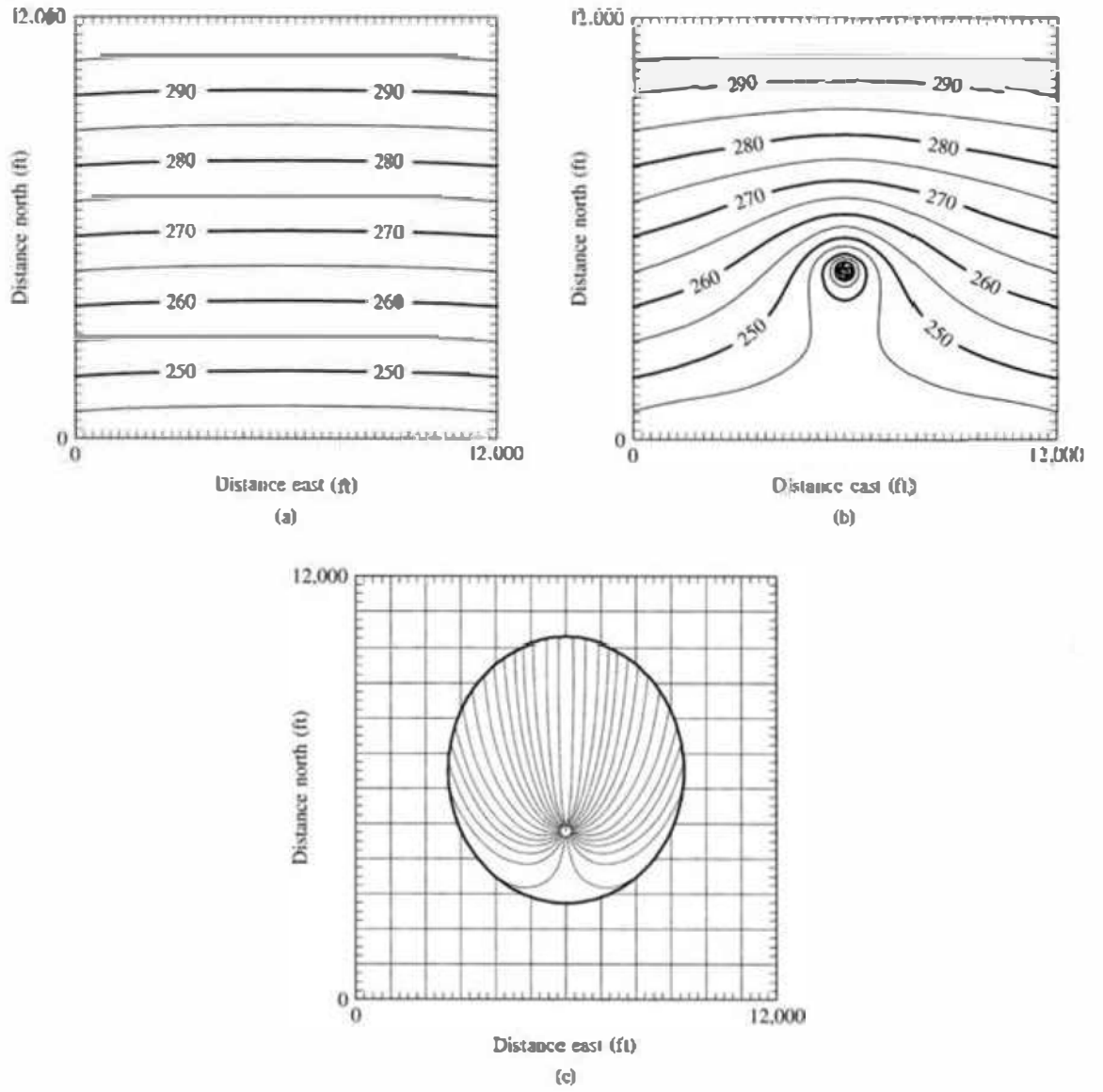
The effect of aquifer heterogeneity was illustrated by Shafer (1987). Figure 9.15a shows the initial hydraulic head for a homogeneous, isotropic, unconfined aquifer. The hydraulic-head distribution after 20 years of pumping from a single well is shown in Figure 9.15b. During this time period, the cone 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.

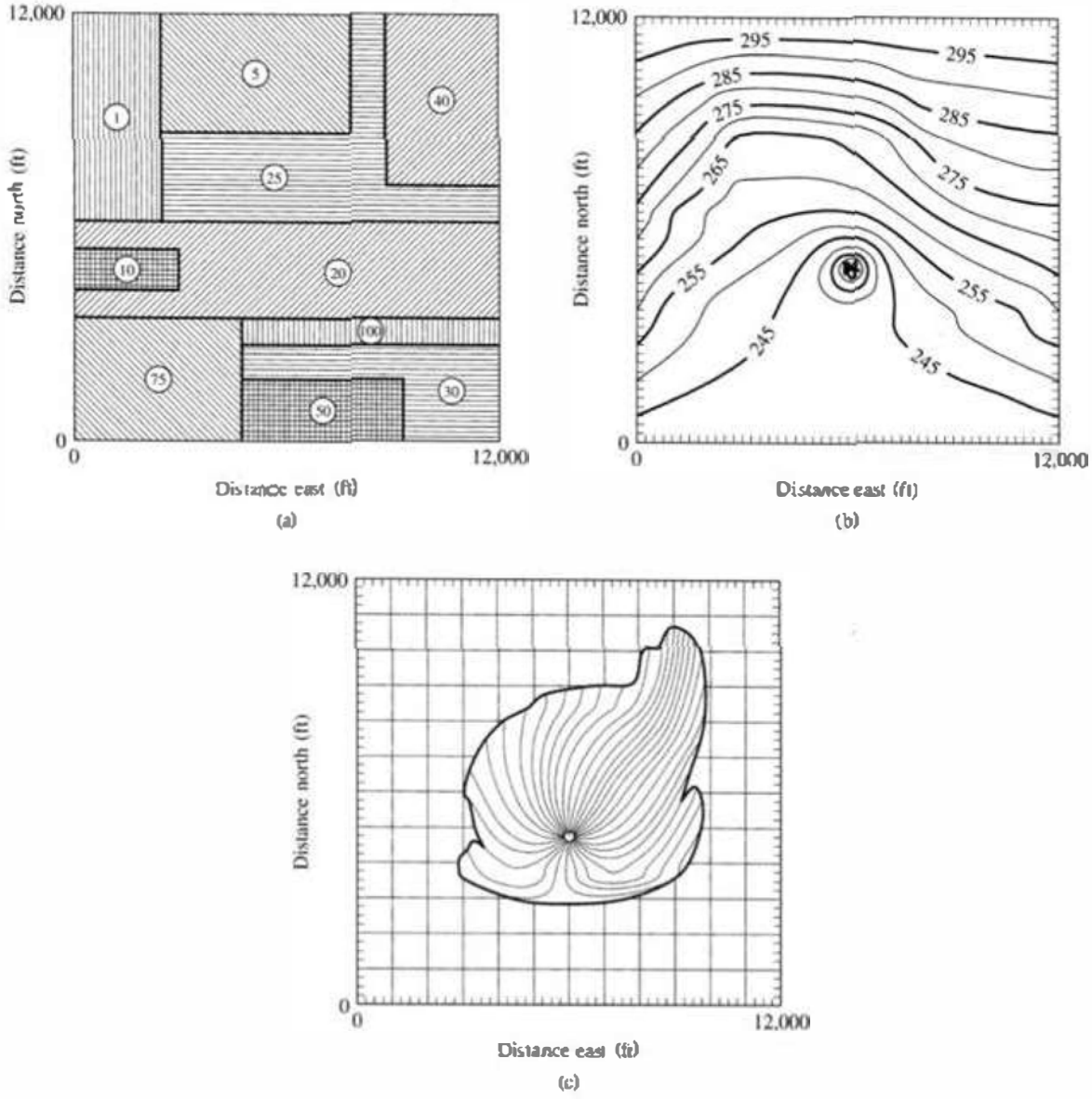


Source: J. M. Shafer. 1987. Reverse pathline calculation of time-related capture zones in nonuniform flow. *Groundwater* 25:283–289. Used with permission.

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.

R000368

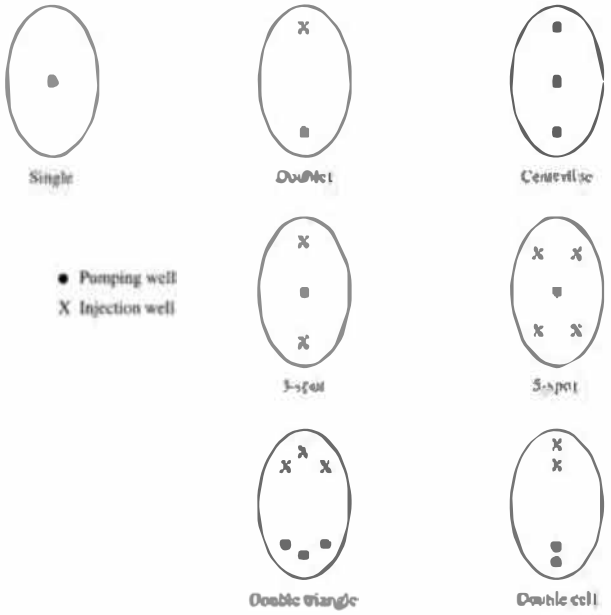
FIGURE 9.16 (a) Distribution of hydraulic conductivity in nonhomogeneous aquifer with the initial head distribution of Figure 9.15a. (b) Hydraulic head distribution in the nonhomogeneous aquifer with one well pumping. (c) Shape of the 20-year capture zone based on hydraulic head distribution of Figure 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

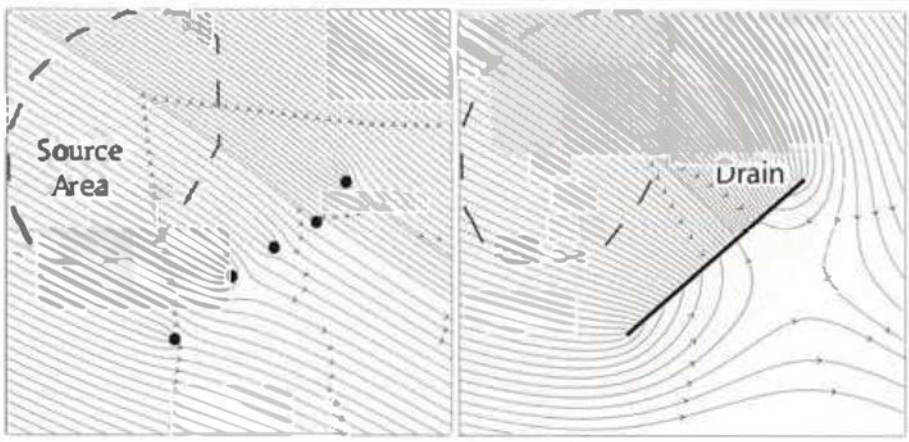
Decades of experience with pump-and-treat technology showed that in most cases it is not feasible or even technically possible to fully remediate a badly contaminated aquifer by pump-and-treat technology. This is especially true if the source cannot be located and removed, for example, if there are nonbiodegradable residual DNAPLs present in a fractured rock aquifer. For such aquifers the only feasible technology might

R000370

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

R000371

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

R000372

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.

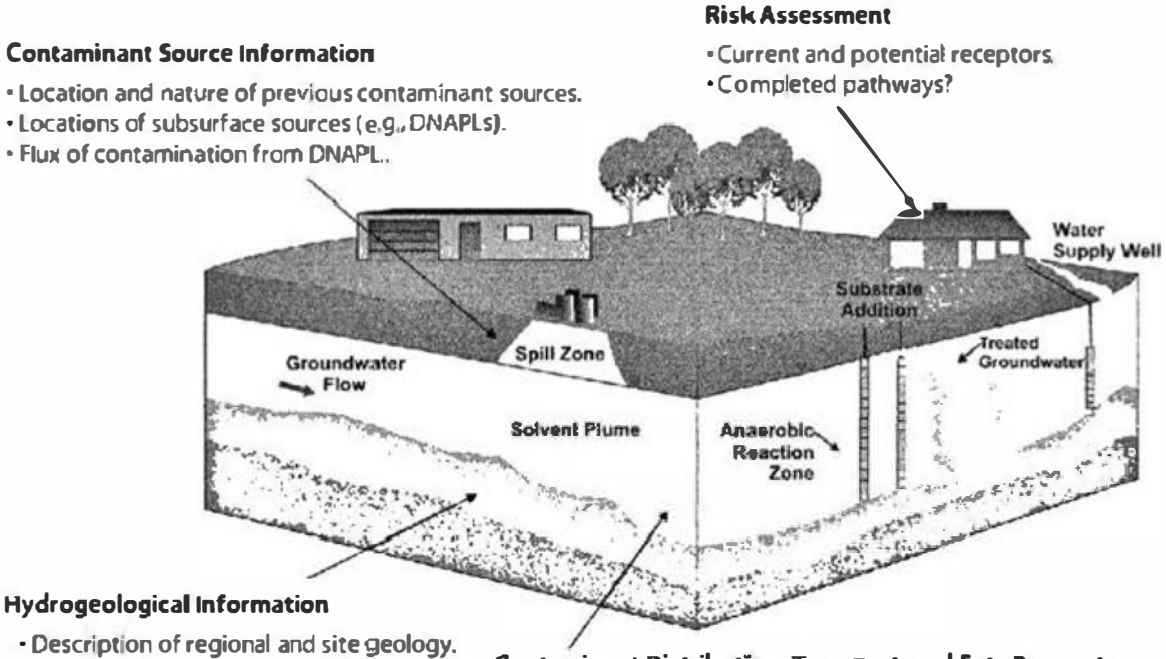
9.11 Conceptual Site Models

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

R000374

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*

R000375

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.

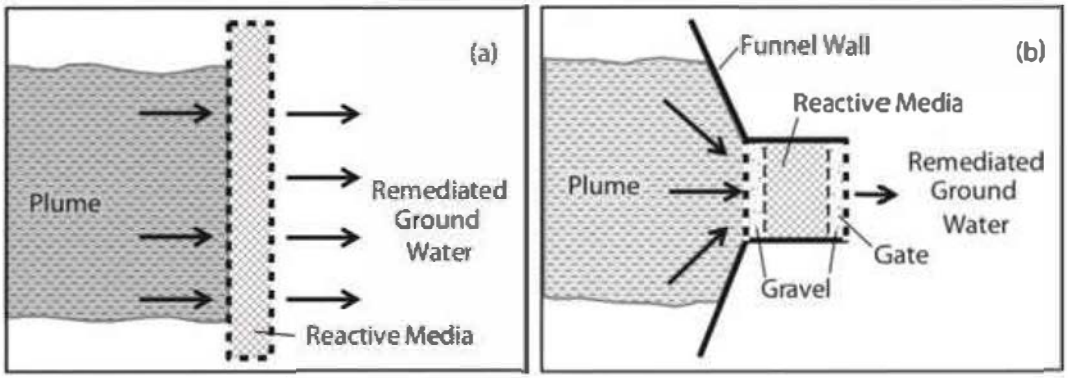
The concept of placing reactive materials in the path of a plume was developed based on observations by Reynolds et al. (1990). The authors noticed that at their field site concentration of dissolved chlorinated compounds were systematically lower in wells with galvanized iron casing compared to wells 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*

R000376

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 flow-through 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

$$\begin{array}{lll} Fe^0 \rightarrow Fe^{2+} + 2e^- & & \text{Oxidation} \\ RCl + 2e^- + H^+ \rightarrow RH + Cl^- & & \text{Reduction} \\ \hline Fe^0 + RCl + H^+ \rightarrow Fe^{2+} + RH + Cl^- & & \text{Net Reaction} \end{array} \quad (9.3)$$

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-dichloroethene, 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).

R000378

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 back-filling 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

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)	Tetrachloroethene (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 ($C_2H_4Cl_2$)		
Other polychlorinated hydrocarbons	Pesticides	Organic dyes	Other organic contaminants
Dioxins	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) ($C_4H_{10}N_2O$)
		Acid Orange	
		Acid Red Arsenic (AsO_3^{-4})	
Heavy metal ions	Radiogenic ions	Inorganic ions	
Mercury (Hg^{2+})	Uranium (U VI)	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 US. EPA 1998.

R000379

R000380

high hydrostatic pressures to the wel. 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 landfil.. 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 (eg., 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, biowals 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,

R000381

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 (Naftz 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 cosolvents (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

R000382

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 (Naftz 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 cosolvents (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

R000383

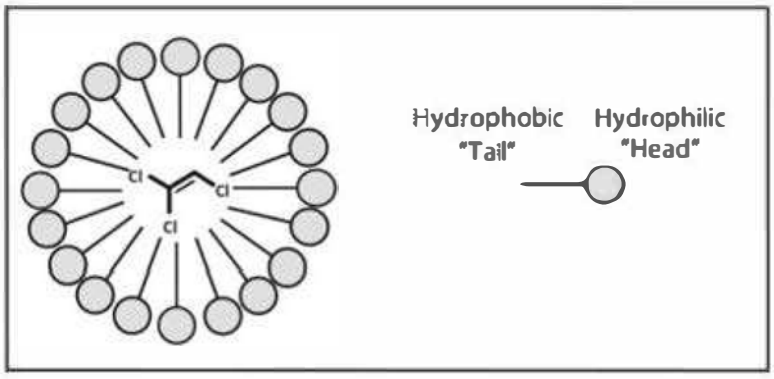
(Naval Facilities Engineering Command 2002). Heterogeneous aquifer conditions, including fractured bedrock aquifers, typically stand in the way of effectively flooding the treatment zone because lower permeable zones may be by-passed. Chemically-enhanced flushing is sometimes used in combination with 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.



R000384

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, firefighting 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 surfactants.

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-801) 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

R000385

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

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 (•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 (•OH)	$2\,{\bullet}OH + 2H^+ + 2e^- \rightarrow 2H_2O$		2.8
	Perhydroxyl radical ($•OH_2$)	$•OH_2 + 2H^+ + 2e^- \rightarrow 2H_2O$		1.7
	Superoxide radical ($•O_2$)	$•O_2 + 4H^+ + 3e^- \rightarrow 2H_2O$		-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 ($•SO_4^-$)	$•SO_4^- + e^- \rightarrow SO_4^{2-}$		2.6V
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 ($•SO_4^-$)	$2\,{\bullet}SO_4^- + 2H_2O \rightarrow 2HSO_4^- + 2\,{\bullet}OH$		2.6V
	Hydroxyl radical (•OH)	$2\,{\bullet}OH + 2H^- + 2e^- \rightarrow 2H_2O$		2.8V

* 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.

R000386

R000387

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,

R000388

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 characteristics.

Phytoremediation bas 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 field 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

R000389

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.

R000390

Chapter Notation

B	Uniform thickness of a confined aquifer	d	Distance between extraction wells
Bgs	Below ground surface	k	Pseudo-first order rate contestant
C	Concentration	x	Distance along the x axis
Co	Initial concentration	y	Distance along the y axis
U	Regional specific discharge (Darcy velocity)	$h_0—h$	Drawdown
		T	Aquifer transmissivity
Q	Pumping rate of plume-capture well	S	Aquifer storativity
		R	Radius of a pumping well
		t	Time since pumping began

References

ADAC. 2015. Entwicklung der Tankstellenanzahl seit 1965 in Deutschland. Accessed September 3, 2015 from https://www.adac.de/infotestrat/tanken-kraftstoffe-und-antrieb/probleme-tankstelle/anzahl-tankstellen-markenverteilung/default.aspx

Air Force Center for Engineering and the Environment (AFCEE). 2008. Technical Protocol for Enhanced Anaerobic Bioremediation Using Permeable Mulch Biowalls and Bioreactors. Available from https://clu-in.org/download/techfocus/prb/Final-Biowall-Protocol-0508.pdf

American Petroleum Institute (API). 2007. API 2007. Technical Protocol for Evaluating the Natural Attenuation of MtBE. API Publication 4761. 186 pp.

Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process. Accessed September 13, 2015 at http://www.astm.org/Standards/E1527.htm

ASTM. 2014. ASTM E1689—95 Standard Guide for Developing Conceptual Site Models for Contaminated Sites. Available from http://www.astm.org/Standards/E1689.htm

Ardito, C. P., and J. F. Billings. 1990. "Alternative remediation strategies: The subsurface volatilization and ventilation system." In *Proceedings of Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection and Restoration*, 281–96. Dublin, Ohio: National Water Well Association.

Bainchi-Mosquera, G. C., R. M. Allen-King, and D. M. Mackay. 1994. Enhancing degradation of dissolved benzene and toluene using a solid oxygen-releasing compound. *Ground Water Monitoring and Remediation* 14:120–128.

Belochini, F., A. Dell'Anno, L. DeProrpis, S. Ubaldini, F. Cerrone, and R. Danovaro. 2009. Auto- and heterotrophic acidophilic bacteria enhance the bioremediation efficiency of sediments contaminated by heavy metals. *Chemosphere* 74:1321–1326.

Blake, S. B., and R. W. Lewis. 1982. "Underground oil recovery." *Proceedings of the Second National Symposium on Aquifer Restoration and Ground Water Monitoring* 69–76. Dublin, OH: National Water Well Association.

Borden, R. C., R. T. Goin, and C.-M. Kao. 1997. Control of BTEX migration using a biologically enhanced permeable barrier. *Ground Water Monitoring and Review* 17:70–80.

Botha, M., L. Bester, and E. Hardwick. 2009. Removal of uranium from mine water using ion exchange at Driefontein Mine. In *Abstracts of the International Mine Water Conference 19th–23rd October 2009*, Pretoria, South Africa.

Bowman, R. S. 2003. Applications of surfactant-modified zeolites to environmental remediation. *Microporous and Mesoporous Materials* 61:43–56.

Boving, T. B., and J. E. McCray. 2000. Cyclodextrin-enhanced remediation of organic and metal contaminants in porous media and groundwater. *Remediation Journal* 10:59–83.

Boving, T. B., and M. L. Brusseau. 2000. Solubilization and removal of residual trichloroethene from porous media: Comparison of several solubilization agents. *Journal of Contaminant Hydrology* 42:51–67.

Boving, T. B., J. E. McCray, W. J. Blanford, and M. L. Brusseau. 2004. "Cyclodextrin enhanced remediation at NAB Little Creek, Virginia Beach, VA: Cost and performance assessment."

DOCUMENT 8

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

SUBPART A: GENERAL PROVISIONS

Section
845.100 Scope and Purpose
845.110 Applicability of Other Regulations
845.120 Definitions
845.130 Surface Impoundment Identification
845.140 Right of Inspection
845.150 Incorporations by Reference
845.160 Severability
845.170 Inactive Closed CCR Surface Impoundments

SUBPART B: PERMITTING

Section
845.200 Permit Requirements and Standards of Issuance
845.210 General Provisions
845.220 Construction Permits
845.230 Operating Permits
845.240 Pre-Application Public Notification and Public Meeting
845.250 Tentative Determination and Draft Permit
845.260 Draft Permit Public Notice and Participation
845.270 Final Permit Determination and Appeal
845.280 Transfer, Modification and Renewal
845.290 Construction Quality Assurance Program

SUBPART C: LOCATION RESTRICTIONS

Section
845.300 Placement Above the Uppermost Aquifer
845.310 Wetlands
845.320 Fault Areas
845.330 Seismic Impact Zones
845.340 Unstable Areas and Floodplains
845.350 Failure to Meet Location Standards

SUBPART D: DESIGN CRITERIA

Section
845.400 Liner Design Criteria for Existing CCR Surface Impoundments
845.410 Liner Design Criteria for New CCR Surface Impoundments and Any Lateral Expansion of a CCR Surface Impoundment
845.420 Leachate Collection and Removal System
845.430 Slope Maintenance
845.440 Hazard Potential Classification Assessment
845.450 Structural Stability Assessment
845.460 Safety Factor Assessment

SUBPART E: OPERATING CRITERIA

Section
845.500 Air Criteria
845.510 Hydrologic and Hydraulic Capacity Requirements for CCR Surface Impoundments
845.520 Emergency Action Plan
845.530 Safety and Health Plan
845.540 Inspection Requirements for CCR Surface Impoundments
845.550 Annual Consolidated Report

SUBPART F: GROUNDWATER MONITORING AND CORRECTIVE ACTION

Section
845.600 Groundwater Protection Standards
845.610 General Requirements
845.620 Hydrogeologic Site Characterization
845.630 Groundwater Monitoring Systems
845.640 Groundwater Sampling and Analysis Requirements
845.650 Groundwater Monitoring Program
845.660 Assessment of Corrective Measures
845.670 Corrective Action Plan
845.680 Implementation of the Corrective Action Plan

SUBPART G: CLOSURE AND POST-CLOSURE CARE

Section
845.700 Required Closure or Retrofit of CCR Surface Impoundments
845.710 Closure Alternatives
845.720 Closure Plan
845.730 Initiation of Closure
845.740 Closure by Removal
845.750 Closure with a Final Cover System
845.760 Completion of Closure Activities
845.770 Retrofitting
845.780 Post-Closure Care Requirements

SUBPART H: RECORDKEEPING

Section
845.800 Facility Operating Record
845.810 Publicly Accessible Internet Site Requirements

SUBPART I: FINANCIAL ASSURANCE

Section
845.900 General Provisions
845.910 Upgrading Financial Assurance
845.920 Release of Financial Institution and Owner or Operator
845.930 Cost Estimates
845.940 Revision of Cost Estimates
845.950 Mechanisms for Financial Assurance
845.960 Trust Fund
845.970 Surety Bond Guaranteeing Payment
845.980 Surety Bond Guaranteeing Performance
845.990 Letter of Credit

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 1×10^{-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 1×10^{-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 6×10^{-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 1×10^{-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 9

Luminant

Electric Energy, Inc.
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: Joppa Power Plant East Ash Pond; IEPA ID # W1270100004-02

Dear Mr. LeCrone:

In accordance with 35 I.A.C. § 845.200, Electric Energy, Inc. (EEI) is submitting an operating permit application for the Joppa Power Plant East Ash Pond (IEPA ID # W1270100004-02). 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 not 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

Electric Energy, Inc.
1500 Eastport Plaza Drive
Collinsville, Illinois 62234

INITIAL OPERATING PERMIT

JOPPA EAST ASH POND

Prepared by

425 South Woods Mill Road, Suite 300
St. Louis, MO 63017

October 25, 2021

1. Introduction 1
1.1. Facility Information 1
1.2. Owner Signatures 2
1.3. Legal Description 2
1.4. Previous Assessments 2

2. Operating Permit 4
2.1. Initial Operating Permit 4
2.2. History of Construction 4
2.3. Chemical Constituents 4
2.4. Location Standards Demonstration 4
2.5. Permanent Markers 6
2.6. Slope Maintenance 6
2.7. Initial Emergency Action Plan 6
2.8. Fugitive Dust Control Plan 7
2.9. Groundwater Monitoring 7
2.10. Initial Post-Closure Care Plan 8
2.11. History of Groundwater Exceedances 8
2.12. Financial Assurance Requirements 8
2.13. Hazard Potential Classification 8
2.14. Structural Stability Assessment 8
2.15. Safety Factor Assessment 9
2.16. Inflow Design Flood Control System Plan 9
2.17. Safety and Health Plan 9
2.18. Proposed Closure Priority Categorization 9

3. Permit Application 10

ATTACHMENTS

Attachment A	Legal Description
Attachment B	History of Construction (845.220)
Attachment C	Chemical Constituent Analysis – CCR, Waste Streams
Attachment D1	Fault Areas (845.320)
Attachment D2	Placement Above the Uppermost Aquifer (845.300)
Attachment D3	Seismic Impact Zones (845.330)
Attachment D4	Unstable Areas and Floodplains (845.340)
Attachment D5	Wetlands (845.310)
Attachment E	Permanent Markers (845.130)
Attachment F	Initial Emergency Action Plan (845.520)
Attachment G	Fugitive Dust Control Plan (845.500)
Attachment H	Hydrogeologic Site Characterization (845.620)
Attachment I	Groundwater Sampling and Analysis Program (845.640)
Attachment J	Slope Maintenance (845.430)
Attachment K	Post Closure Care Plan (845.780)
Attachment M	History of Known Groundwater Exceedances (845.600)
Attachment N	Financial Assurance Requirements (845.900)
Attachment O	Hazard Potential Classification Assessment (845.440)
Attachment P	Structural Stability Assessment (845.450)
Attachment Q	Safety Factor Assessment (845.460)
Attachment R	Inflow Design Flood Control System Plan (845.510)
Attachment S	Safety and Health Plan (845.530)
Attachment T	Proposed Closure Priority Categorization (845.700)
Attachment U	5-Year Updates

1. INTRODUCTION

Electric Enery, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois.The IEPA assigned identification number assigned to this impoundment is: W1270100004-01 for the East Ash Pond. The National Inventory of Dams (NID) number assigned for the East Ash Pond 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 the East Ash Pond.

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:	Joppa East Ash Pond Joppa Power Plant 2100 Portland Road Joppa, IL 62953
Owner/Operator:	Electric Energy, Inc. 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 Joppa 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 Electric Energy, Inc. 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.*

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) in Attachment D.

> *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.*

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) in Attachments O, P, and Q respectively. The addendum and certification for the Hazard Potential Classification Assessment, Structural Stability Assessment and Safety Factor Assessment are located in Attachment U.

> *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 Joppa East Ash Pond as defined by IEPA is an existing CCR surface impoundment that has not completed post-closure care. Per Part 845, Electric Energy, Inc. 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. An amendment to the history of construction has been prepared in compliance with Section 845.220(a)(1) and is provided in Attachment U.

2.3. Chemical Constituents

Section 845.230(d)(2)(B): An analysis of the chemical constituents found within the CCR to be placed in the CCR surface impoundment;

An analysis of the chemical constituents found within the CCR placed within the Joppa East Ash Pond is provided in Attachment C.

Section 845.230(d)(2)(C): An analysis of the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained in the CCR surface impoundment;

An analysis of the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained within the Joppa East Ash Pond is provided in Attachment C.

2.4. Location Standards Demonstration

Section 845.230(d)(2)(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:

The Joppa East Ash Pond location standards as specified in Section 845.230(d)(2)(D) are described in the following sections.

Section 845.230(d)(2)(D)(i): Placement Above the Uppermost Aquifer;

The previous upper aquifer demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.60. The requirements described in 40 C.F.R. § 257.60 are identical to the requirements contained in Section 845.300. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed upper aquifer demonstration is included in Attachment D.

Section 845.230(d)(2)(D)(ii): Wetlands;

The previous wetlands demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.61. The requirements described in 40 C.F.R. § 257.61 are identical to the requirements contained in Section 845.310. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed wetlands demonstration is included in Attachment D.

Section 845.230(d)(2)(D)(iii): Fault Areas;

The previous fault area demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.62. The requirements described in 40 C.F.R. § 257.62 are identical to the requirements contained in Section 845.320. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed fault area demonstration is included in Attachment D.

Section 845.230(d)(2)(D)(iv): Seismic Impact Zone; and

The previous seismic impact zone demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.63. The requirements described in 40 C.F.R. § 257.63 are identical to the requirements contained in Section 845.330. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed seismic impact zone demonstration is included in Attachment D.

Section 845.230(d)(2)(D)(v): Unstable Areas and Floodplains;

The previous unstable area demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.64. The requirements described in 40 C.F.R. § 257.64 are identical to the requirements contained in Section 845.340. Pursuant to Section 845.210(d)(2), a certification is not required for the unstable area demonstration. The previously completed unstable area demonstration is included in Attachment D.

The boundaries of the East Ash Pond were determined in 2020 by a survey conducted by a professional surveyor licensed in the State of Illinois. The boundaries and elevations of the East Ash Pond were compared to the existing 1983 and 2008 FEMA floodplain maps, and it was determined that East Ash Pond is not located within the base flood elevation or 100-year floodplain.

A certification attesting to this is provided in Attachment D.

2.5. 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 Joppa East Ash Pond as required by Section 845.130 is provided in Attachment E.

2.6. 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 Joppa East Ash Pond is not incised. Documentation of slope protection as required by Section 845.430 is provided in Attachment J.

2.7. Initial Emergency Action Plan

Section 845.230(d)(2)(G): Initial Emergency Action Plan and accompanying certification (see Section 845.520(e));

The initial emergency action plan and certification has been completed as specified by Section 845.520(e) and is provided in Attachment F.

2.8. Fugitive Dust Control Plan

Section 845.230(d)(2)(H): Fugitive dust control plan and accompanying certification (see Section 845.500(b)(7));

The fugitive dust control plan and certification has been completed as specified by Section 845.500(b)(7) and is provided in Attachment G.

2.9. Groundwater Monitoring

Section 845.230(d)(2)(I): Groundwater monitoring information:

The groundwater monitoring information for the Joppa East Ash Pond 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 Joppa East Ash Pond 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.

2.10. 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 Joppa East Ash Pond closure will be 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.

2.11. 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.

2.12. 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.

2.13. Hazard Potential Classification

Section 845.230(d)(2)(O): Hazard potential classification assessment and accompanying certification (see Section 845.440(a)(2));

The previous Hazard Potential Classification Assessment completed in compliance with 40 CFR §257.73(a) is provided in Attachment O. The addendum to the Hazard Potential Classification Assessment and certification as required by Section 845.440(a) is provided in Attachment U.

2.14. Structural Stability Assessment

Section 845.230(d)(2)(P): Structural stability assessment and accompanying certification (see Section 845.450(c));

The previous Structural Stability Assessment completed in compliance with 40 CFR §257.73(d) is provided in Attachment P. The addendum to the Structural Stability Assessment and certification as required by Section 845.450(c) is provided in Attachment U.

2.15. Safety Factor Assessment

Section 845.230(d)(2)(Q): Safety factor assessment and accompanying certification (see Section 845.460(b));

The previous Safety Factor Assessment completed in compliance with 40 CFR §257.73(e) is provided in Attachment Q. The addendum to the Safety Factor Assessment and certification as required by Section 845.460(b) is provided in Attachment U.

2.16. Inflow Design Flood Control System Plan

Section 845.230(d)(2)(R): Inflow design flood control system plan and accompanying certification (see Section 845.510(c)(3));

The previous Inflow Design Flood Control System Plan Assessment completed in compliance with 40 CFR §257.82 is provided in Attachment R. The addendum to the Inflow Design Flood Control Plan Assessmentas required by Section 845.510(c)(3) is provided in Attachment U.

2.17. Safety and Health Plan

Section 845.230(d)(2)(S): Safety and health plan (see Section 845.530); and

The safety and health plan in accordance with Section 845.530 is included in Attachment S.

2.18. Proposed Closure Priority Categorization

Section 845.230(d)(2)(T): For CCR surface impoundments required to close under 845.700, the proposed closure priority categorization required by Section 845.700(g).

A CCR Surface Impoundment Category Designation and Justification letter was submitted to IEPA on May 19, 2021. The Joppa East Ash Pond was designated as Category 5 Existing CCR surface impoundment with exceedances of the groundwater protection standards in Section 845.600. This letter is provided in Attachment T.

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-2E) 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:
W1270100004-02

CCR Permit Number:
Initial Permit

Facility Name:
Joppa Power Plant

For IEPA Use Only

SECTION 1: FACILITY, OPERATOR, AND OWNER INFORMATION (35 Ill. Adm. Code 845.210(b))

Facility, Operator, and Owner Information

1.1	Facility Name		
	Electric Energy, Inc. - Joppa Power Plant		
1.2	Illinois EPA CCR Permit Number (if applicable)		
	Initial Permit		
1.3	Facility Contact Information		
	Name (first and last) Phil Morris	Title Senior Director - Environmental	Phone Number 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 Collinsville	State IL	Zip Code 62234
1.5	Facility Location		
	Street, route number, or other specific identifier 2100 Portland Road		
	County name Massac	County code (if known)	
	City or town Joppa	State IL	Zip Code 62953
1.6	Name of Owner/Operator		
	Electric Energy, Inc.		

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/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.

W1270100004-02 (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

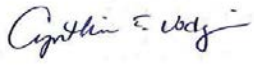
Checklist and Certification Statement

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	Official Title
Cynthia Vodopivec	SVP - Environmental
Signature 	Date Signed 10/25/2021

Form CCR 2E	Illinois Environmental Protection Agency CCR Surface Impoundment Permit Application Form CCR 2E – Initial Operating Permit for Existing or Inactive CCR Surface Impoundments That Have Not Completed an Agency-approved Closure Before July 30, 2021

Bureau of Water ID Number:
W1270100004-02

CCR Permit Number:
Initial Permit

Facility Name:
Joppa Power Plant

For IEPA Use Only

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.
	East Ash Pond
1.2	Identification number of the CCR surface impoundment (if one has been assigned by the Agency).
	W1270100004-02
1.3	Description of 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 C.

Construction History (Continued)

1.7	List name of the watershed within which the CCR surface impoundment is located.	
	See Attachment B.	
1.8	Size in acres of the watershed within which the CCR surface impoundment is located.	
	See Attachment B.	
1.9	Check the corresponding box to indicate that you have attached the following:	
	☑	Description of the physical and engineering properties of the foundation and abutment materials on which the CCR surface impoundment is constructed.
	☑	Description 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.
	☑	Describe the method of site preparation and construction of each zone of the CCR surface impoundment.
	☑	A listing of the approximate dates of construction of each successive stage of construction of the CCR surface impoundment.
	☑	Drawing satisfying the requirements of 35 Ill. Adm. Code 845.220(a)(1)(F).
	☑	Description of the type, purpose, and location of existing instrumentation.
	☑	Area capacity curves for the CCR Impoundment.
	☑	Description of each spillway and diversion design features and capacities and provide the calculations used in their determination.
	☑	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?	
	☑ Yes	☐ No
1.10.2	If you answered yes to Item 1.10.1, provide detailed explanation of the structural instability.	
	See Attachment P - Structural Stability Assessment.	

SECTION 2: ANALYSIS OF CHEMICAL CONSTITUENTS (35 Ill. Adm. Code 845.230(d)(2)(B))

Constituents

2.1	Check the corresponding boxes to indicate you have attached the following:	
	☑	An analysis of the chemical constituents found within the CCR to be placed in the CCR surface impoundment.
	☑	An analysis of the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained in the CCR surface impoundment.

SECTION 3: DEMONSTRATIONS AND CERTIFICATIONS (35 Ill. Adm. Code 845.230(d)(2)(D))

Demonstrations

3.1 Indicate whether you have attached 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:

35 Ill. Adm. Code 845.300 (Placement Above the Uppermost Aquifer)	☑	Demonstration	☐	Explanation
35 Ill. Adm. Code 845.310 (Wetlands)	☑	Demonstration	☐	Explanation
35 Ill. Adm. Code 845.320 (Fault Areas)	☑	Demonstration	☐	Explanation
35 Ill. Adm. Code 845.330 (Seismic Impact Zones)	☑	Demonstration	☐	Explanation
35 Ill. Adm. Code 845.340 (Unstable Areas and Floodplains)	☑	Demonstration	☐	Explanation

SECTION 4: ATTACHMENTS

Attachments

4.1 Check the corresponding boxes to indicate that you have attached the following:

☑	Evidence that the permanent markers required by 35 Ill. Adm. Code 845.130 have been installed.
☑	Documentation 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.
☑	Initial Emergency Action Plan and accompanying certification required by 35 Ill. Adm. Code 845.520(e).
☑	Fugitive dust control plan and accompanying certification required by 35 Ill. Adm. Code 845.500(b)(7).
☐	Preliminary written closure plan as specified in 35 Ill. Adm. Code 845.720(a).
☑	Initial written post-closure care plan as specified in 35 Ill. Adm. Code 845.780(d), if applicable.
☐	A certification as specified in 35 Ill. Adm. Code 845.400(h), or a statement that the CCR surface impoundment does not have a liner than meets the requirements of 35 Ill. Adm. Code 845.400(b) or (c).
☑	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.
☑	Safety and health plan, as required by 35 Ill. Adm. Code 845.530.
☑	For CCR surface impoundments required to close under 35 Ill. Adm. Code 845.700, the proposed closure priority categorization required by 35 Ill. Adm. Code 845.700(g).

SECTION 5: GROUNDWATER MONITORING

Groundwater

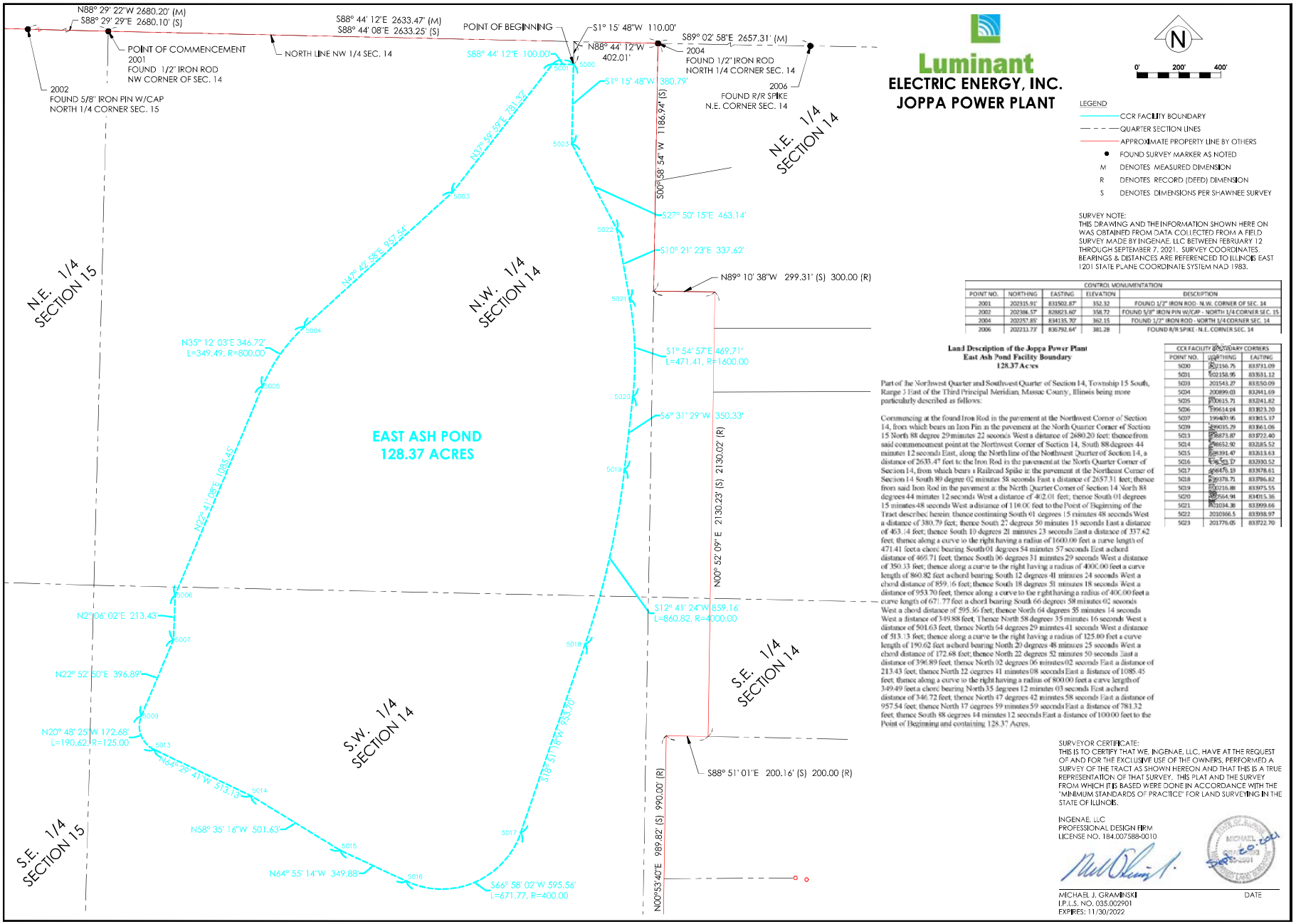
5.1 Check the corresponding boxes to indicate you have attached the following groundwater monitoring information:

☑	A hydrogeologic site characterization meeting the requirements of 35 Ill. Adm. Code 845.620.
☑	Design and construction plans of a groundwater monitoring system meeting the requirements of 35 Ill. Adm. Code 845.630.

		☑	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.
		☑	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).
SECTION 6: CERTIFICATIONS			
Certifications	6.1	Check the corresponding boxes to indicate you have attached the following certifications:	
		☑	A certification that the owner or operator meets the financial assurance requirements of Subpart I, as required by 35 Ill. Adm. Code 845.230(d)(2)(N).
		☑	Hazard potential classification assessment and accompanying certifications required by 35 Ill. Adm. Code 845.440(a)(2).
		☑	Structural stability assessment and accompanying certification, required by 35 Ill. Adm. Code 845.450(c).
		☑	Safety factor assessment and accompanying certification, as required by 35 Ill. Adm. Code 845.460(b).
		☑	Inflow design flood control system plan and accompanying certification, as required by 35 Ill. Adm. Code 845.510(c)(3).

ATTACHMENT A

October 2021



Luminant

ELECTRIC ENERGY, INC.
JOPPA POWER PLANT

N

0' 200' 400'

LEGEND

- CCR FACILITY BOUNDARY
- QUARTER SECTION LINES
- APPROXIMATE PROPERTY LINE BY OTHERS
- FOUND SURVEY MARKER AS NOTED
- M DENOTES MEASURED DIMENSION
- R DENOTES RECORD (DEED) DIMENSION
- S DENOTES DIMENSIONS PER SHAWNEE SURVEY

SURVEY NOTE:
THIS DRAWING AND THE INFORMATION SHOWN HERE ON WAS OBTAINED FROM DATA COLLECTED FROM A FIELD SURVEY MADE BY INGENAE, LLC BETWEEN FEBRUARY 12 THROUGH SEPTEMBER 7, 2021. SURVEY COORDINATES BEARINGS & DISTANCES ARE REFERENCED TO ILLINOIS EAST 1201 STATE PLANE COORDINATE SYSTEM NAD 1983.

CONTROL MONUMENTATION

POINT NO.	NORTHING	EASTING	ELEVATION	DESCRIPTION
2001	202315.91'	831502.87'	352.32	FOUND 1/2" IRON ROD - N.W. CORNER OF SEC. 14
2002	202386.57'	828823.60'	358.72	FOUND 5/8" IRON PIN W/CAP - NORTH 1/4 CORNER SEC. 15
2004	202257.85'	834135.70'	362.15	FOUND 1/2" IRON ROD - NORTH 1/4 CORNER SEC. 14
2006	202233.73'	836792.64'	381.28	FOUND R/R SPIKE - N.E. CORNER SEC. 14

Land Description of the Joppa Power Plant
East Ash Pond Facility Boundary
128.37 Acres

Part of the Northwest Quarter and Southwest Quarter of Section 14, Township 15 South, Range 3 East of the Third Principal Meridian, Massac County, Illinois being more particularly described as follows:

Commencing at the found Iron Rod in the pavement at the Northwest Corner of Section 14, from which bears an Iron Pin in the pavement at the North Quarter Corner of Section 15 North 88 degree 29 minutes 22 seconds West a distance of 2680.20 feet; thence from said commencement point at the Northwest Corner of Section 14, South 88 degrees 44 minutes 12 seconds East, along the North line of the Northwest Quarter of Section 14, a distance of 2633.47 feet to the Iron Rod in the pavement at the North Quarter Corner of Section 14, from which bears a Railroad Spike in the pavement at the Northeast Corner of Section 14 South 89 degree 02 minutes 58 seconds East a distance of 2657.31 feet; thence from said Iron Rod in the pavement at the North Quarter Corner of Section 14 North 88 degrees 44 minutes 12 seconds West a distance of 402.01 feet; thence South 01 degrees 15 minutes 48 seconds West a distance of 110.00 feet to the Point of Beginning of the Tract described herein; thence continuing South 01 degrees 15 minutes 48 seconds West a distance of 380.79 feet; thence South 27 degrees 50 minutes 15 seconds East a distance of 463.14 feet; thence South 10 degrees 21 minutes 23 seconds East a distance of 337.62 feet; thence along a curve to the right having a radius of 1600.00 feet a curve length of 471.41 feet a chord bearing South 01 degrees 54 minutes 57 seconds East a chord distance of 469.71 feet; thence South 06 degrees 31 minutes 29 seconds West a distance of 350.33 feet; thence along a curve to the right having a radius of 4000.00 feet a curve length of 860.82 feet a chord bearing South 12 degrees 41 minutes 24 seconds West a chord distance of 859.16 feet; thence South 18 degrees 51 minutes 18 seconds West a distance of 953.70 feet; thence along a curve to the right having a radius of 400.00 feet a curve length of 671.77 feet a chord bearing South 66 degrees 58 minutes 02 seconds West a chord distance of 595.56 feet; thence North 64 degrees 55 minutes 14 seconds West a distance of 349.88 feet; Thence North 58 degrees 35 minutes 16 seconds West a distance of 501.63 feet; thence North 64 degrees 29 minutes 41 seconds West a distance of 513.13 feet; thence along a curve to the right having a radius of 125.00 feet a curve length of 190.62 feet a chord bearing North 20 degrees 48 minutes 25 seconds West a chord distance of 172.68 feet; thence North 22 degrees 52 minutes 50 seconds East a distance of 396.89 feet; thence North 02 degrees 06 minutes 02 seconds East a distance of 213.43 feet; thence North 22 degrees 41 minutes 08 seconds East a distance of 1085.45 feet; thence along a curve to the right having a radius of 800.00 feet a curve length of 349.49 feet a chord bearing North 35 degrees 12 minutes 03 seconds East a chord distance of 346.72 feet; thence North 47 degrees 42 minutes 58 seconds East a distance of 957.54 feet; thence North 37 degrees 59 minutes 59 seconds East a distance of 781.32 feet; thence South 88 degrees 44 minutes 12 seconds East a distance of 100.00 feet to the Point of Beginning and containing 128.37 Acres.

CCR FACILITY BOUNDARY CORNERS

POINT NO.	NORTHING	EASTING
5000	202156.75	833731.09
5001	202158.95	833631.12
5003	201543.27	833150.09
5004	200899.03	832941.69
5005	200615.71	833241.82
5006	199614.94	833823.20
5007	199483.95	833815.37
5009	199035.29	833861.06
5013	198873.87	833722.40
5014	198652.92	833185.52
5015	198391.47	833613.63
5016	198153.17	833930.52
5017	198476.19	833978.61
5018	199378.71	833786.82
5019	200216.88	833975.55
5020	200564.94	834015.36
5021	201034.38	833999.66
5022	201036.5	833938.97
5023	201776.05	833722.70

SURVEYOR CERTIFICATE:
THIS IS TO CERTIFY THAT WE, INGENAE, LLC, HAVE AT THE REQUEST OF AND FOR THE EXCLUSIVE USE OF THE OWNERS, PERFORMED A SURVEY OF THE TRACT AS SHOWN HEREON AND THAT THIS IS A TRUE REPRESENTATION OF THAT SURVEY. THIS PLAT AND THE SURVEY FROM WHICH IT IS BASED WERE DONE IN ACCORDANCE WITH THE "MINIMUM STANDARDS OF PRACTICE" FOR LAND SURVEYING IN THE STATE OF ILLINOIS.

INGENAE, LLC
PROFESSIONAL DESIGN FIRM
LICENSE NO. 184.007588-0010

MICHAEL J. GRAMINSKI
I.P.L.S. NO. 035.002901
EXPIRES: 11/30/2022

DATE

IngenAE
502 Earth City Plaza, Suite 120
Earth City, MO 63045
www.ingenae.com

Submissions / Revisions: Date:

1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		

Luminant

Project Name & Location:

JOPPA
POWER PLANT

2100 PORTLAND ROAD
JOPPA, IL 62953

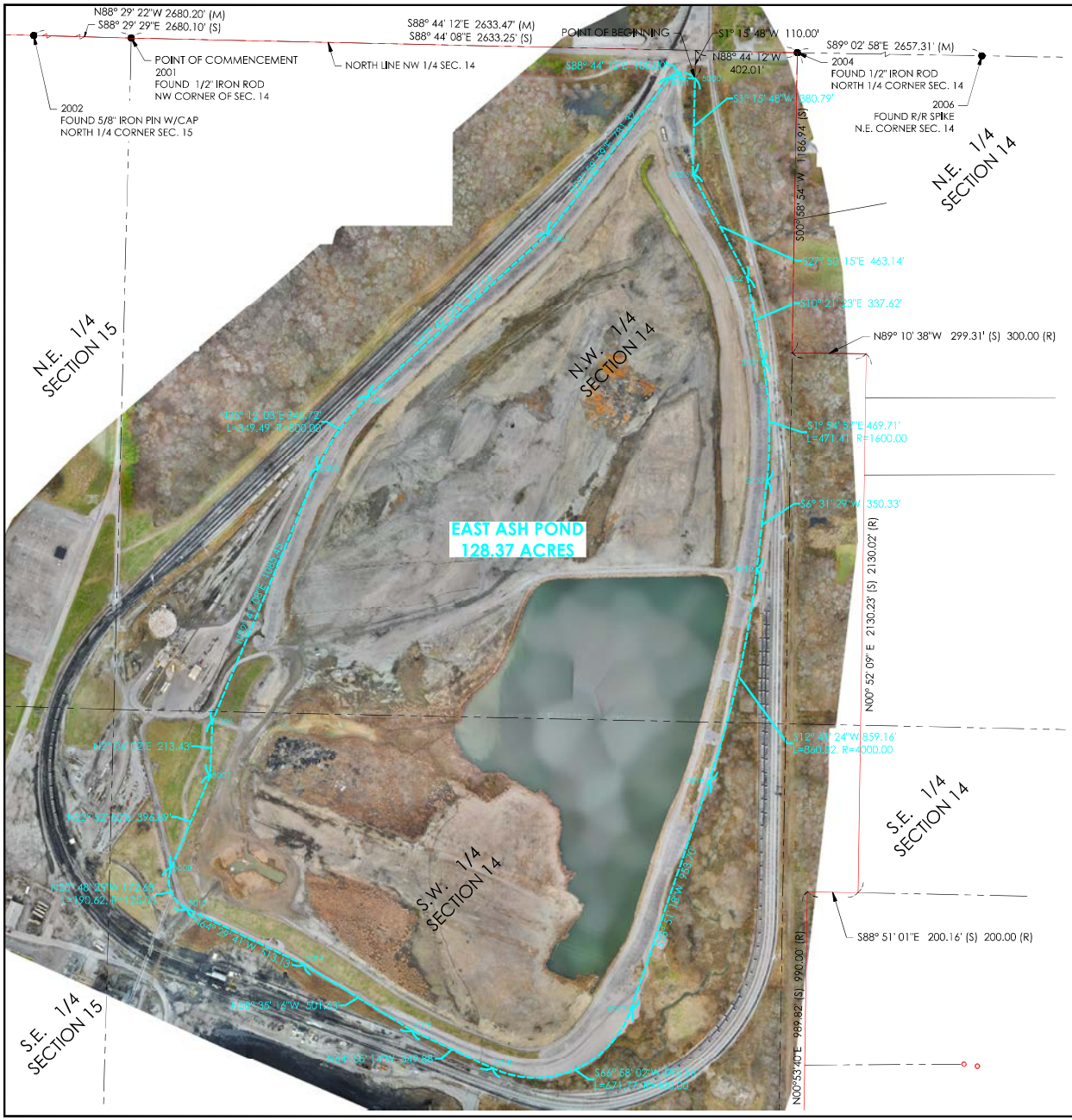
Copyright © 2021
INGENAE
ALL RIGHTS RESERVED

DO NOT SCALE PLANS
Copying, Printing, Software and other processes required to produce these prints can stretch or shrink the actual paper or layout. Therefore, scaling of this drawing may be inaccurate. Contact IngenAE with any need for additional dimensions or clarifications.

Drawing Name:
CCR FACILITY BOUNDARY EXHIBIT

Date: 09/07/2021	Project No.
Type: SITE	Drawing No. 1
Drawn By: CB	
Approved By: BH	
Scale: AS NOTED	

R000555



Luminant

ELECTRIC ENERGY, INC.
JOPPA POWER PLANT

N

0' 200' 400'

LEGEND

- CCR FACILITY BOUNDARY
- QUARTER SECTION LINES
- APPROXIMATE PROPERTY LINE BY OTHERS
- FOUND SURVEY MARKER AS NOTED
- M DENOTES MEASURED DIMENSION
- R DENOTES RECORD (DEED) DIMENSION
- S DENOTES DIMENSIONS PER SHAWNEE SURVEY

SURVEY NOTE:
THIS DRAWING AND THE INFORMATION SHOWN HERE ON WAS OBTAINED FROM DATA COLLECTED FROM A FIELD SURVEY MADE BY INGENAE, LLC BETWEEN FEBRUARY 12 THROUGH SEPTEMBER 7, 2021. SURVEY COORDINATES, BEARINGS & DISTANCES ARE REFERENCED TO ILLINOIS EAST 1201 STATE PLANE COORDINATE SYSTEM NAD 1983.

IngenAE
502 Earth City Plaza, Suite 120
Earth City, MO 63045
www.ingenae.com

Submissions / Revisions:		Date:
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		

Luminant

Project Name & Location:

JOPPA
POWER PLANT

2100 PORTLAND ROAD
JOPPA, IL 62953

Copyright © 2021
IngenAE LLC
www.ingenae.com

DO NOT SCALE PLANS
Copying, Printing, Software and other processes required to produce these prints can stretch or shrink the actual paper or layout. Therefore, scaling of this drawing may be inaccurate. Contact IngenAE with any need for additional dimensions or clarifications.

Drawing Name:
CCR FACILITY BOUNDARY EXHIBIT

Date:	Project No.
09/07/2021	
Type: SITE	Drawing No. 2
Drawn By: CB	
Approved By: BH	
Scale: AS NOTED	

R000556

ATTACHMENT B

October 2021

AECOM

October 2016

Electric Energy, Inc.
1500 Eastport Plaza Drive
Collinsville, IL 62234

RE: History of Construction
USEPA Final CCR Rule, 40 CFR § 257.73(c)
Joppa Power Station
Joppa, Illinois

On behalf of Electric Energy, Inc., AECOM has prepared the following history of construction for the East Ash Pond at the Joppa 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, etc. for the East Ash Pond at the Joppa Power Station.

AECOM

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: Electric Energy, Inc.

Address: 1500 Eastport Plaza Drive
Collinsville, IL 62234

CCR Unit: East Ash Pond

The East Ash Pond does 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 location of the East Ash Pond has 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 East Ash Pond is being used to store and dispose of sluiced bottom ash, fly ash, and dredged material from the coal pile runoff pond and to clarify other plant process wastewaters prior to discharge in accordance with the station's NPDES permit.

§ 257.73(c)(1)(iv): The name and size in acres of the watershed where the CCR unit is located.

The East Ash Pond and the Joppa Power Station are located in the Bayou Creek-Ohio River Watershed with a 12-digit Hydrologic Unit Code (HUC) of 051402060701 and a drainage area of 47,283 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 materials consist of foundation clay and foundation sand layers. These layers are of Pleistocene origin and in the same geologic formation. The physical properties of the foundation clay layer for the East Ash Pond are described as lean clay and sandy clay with a generally stiff consistency. Some of these clay soils exhibit a dilative behavior while a limited amount of the clay soils exhibit a contractive behavior. The soils are highly interbedded; however, the contractive clay is generally identified in deeper stratum and is less prevalent in surficial and shallow foundation clays. Soft to very soft dark brown to brown clay with some organics is present in several locations immediately below the embankment. These areas are generally isolated and are generally located in areas of historic drainages. The physical properties of the foundation sand layer for the East Ash Pond are described as

AECOM

dense silty sand and poorly graded sand with some gravel. An available summary of the engineering properties of the foundation materials is presented in **Table 1** below.

In 2016, the soils located below the East Ash Pond southeast corner embankment were improved using the Deep Mixing Method (DMM). An available summary of the engineering properties of the foundation materials is presented in **Table 1** below. The engineering properties are based on previous geotechnical explorations and laboratory testing.

Table 1. Summary of Material Engineering Properties

Material	Unit Weight (pcf)	Drained Strength		Peak Undrained Strength S_u (psf)	Post-Earthquake Strength S_u[1] (psf)
		Cohesion (psf)	Friction Angle[1] (deg)		
Embankment Clay [Fill]	131	Non-linear strength envelope. See Table 1A below.		$\sigma'_{fc} < 0.5$ ksf: $S_u = 600$ psf $\sigma'_{fc} \geq 0.5$ ksf: $S_u/\sigma'_{fc} = 0.65$ and $c_o = 274$ psf	Peak undrained strength. Cyclic softening is not expected due to stiff nature of soil.
Foundation Clay	128	0	$\alpha > 5°$: 33 $-5° \leq \alpha \leq 5°$: 29 $\alpha < -5°$: 33	$S_u/\sigma'_{fc} = 0.41$ $c_o = 700$ psf	
Foundation Sand	130	0	35	Drained Strength	Drained Strength
Soft Clay (Miscellaneous Fill)[2]	125	0	24	$S_u/\sigma'_{fc} = 0.25$, min $S_u = 500$ psf	$S_u/\sigma'_{fc} = 0.18$, min $S_u = 400$ psf
DMM Material (soil and cement)	125	Not Applicable		7200 psf	Peak Undrained

1. Where applicable, α represents the failure plane angle measured from horizontal.

Table 1A: Embankment Clay [Fill] Non-linear Drained Strength Failure Envelope

Normal Effective Stress on Failure Plane (σ'_{ff}), psf	Shear Strength (τ_{ff}), psf
0	0
585.2	561
1308.6	1050.4
1497.4	1124.6
2000	1400.4
10000	7002.1

The East Ash Pond is an enclosed impoundment with embankments and does not have abutments.

§ 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

AECOM

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 original embankment construction are described as over-consolidated, silty clay and sandy clay with a general stiff consistency. Some isolated soft clay (dark brown in color) layers are presented. In 2016, the soils located within the East Ash Pond southeast corner embankment were improved using the Deep Mixing Method (DMM). An available summary of the engineering properties of the construction materials is presented in **Table 1** above. The engineering properties are based on previous geotechnical explorations and laboratory testing.

The method of site preparation and construction of the East Ash Pond is not reasonably and readily available.

The approximate dates of construction of each successive stage of construction of the East Ash Pond are provided in **Table 2** below.

Table 2. Approximate dates of construction of each successive stage of construction.

Date	Event
1973	Construction of the northern portion of the East Ash Pond
1977-1985	Construction of the southern portion of the East Ash Pond
1992	New outlet structure installed in the southern portion of East Ash Pond
1998	Changed the outlet from a high-density polyethylene (HDPE) tee drain to a ductile iron pipe (DIP) tee drain in the southern portion of East Ash Pond
2011	Perimeter berm repairs at select locations and rip-rap placement at select locations of the perimeter embankment.
2016	Ground improvement along the southeastern portion of the East Ash Pond using the wet soil cement deep mixing method (DMM)

§ 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 the Ash Pond are listed in **Table 3** below. Items marked as "Not Available" are items not found during a review of the reasonably and readily available record documentation.

AECOM

Table 3. List of drawings containing items pertaining to the information requested in § 257.73(c)(1)(vii).

	East Ash Pond
Dimensional plan view (all zones)	EE-AP-1, C-106, 4229-8211
Dimensional cross sections	C-106, 4229-8211
Foundation Improvements	C-100 to C-106
Drainage Provisions	EE-AP-2, C-107, 02199 (sheets 2 to 8)
Spillways and Outlets	02199 (sheets 2 to 8)
Diversion Ditches	Not Applicable
Instrument Locations	Plate 2, Fig. No. 2A
Slope Protection	Not Available
Normal Operating Pool Elevation	C-107, 02199 (sheet 8)
Maximum Pool Elevation	Not Available
Approximate Maximum Depth of CCR in 2016	52 feet

All drawings referenced in **Table 3** 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 this CCR unit due to malfunction or mis-operation were identified.

AECOM

§ 257.73(c)(1)(viii): A description of the type, purpose, and location of existing instrumentation.

Existing instrumentation at the East Ash Pond include vibrating-wire and open-standpipe piezometers. The purpose of the piezometers is to measure the pore water pressures within and around the impoundment. Two (2) existing open-standpipe piezometers (B-1 and B-4) were installed in 2010 and the locations are presented on Plate 2 in **Appendix C**. Eighteen (18) vibrating-wire piezometers were installed in 2015 and the locations are presented on Figure 2A in **Appendix C**.

§ 257.73(c)(1)(ix): Area-capacity curves for the CCR unit.

The area-capacity curves for the East Ash Pond are presented in **Figures 1** and **2** 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."

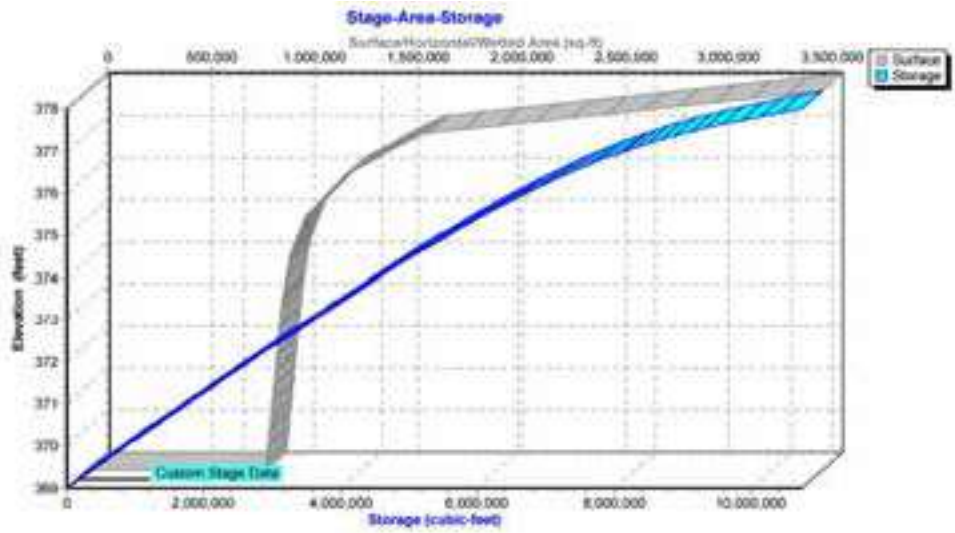


Figure 1. Area-capacity curve for East Ash Pond - south sub-basin

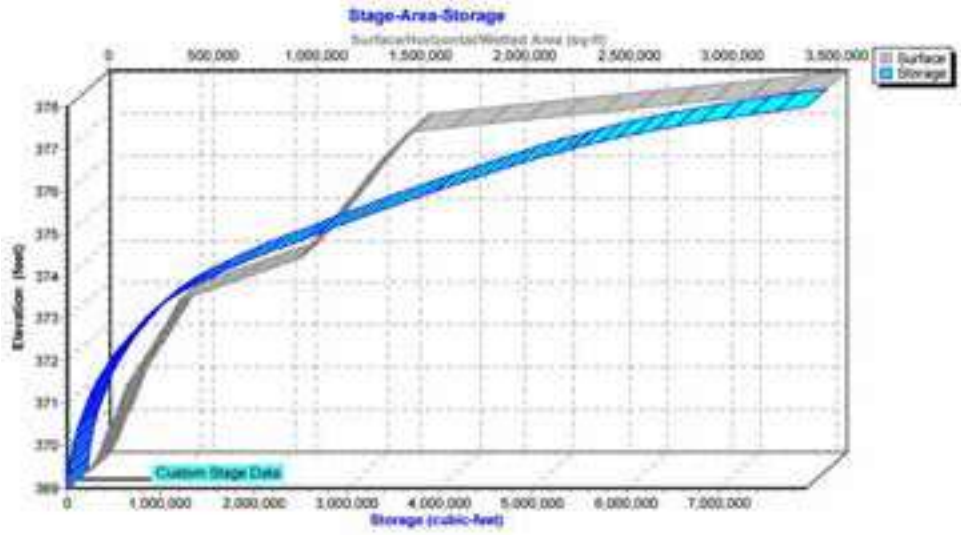


Figure 2. Area-capacity curve for East Ash Pond - north sub-basin

§ 257.73(c)(1)(x): A description of each spillway and diversion design features and capacities and calculations used in their determination.

The northern portion of the East Ash Pond contains stacked 48-inch diameter (dia.) concrete pipe sections seated on a 72-inch dia. precast manhole. The structure discharges water through a 48-inch-dia. reinforced concrete pipe (RCP) to the effluent control basin. The southern portion of the East Ash Pond contains a 24-inch dia. ductile iron tee pipe drain located on the east side of the impoundment. The tee pipe drains into a 26-inch outer-dia. high-density polyethylene (HDPE) pipe that transports the water to the 48-inch-dia. RCP discharge line from the northern portion of the East Ash Pond. The East Ash Pond also contains an internal 36-inch-dia. corrugated HDPE pipe culvert to allow for water to flow from the southern portion of the pond to the northern portion. The East Ash Pond's discharge capability was evaluated using HydroCAD 10 software modeling a 1,000-year, 24-hour rainfall event. The model results indicate that the East Ash Pond has enough storage capacity and will not overtop the embankment during the 1,000-year, 24-hour storm event. The results of the HydroCAD 10 analysis are presented below in **Table 4**.

The East Ash Pond includes a north sub-basin and a south sub-basin which is surrounded by a continuous perimeter embankment. The two sub-basins are separated by a common embankment and were modeled individually.

AECOM

Table 4. Results of HydroCAD 10 analysis

	North Sub-Basin	South Sub-Basin
Approximate Berm Elevation[1] (ft)	378.0	378.0
Approximate Emergency Spillway Elevation[1] (ft)	Not Applicable	Not Applicable
Starting Pool Elevation[1] (ft)	370.0	373.2
Peak Elevation[1] (ft)	376.2	377.6
Time to Peak (hr)	14.0	15.4
Surface Area (ac)	31.8	63.4
Storage[2] (ac-ft)	93.9	129.9

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.

Drawings for the East Ash Pond refer to construction specification *Specifications for Construction of Waste Treatment Facilities*, but those specifications are not reasonably and readily available.

The operations and maintenance plan for the East Ash Pond is currently being prepared by Electric Energy, Inc.

§ 257.73(c)(1)(xii): Any record or knowledge of structural instability of the CCR unit.

In 2011, eight (8) separate surficial movements occurred along the downstream slope of the perimeter embankment. The soil movements were investigated by Hanson Professional Services (Hanson) and were believed to be caused by recent heavy rains and sliding along the interface of the original embankment and the subsequently placed ash materials. The surficial movements were recompacted with replacement material and portions of the south embankment were rock lined. Information about this event can be found in the 2011 letter by Hanson presented in **Appendix D**. Photos of the repaired slopes are presented in **Appendix E**.

There is no record or knowledge of any other structural instability of the East Ash Pond at Joppa Power Station.

AECOM

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
Project Manager

Victor Modeer, P.E., D.GE
Senior Project Manager

REFERENCES

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.

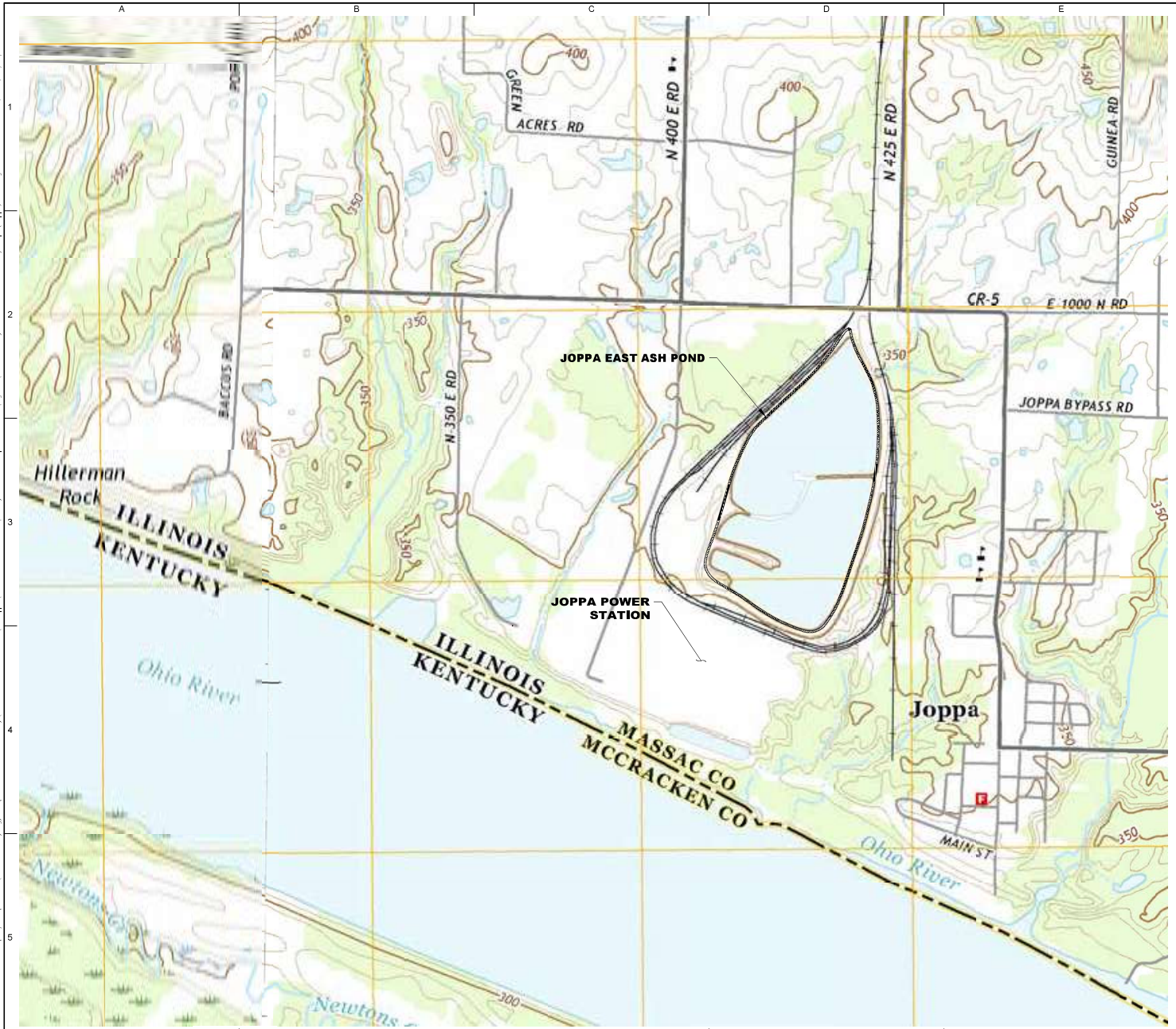
United States Geological Survey (USGS). (2016). The National Map Viewer. http://viewer.nationalmap.gov/viewer/. USGS data first accessed in March of 2016.

APPENDICES

Appendix A: History of Construction Vicinity Map
Appendix B: Joppa Power Station Drawings
Appendix C: Joppa East Ash Pond Piezometer and Boring Locations
Appendix D: Ash Pond Embankment Instability, Hanson Professional Services Inc. (2011)
Appendix E: Photos of Slope Repairs

AECOM

Appendix A: History of Construction Vicinity Map



LEGEND

CCR UNITS

SOURCE:
MAP PROVIDED FROM ELECTRONIC USGS DIGITAL RASTER GRAPHIC 7.5 MINUTE TOPOGRAPHIC MAP OF BANDANA, ILLINOIS AND JOPPA, ILLINOIS, REVISED 2015.

QUADRANGLE LOCATION

N

0 600 1200 1800
SCALE IN FEET

AECOM
1001 Highlands Plaza Drive, Suite 300
St. Louis, Mo. 63110
314 429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.

2100 Portland Road,
Joppa, IL 62953

HISTORY OF CONSTRUCTION

JOPPA POWER STATION
JOPPA, ILLINOIS

ISSUED FOR BIDDING DATE BY

ISSUED FOR CONSTRUCTION DATE BY

REVISIONS

NO.	DESCRIPTION	DATE

AECOM PROJECT NO:	60489731
DRAWN BY:	DJD
DESIGNED BY:	DJD
CHECKED BY:	MN
DATE CREATED:	2016-04-13
PLOT DATE:	
SCALE:	1" = 600'
ACAD VER:	2014

SHEET TITLE

HISTORY OF CONSTRUCTION VICINITY MAP

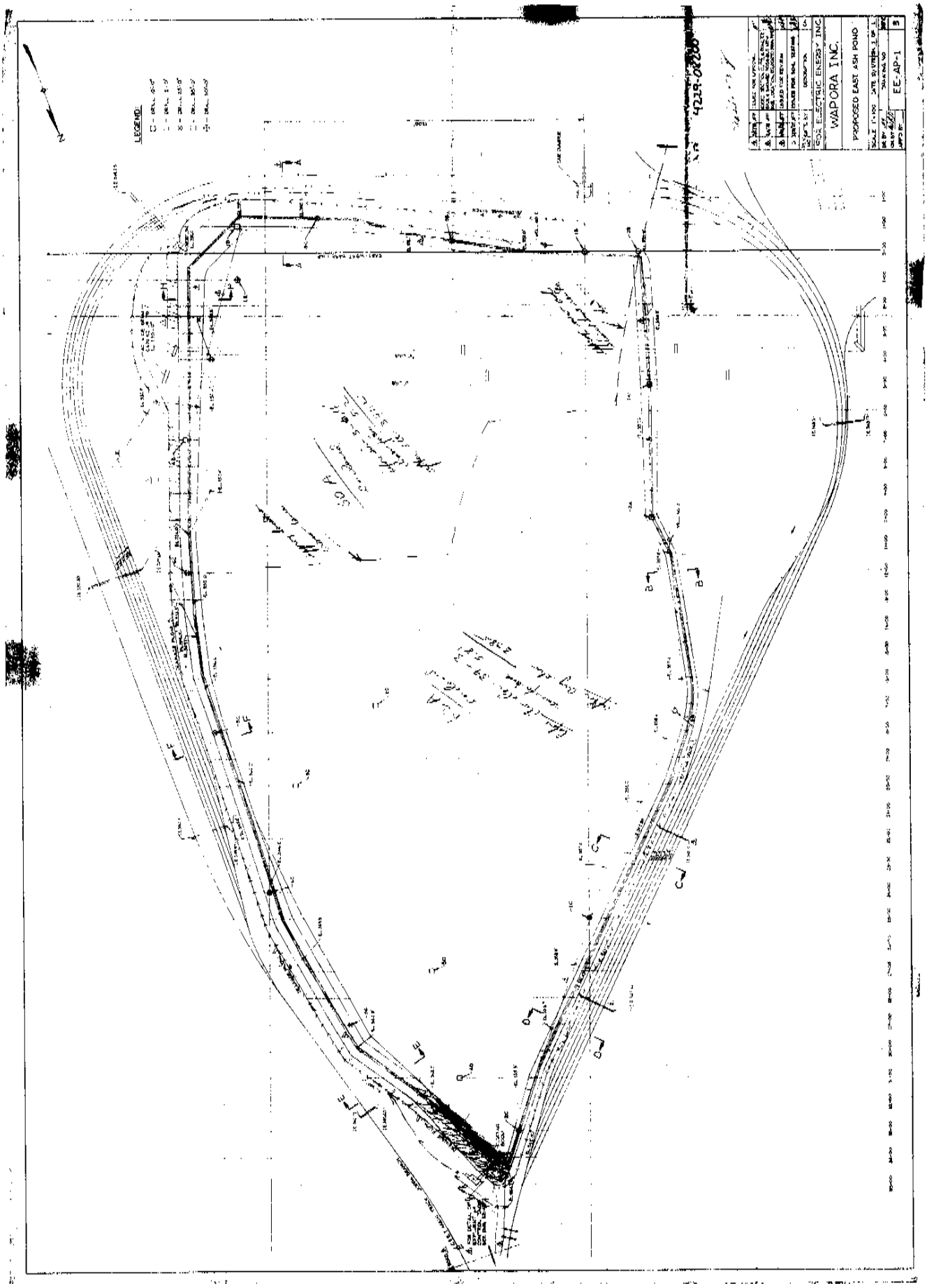
01

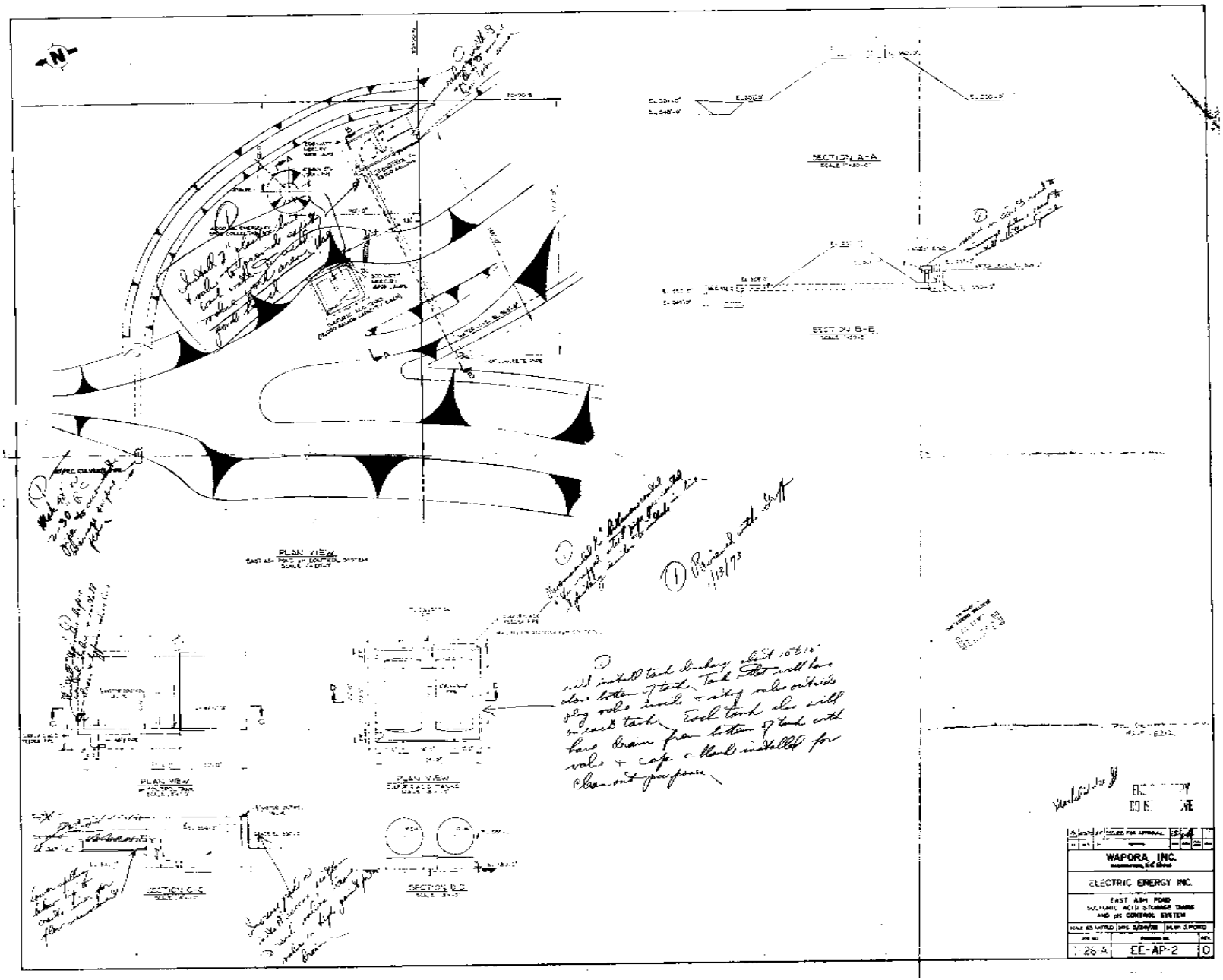
R000568

AECOM

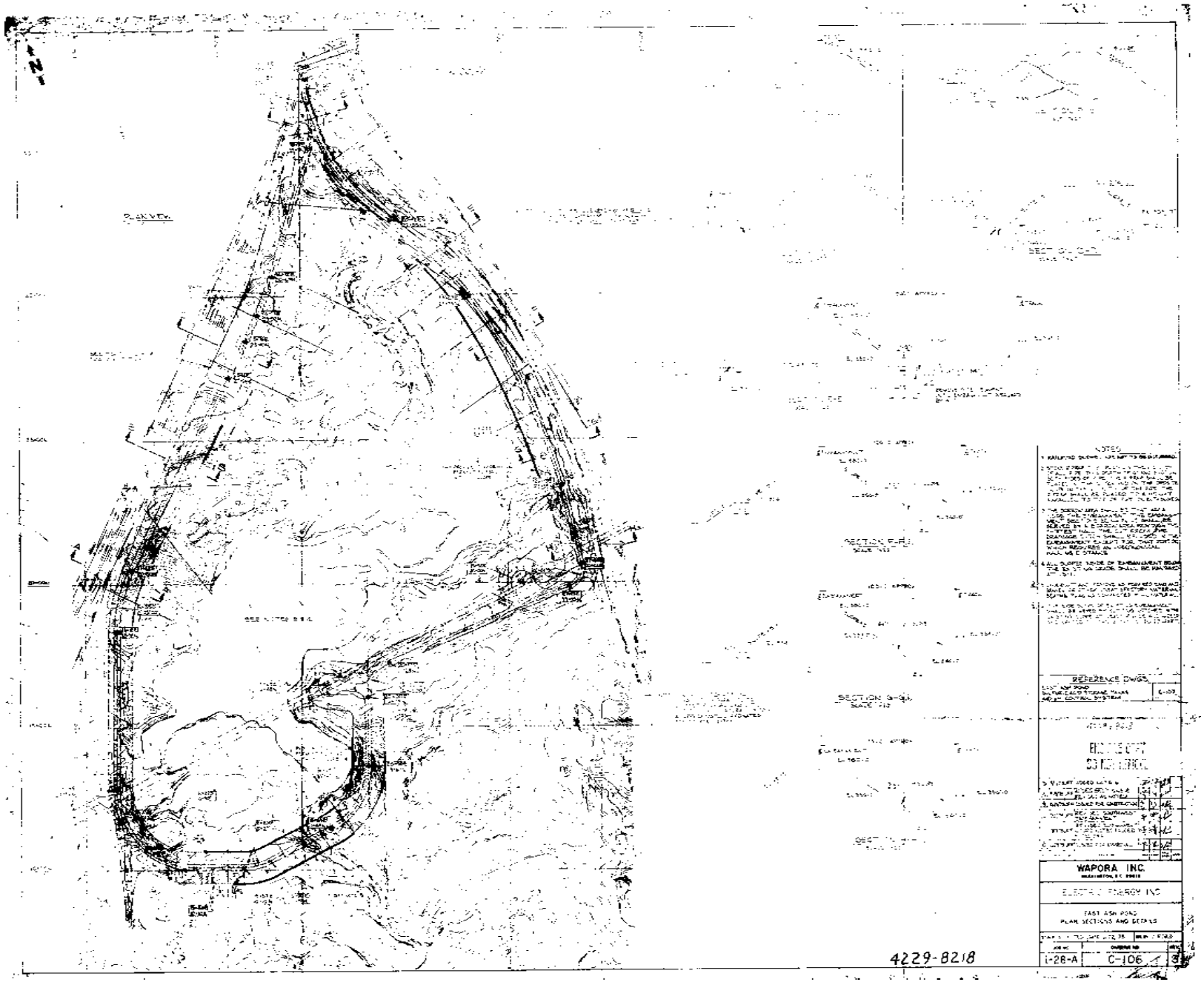
Appendix B: Joppa Power Station Drawings

1. "Proposed East Ash Pond", Drawing No. EE-AP-1, Revision 3, 7 December, 1972, Wapora Inc.
2. "East Ash Pond Sulfuric Acid Storage Tanks and pH Control System", Drawing No. EE-AP-2, Revision 0, 24 May, 1973, Wapora Inc.
3. "East Ash Pond, Plan, Sections and Details", Drawing No. C-106, Revision 5, 11 September, 1973, Wapora Inc.
4. "East Ash Pond, Sulfuric Acid Storage Tanks and pH Control System, Plan, Sections and Details", Drawing No. C-107, Revision 4, 14 July, 1975, Wapora Inc.
5. "East Ash Pond, Plan", Drawing No. 4229-8211, Revision 4, 13 June, 1986, Wapora Inc.
6. "Plan and Profile", Drawing No. 02199 sh. 2, March, 1992, Keuffel & Esser Company.
7. "Plan and Profile", Drawing No. 02199 sh. 3, March, 1992, Keuffel & Esser Company.
8. "Cross-Sections", Drawing No. 02199 sh. 4, March, 1992, Keuffel & Esser Company.
9. "Cross-Sections", Drawing No. 02199 sh. 5, March, 1992, Keuffel & Esser Company.
10. "Cross-Sections", Drawing No. 02199 sh. 6, March, 1992, Keuffel & Esser Company.
11. "Cross-Sections", Drawing No. 02199 sh. 7, March, 1992, Keuffel & Esser Company.
12. "Ash Lagoon Overflow, Miscellaneous Details", Drawing No. 02199 sh. 8, 10 March, 1992, Brown, Roffmann & Roberts, Inc.
13. "Overall Site Plan", Drawing No. C-100, Revision 1, 2 June, 2016, AECOM.
14. "Pre-DMM Site Clearing Plan", Drawing No. C-101, Revision 1, 2 June, 2016, AECOM.
15. "Pre-DMM Site Plan", Drawing No. C-102, Revision 1, 2 June, 2016, AECOM.
16. "Pre-DMM Cross Sections", Drawing No. C-103, Revision 1, 2 June, 2016, AECOM.
17. "Pre-DMM Details", Drawing No. C-104, Revision 1, 2 June, 2016, AECOM.
18. "Post-DMM Site Restoration Plan", Drawing No. C-105, Revision 1, 2 June, 2016, AECOM.
19. "Post-DMM Details", Drawing No. C-106, Revision 1, 2 June, 2016, AECOM.

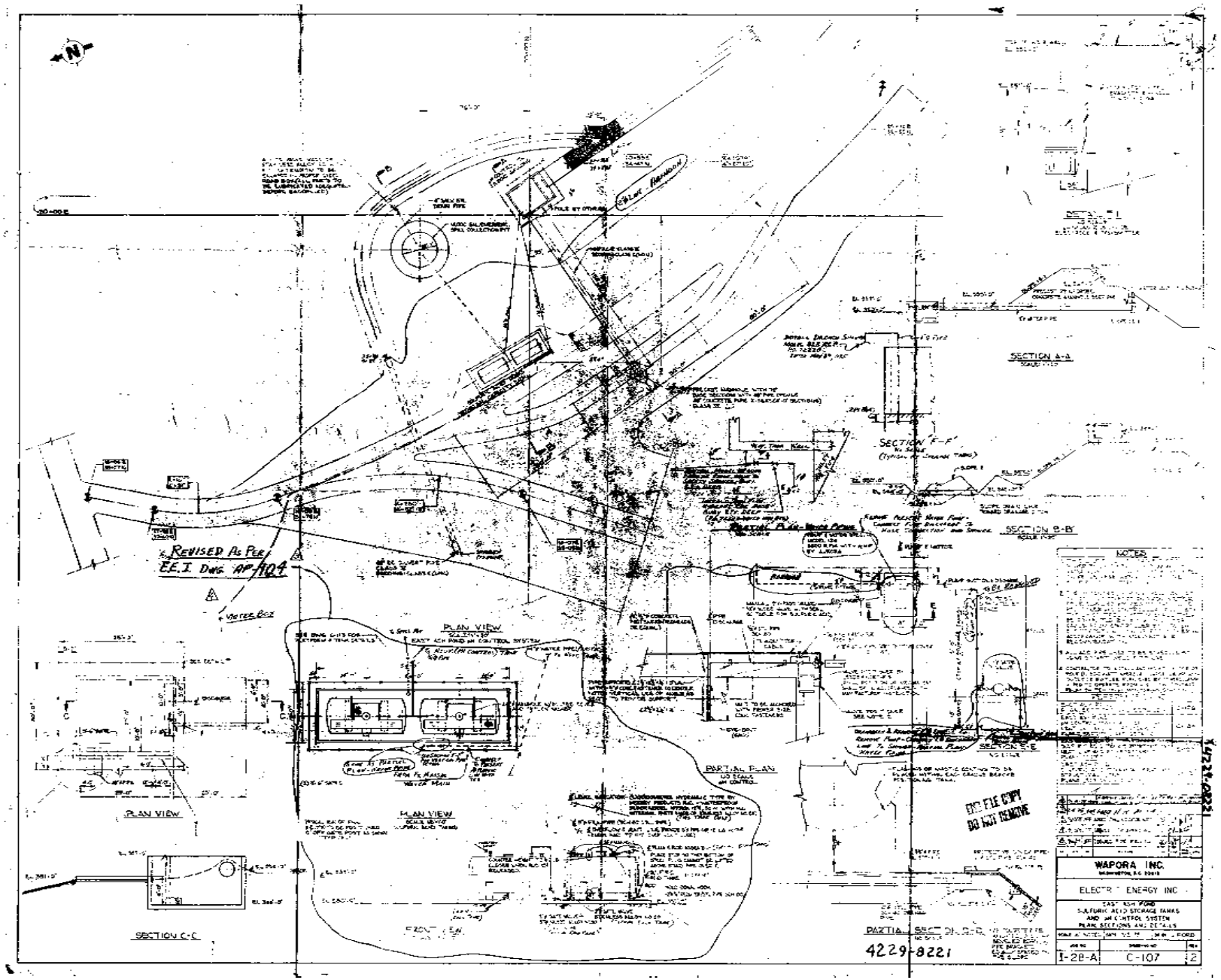

LEGEND:
WAPORA INC.
PROPOSED EAST ASH POND
EE-AP-1


N
PLAN VIEW
SECTION A-A
SECTION B-B
PLAN VIEW
PLAN VIEW
SECTION C-C
SECTION D-D
WAPORA, INC.
ELECTRIC ENERGY INC.
EAST ASH POND
SULFURIC ACID STORAGE TANKS
AND pH CONTROL SYSTEM
EE-AP-2

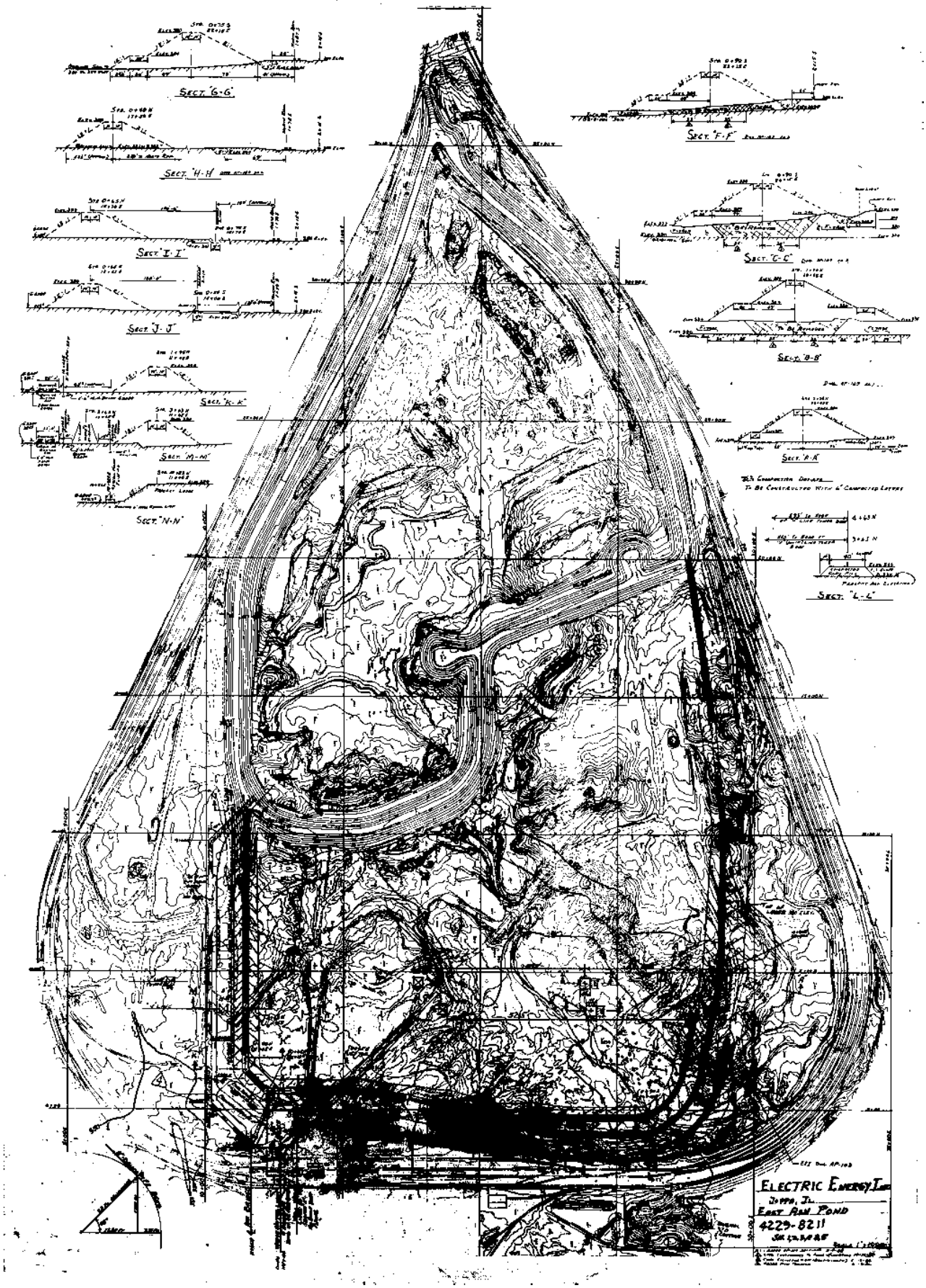
R000571

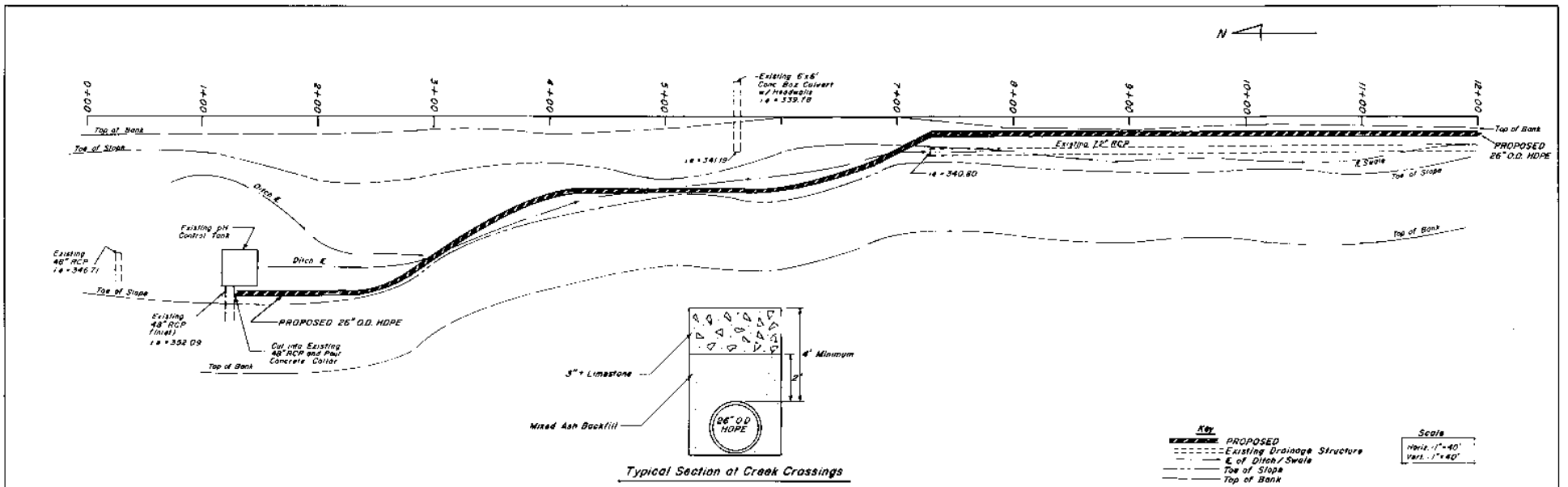

NOTES
REFERENCE DWGS.
WAPORA INC.
ELECTRIC ENERGY INC.
FAST ASH POND
PLAN, SECTIONS AND DETAILS
4229-8218
I-28-A
C-106

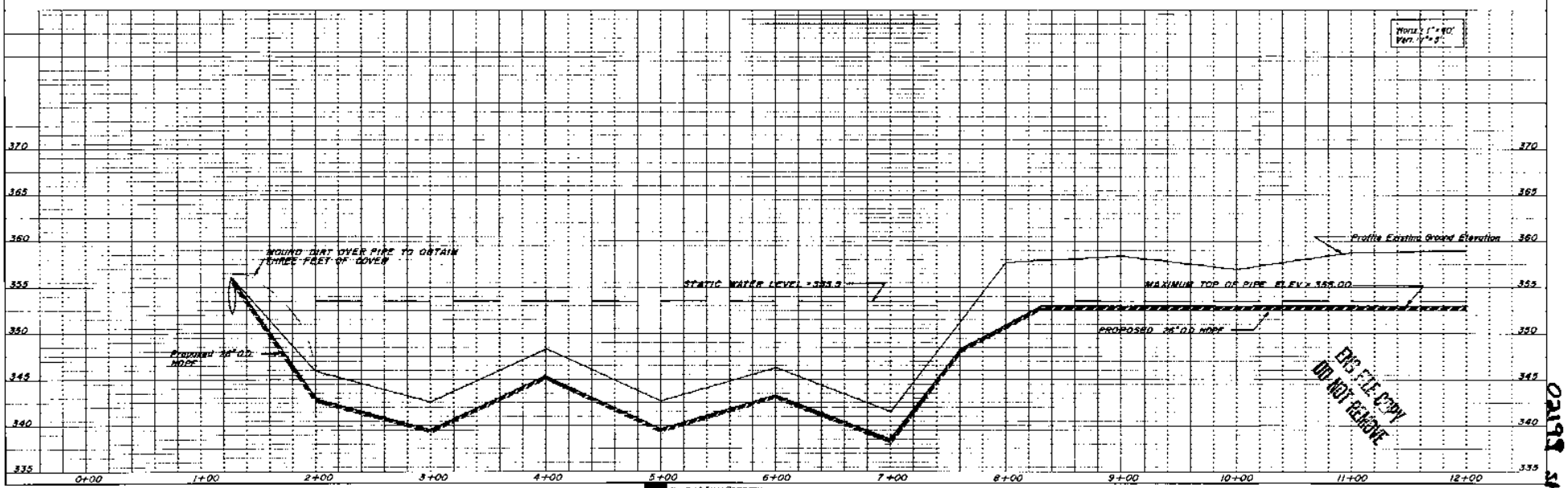
R000572


REVISED AS PER EE.I DWG. AP-104
SECTION A-A
SECTION F-F
SECTION B-B
SECTION E-E
PLAN VIEW
PARTIAL PLAN
SECTION C-C
NOTES
WAPORA INC.
ELECTRIC ENERGY INC.
4229-8221
I-28-A
C-107

R000573

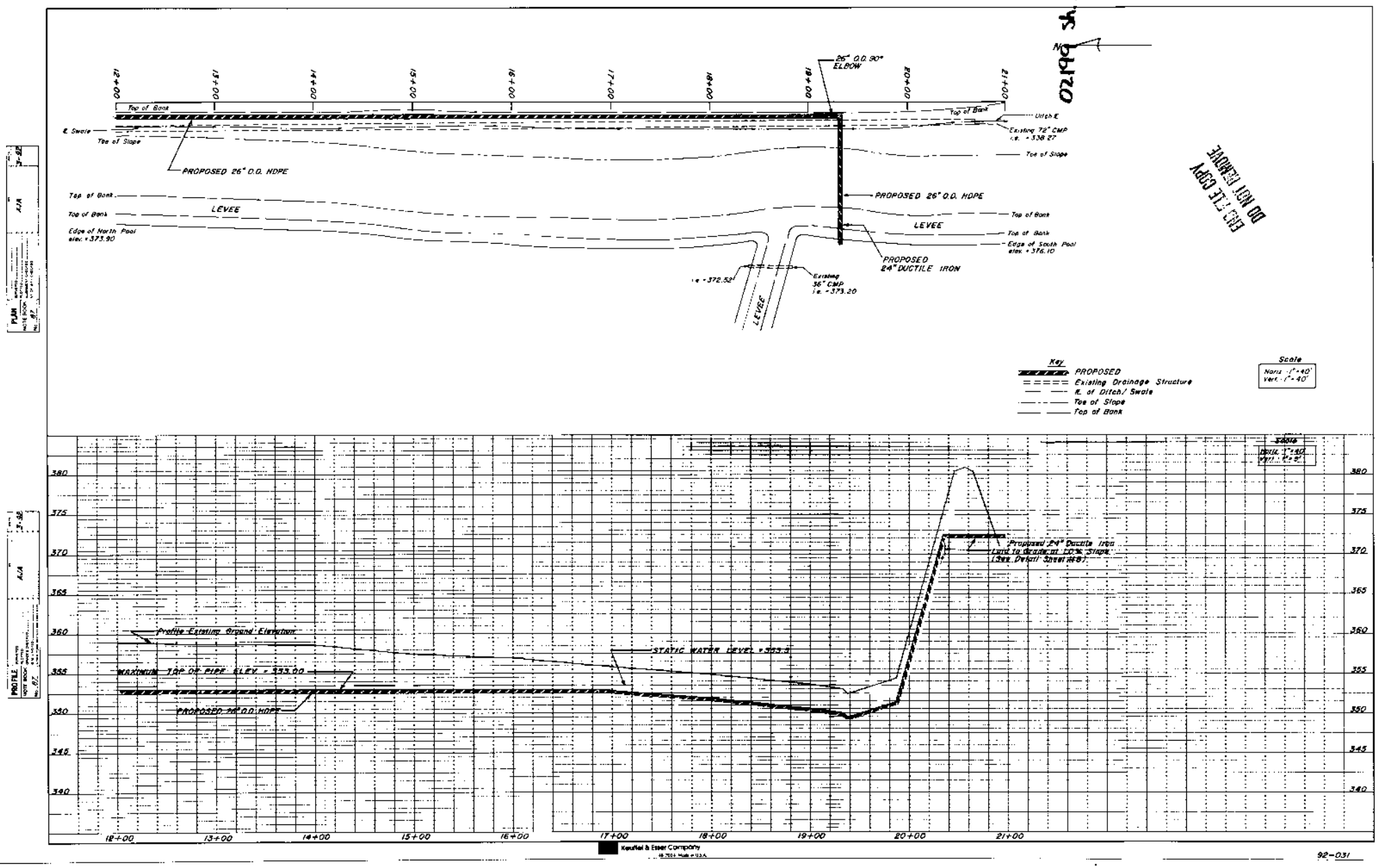

SECT. 'G-G'
SECT. 'H-H'
SECT. 'I-I'
SECT. 'J-J'
SECT. 'K-K'
SECT. 'M-M'
SECT. 'N-N'
SECT. 'F-F'
SECT. 'C-C'
SECT. 'B-B'
SECT. 'A-A'
SECT. 'L-L'
ELECTRIC ENERGY, INC.
JOPPA, IL.
EAST ASH POND
4229-8211





EPD FILE COPY
DO NOT REMOVE

R000575



02199 Sh. 3

ENG FILE COPY
DO NOT REMOVE

92-031

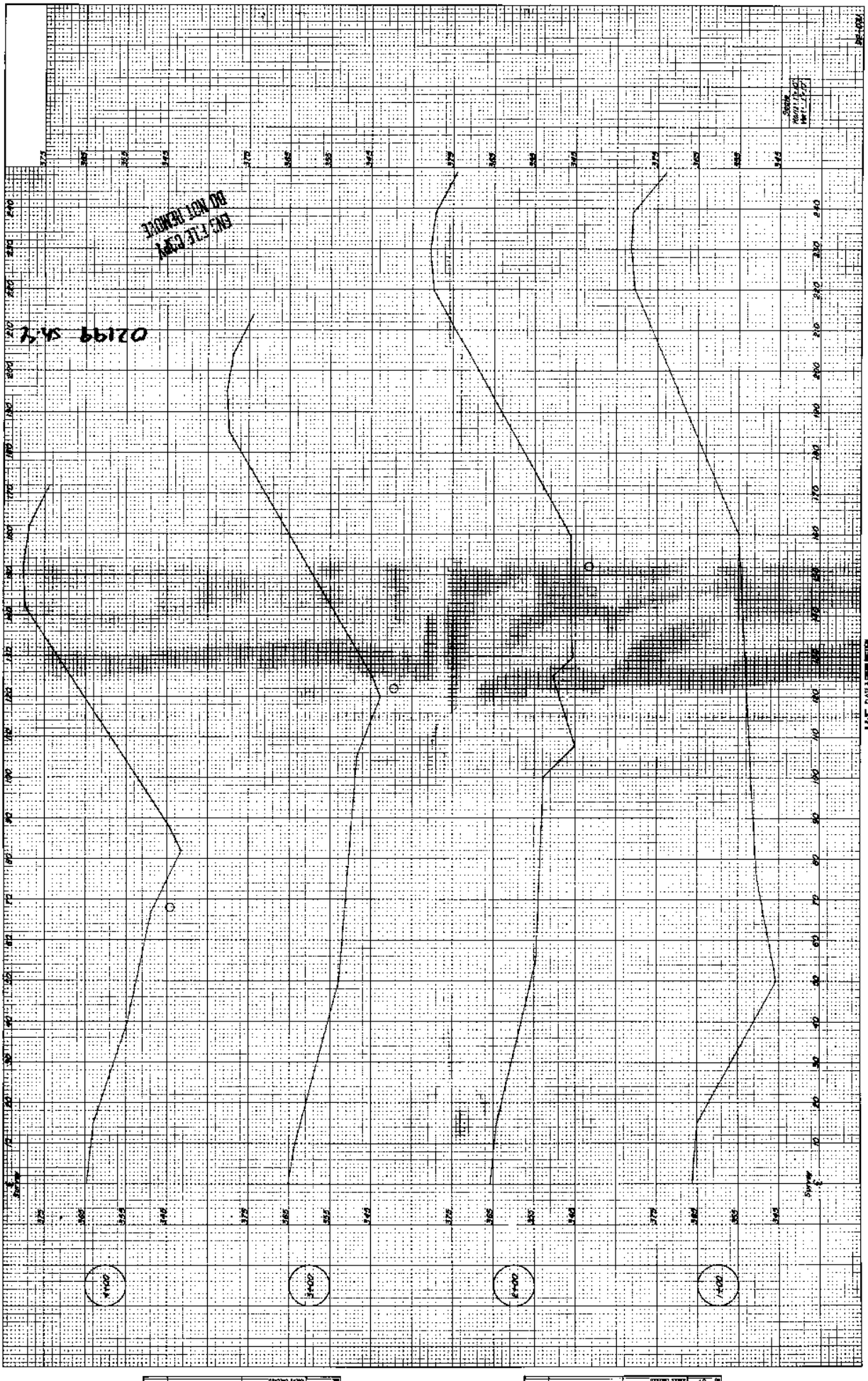
Sheet 3 of 8

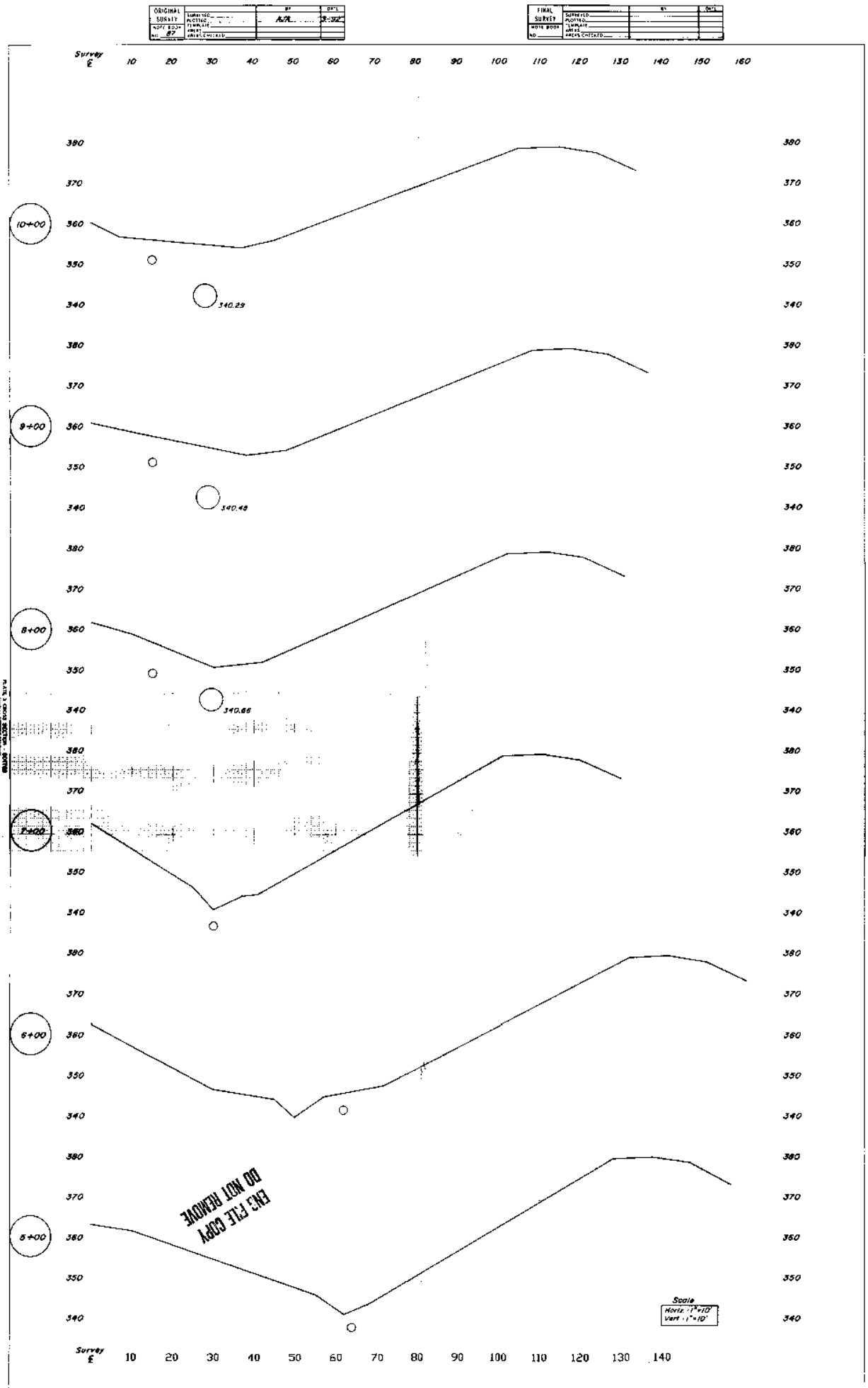
R000576

R000577

Sheet 4 of 8

Cross-Sections



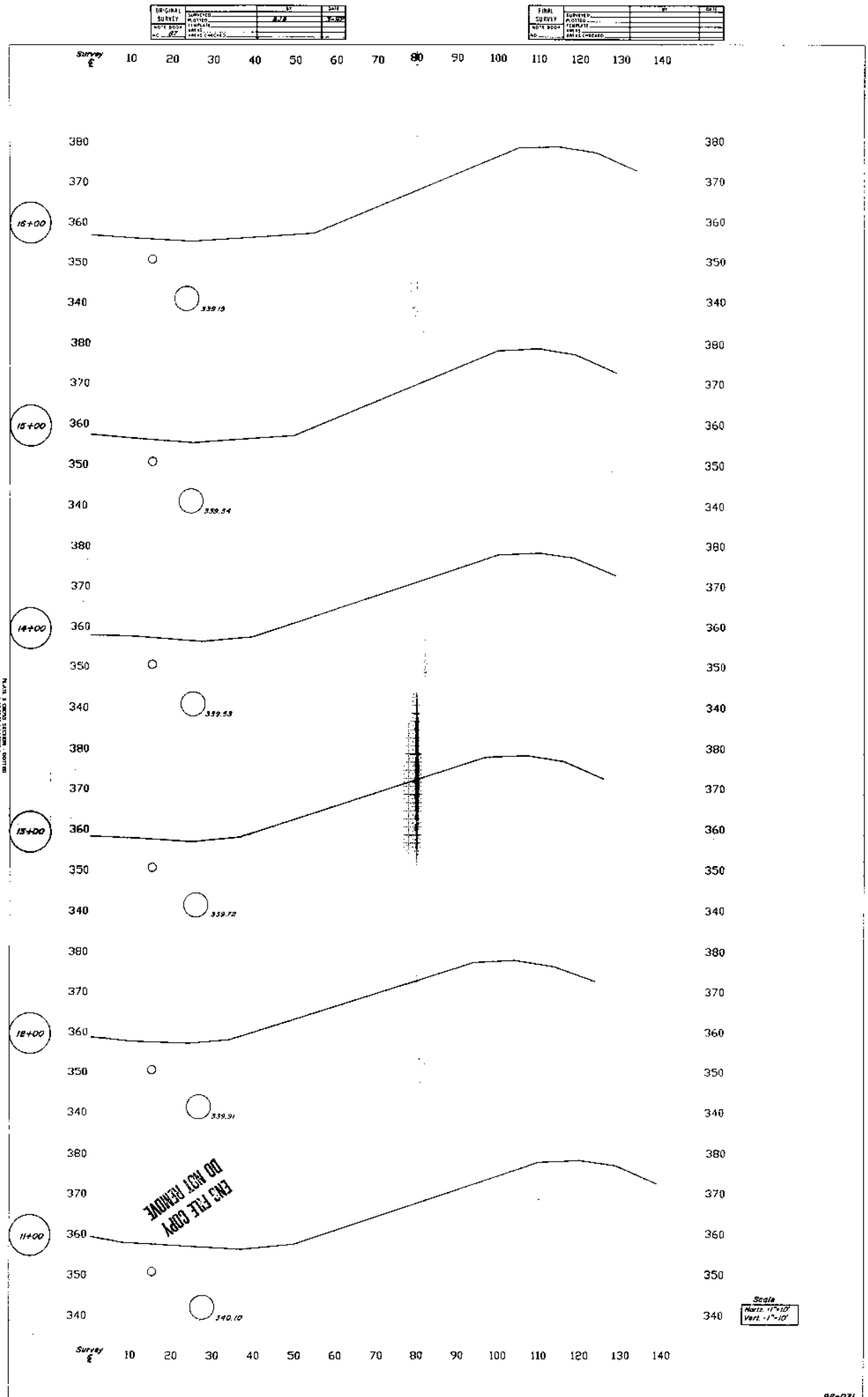


ENG FILE COPY
DO NOT REMOVE

Cross-Sections

Sheet 5 of 8

02144 SH. 5 R000578



ENG FILE COPY
DO NOT REMOVE

Cross-Sections

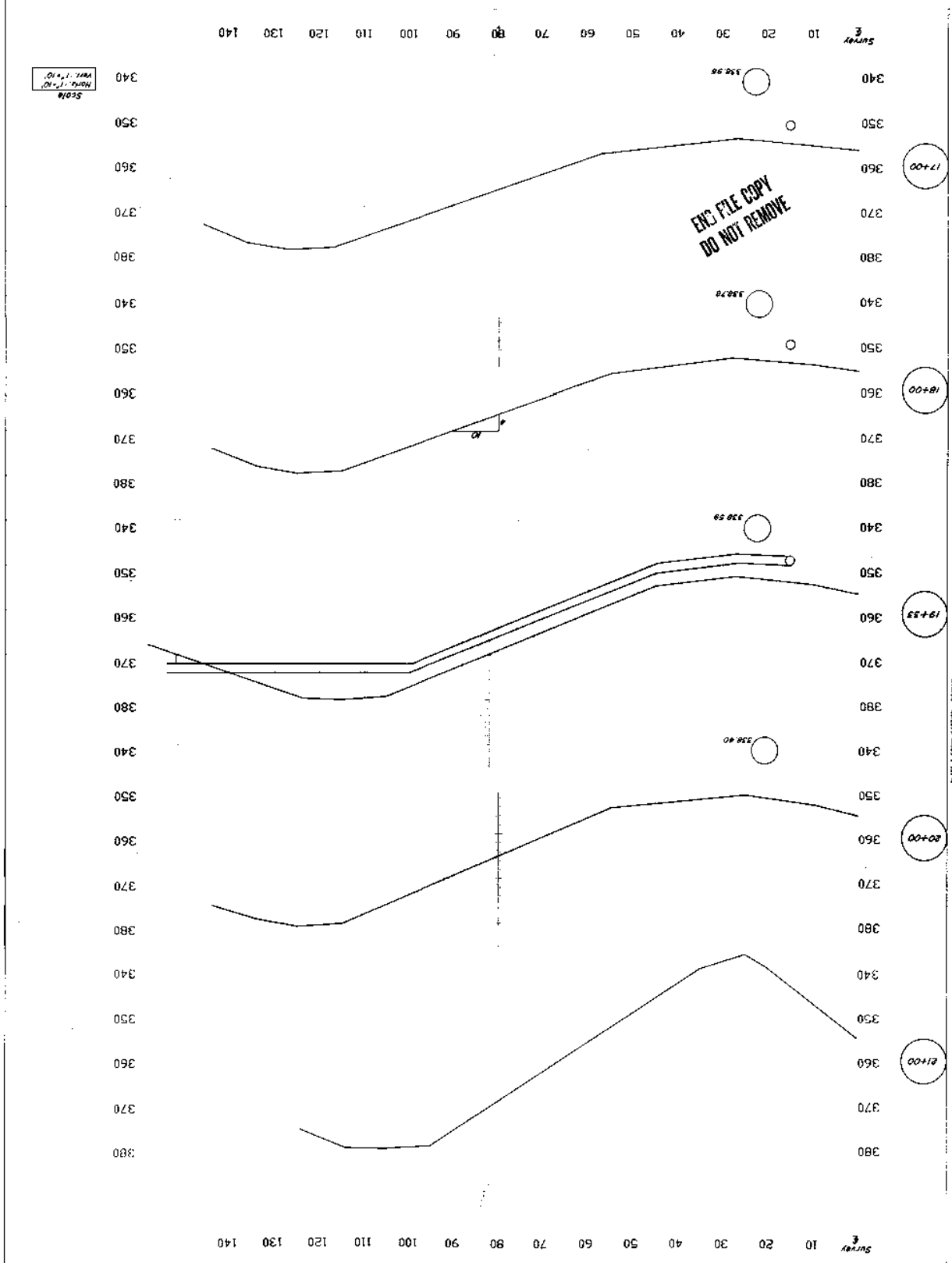
Sheet 6 of 8

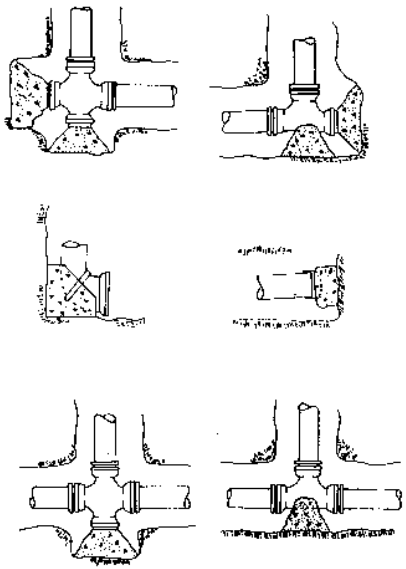
R000579

02199 Sh. 7

Sheet 7 of 8

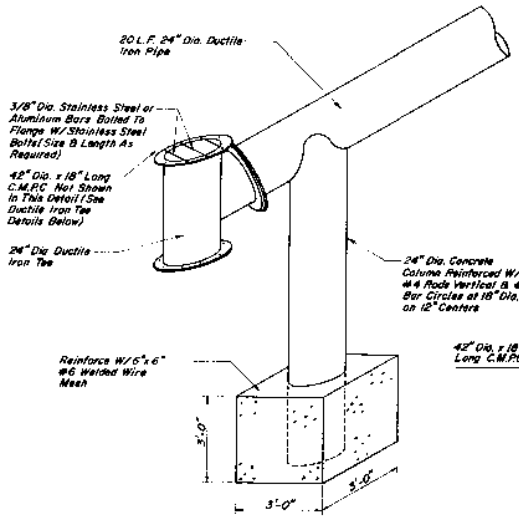
Cross-Sections





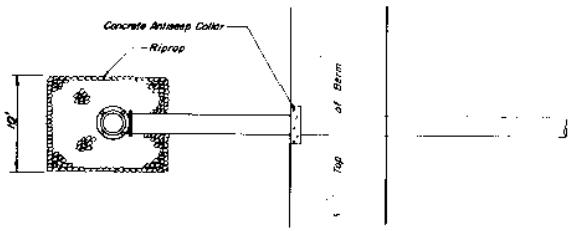
Typical Thrust Block Installation

ALL THRUST BLOCKING SHALL BE READI-MIX CONCRETE POURED AGAINST UNDISTURBED EARTH AT ALL LOCATIONS ILLUSTRATED ABOVE

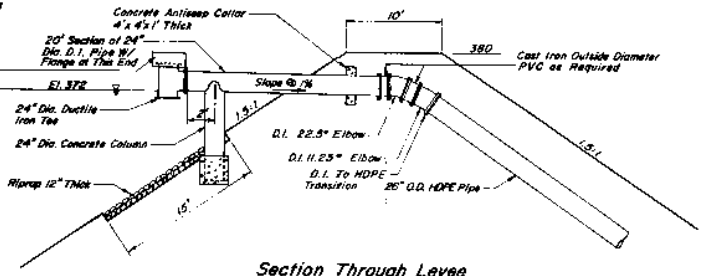


Section at Pipe Support

No Scale

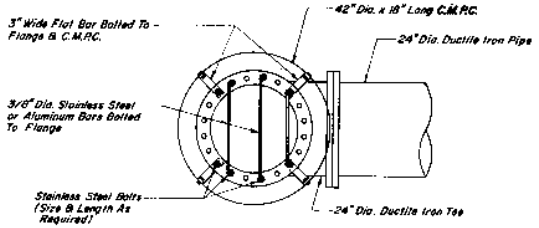


Plan



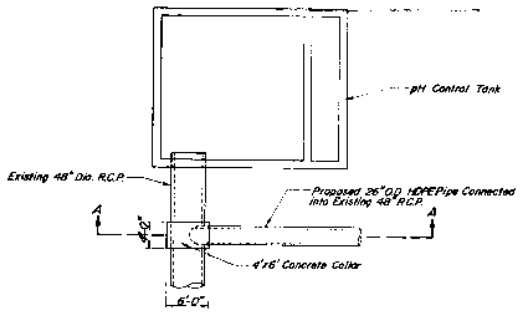
Section Through Levee

No Scale

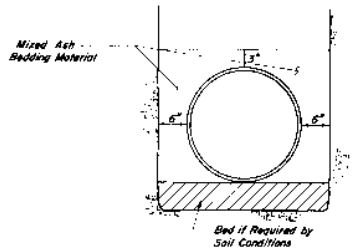


Plan View - Ductile Iron Tee

No Scale

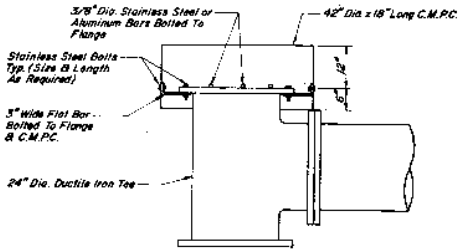


Plan at pH Control Tank



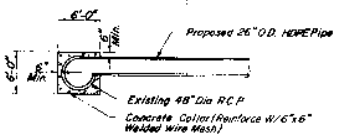
Typical Bedding Detail

No Scale



Elevation - Ductile Iron Tee

No Scale



Section A-A

No Scale

ENG FILE COPY DO NOT REMOVE

BROWN, ROFFMANN & ROBERTS, INC.
CONSULTING ENGINEERS AND LAND SURVEYORS
500 W. POPLAR ST. HARRISBURG, IL 62946 (618) 252-8111

ELECTRIC ENERGY, INC.
ASH LAGOON OVERFLOW
Miscellaneous Details

Drawn By	Checked By
MJK	

Revisions		
Item	Date	By

Scale	Field Book
As Shown	N/A
Job Number	Date
97-016	3/10/97

Sheet

8 of 8

02199-3.2

R000581

LEGEND:

- GROUNDWATER MONITORING WELL
- SURVEY CONTROL POINT

0 400 800 1200
SCALE IN FEET

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING	DATE	BY
ISSUED FOR CONSTRUCTION	05/24/16	VAM

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/13/2016
PLOT DATE:	6/2/2016
SCALE:	1" = 40'
ACAD VER:	2014

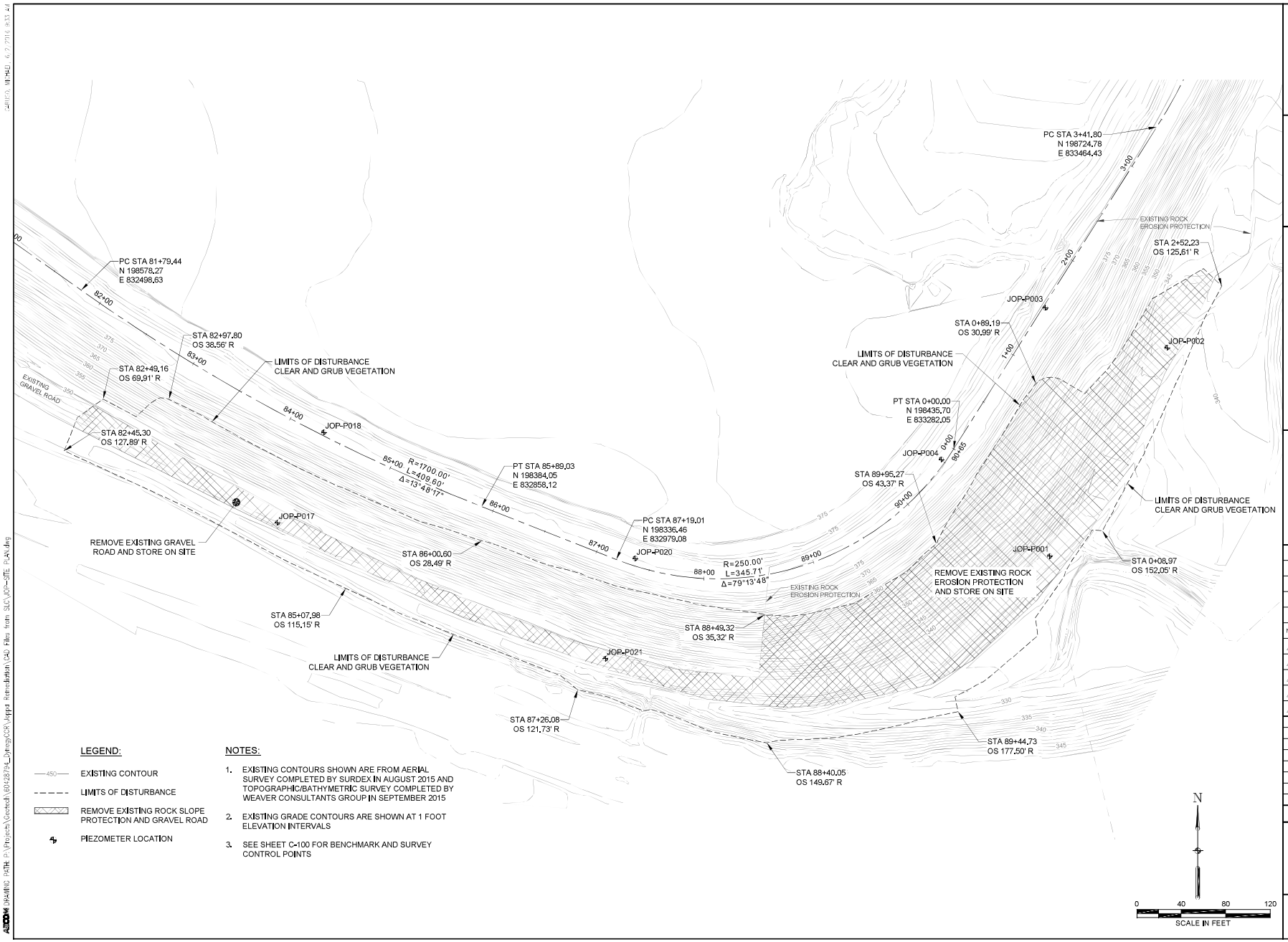
SHEET TITLE

OVERALL SITE PLAN

C-100

SHEET 4 OF 14

R000582



LEGEND:

- EXISTING CONTOUR
- LIMITS OF DISTURBANCE
- REMOVE EXISTING ROCK SLOPE PROTECTION AND GRAVEL ROAD
- PIEZOMETER LOCATION

NOTES:

1. EXISTING CONTOURS SHOWN ARE FROM AERIAL SURVEY COMPLETED BY SURDEX IN AUGUST 2015 AND TOPOGRAPHIC/BATHYMETRIC SURVEY COMPLETED BY WEAVER CONSULTANTS GROUP IN SEPTEMBER 2015
2. EXISTING GRADE CONTOURS ARE SHOWN AT 1 FOOT ELEVATION INTERVALS
3. SEE SHEET C-100 FOR BENCHMARK AND SURVEY CONTROL POINTS

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING — DATE BY

ISSUED FOR CONSTRUCTION 05/24/16 VAM — DATE BY

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/13/2016
PLOT DATE:	6/2/2016
SCALE:	1" = 40'
ACAD VER:	2014

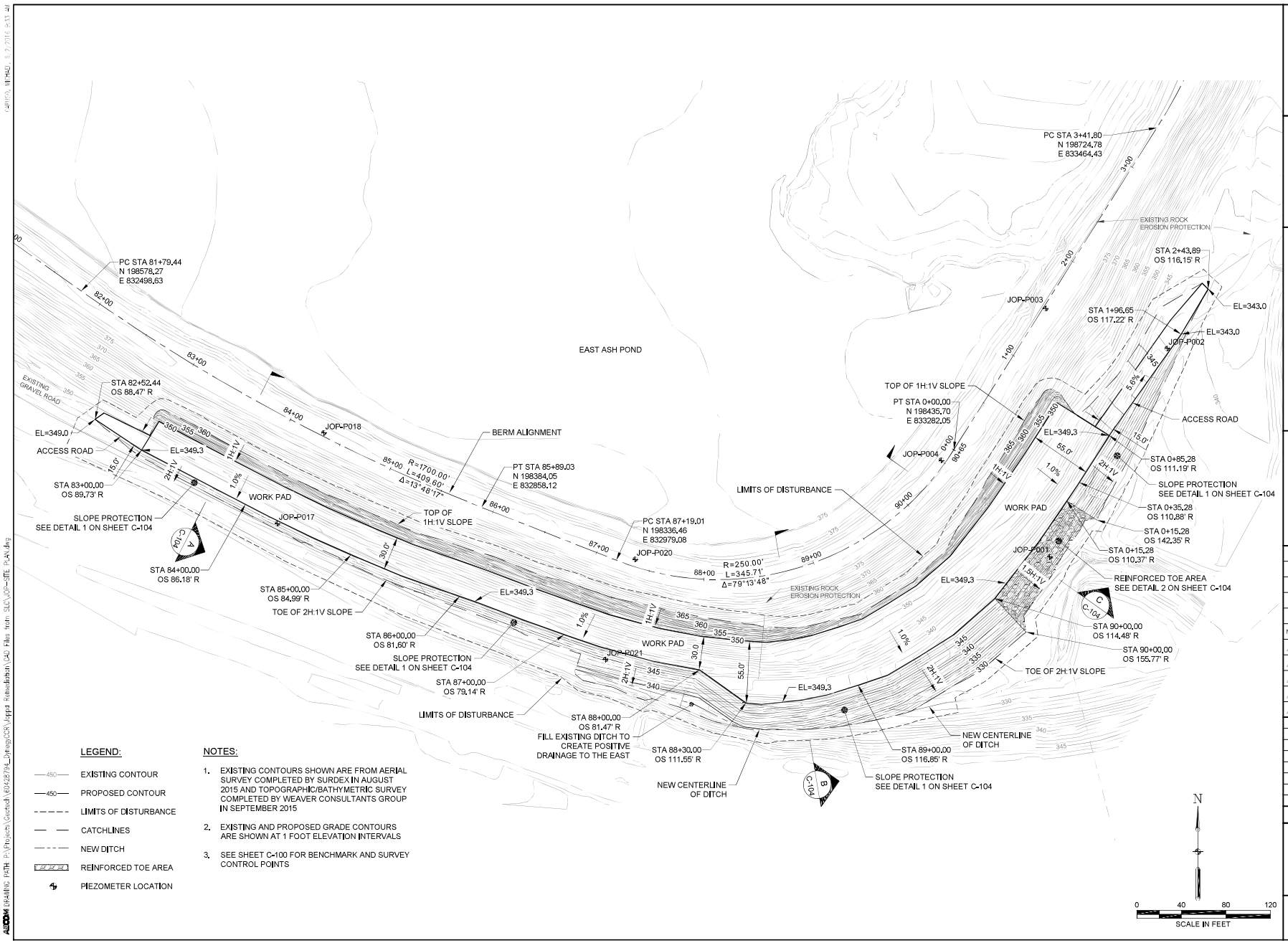
SHEET TITLE

PRE-DMM SITE CLEARING PLAN

C-101

SHEET 5 OF 14

R000583



LEGEND:

- EXISTING CONTOUR
- PROPOSED CONTOUR
- LIMITS OF DISTURBANCE
- CATCHLINES
- NEW DITCH
- REINFORCED TOE AREA
- PIEZOMETER LOCATION

NOTES:

1. EXISTING CONTOURS SHOWN ARE FROM AERIAL SURVEY COMPLETED BY SURDEX IN AUGUST 2015 AND TOPOGRAPHIC/BATHYMETRIC SURVEY COMPLETED BY WEAVER CONSULTANTS GROUP IN SEPTEMBER 2015
2. EXISTING AND PROPOSED GRADE CONTOURS ARE SHOWN AT 1 FOOT ELEVATION INTERVALS
3. SEE SHEET C-100 FOR BENCHMARK AND SURVEY CONTROL POINTS

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING	DATE	BY
ISSUED FOR CONSTRUCTION	05/24/16	VAM

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016
2		
3		
4		
5		

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/13/2016
PLOT DATE:	6/2/2016
SCALE:	1" = 40'
ACAD VER:	2014

SHEET TITLE

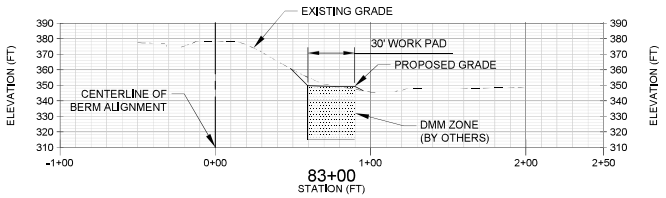
PRE-DMM SITE PLAN

C-102

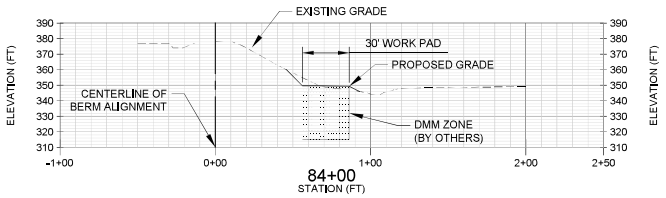
SHEET 6 OF 14

AECOM DRAWING PATH: P:\Projects\Geotech\60439794_DynegyCCR\Appd Rehabilitation\CAD Files from SLC\JOP-SITE PLAN.dwg
CAPTION: 11-HPEL 6/2/2016 8:51 AM

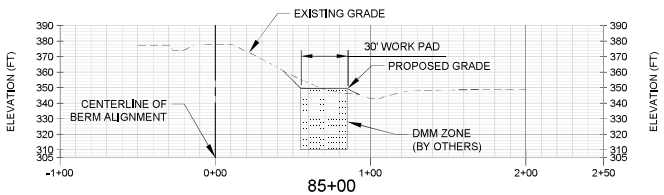
R0000584



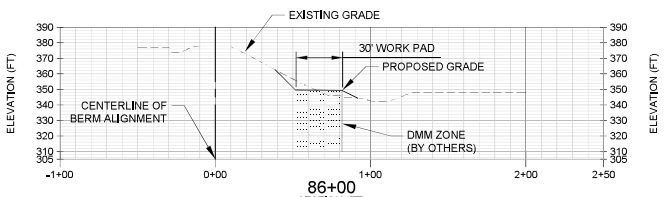
83+00



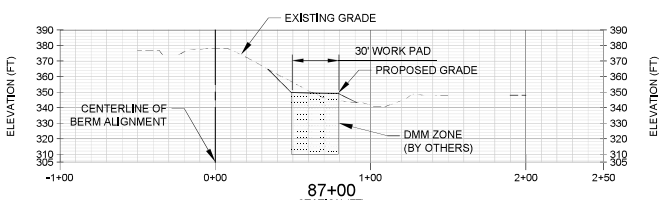
84+00



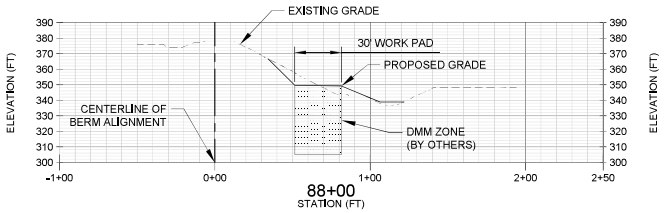
85+00



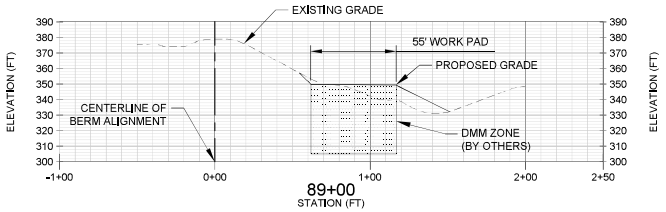
86+00



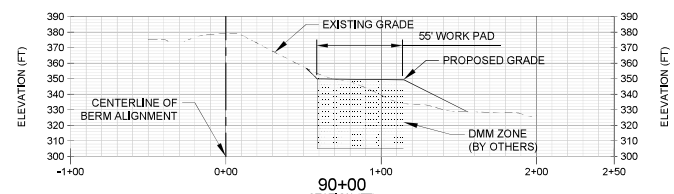
87+00



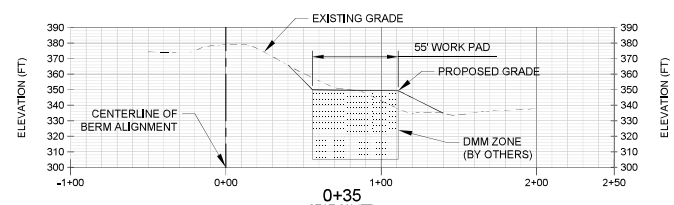
88+00



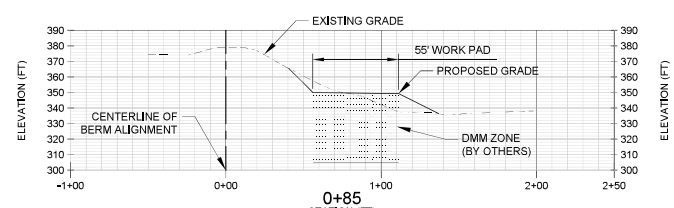
89+00



90+00



0+35



0+85

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING _____ DATE BY

ISSUED FOR CONSTRUCTION 05/24/16 VAM DATE BY

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016
2		
3		
4		
5		

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	TLE
DATE CREATED:	04/13/16
PLOT DATE:	6/2/2016
SCALE:	1" = 40'
ACAD VER:	2014

SHEET TITLE

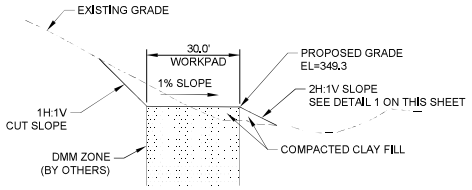
PRE-DMM CROSS SECTIONS

C-103

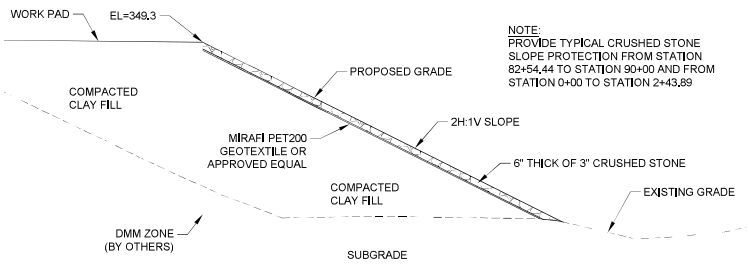
SHEET 7 OF 14

R000585

NOTE:
1. PROVIDE TYPICAL SECTION 30' WIDE WORK PAD FROM STATION 83+00 TO STATION 88+00
2. SEE GENERAL NOTES SECTION 10 EARTHWORK ON SHEET G-003 FOR ADDITIONAL EARTHWORK NOTES

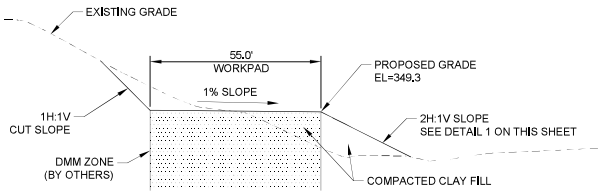


A / C-102 TYPICAL SECTION
30' WIDE WORK PAD WITH SLOPE PROTECTION
SCALE 1" = 20'

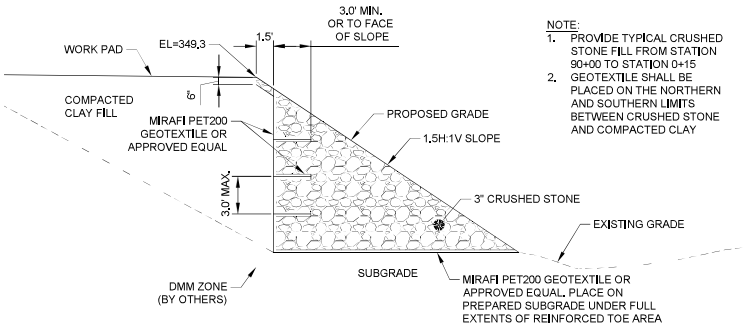


1 / C-102 TYPICAL PRE-DMM SLOPE PROTECTION
SCALE 1" = 5'

NOTE:
1. PROVIDE TYPICAL SECTION 55' WIDE WORK PAD WITH SLOPE PROTECTION FROM STATION 88+30 TO STATION 90+00 AND FROM STATION 0+15 TO STATION 0+85
2. SEE GENERAL NOTES SECTION 10 EARTHWORK ON SHEET G-003 FOR ADDITIONAL EARTHWORK NOTES

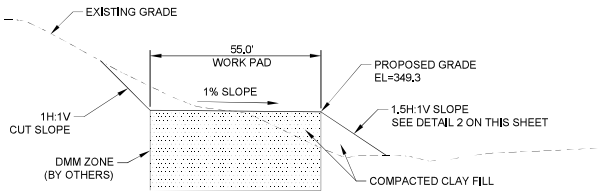


B / C-102 TYPICAL SECTION
55' WIDE WORK PAD WITH SLOPE PROTECTION
SCALE 1" = 20'



2 / C-102 TYPICAL PRE-DMM REINFORCED TOE AREA
SCALE 1" = 5'

NOTE:
1. PROVIDE TYPICAL SECTION 55' WIDE WORK PAD WITH REINFORCED TOE AREA FROM STATION 90+00 TO STATION 0+15
2. SEE GENERAL NOTES SECTION 10 EARTHWORK ON SHEET G-003 FOR ADDITIONAL EARTHWORK NOTES



C / C-102 TYPICAL SECTION
55' WIDE WORK PAD WITH REINFORCED TOE AREA
SCALE 1" = 20'

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING	DATE	BY
ISSUED FOR CONSTRUCTION	05/24/16	VAM

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016
2		
3		
4		
5		

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/13/2016
PLOT DATE:	6/2/2016
SCALE:	AS SHOWN
ACAD VER:	2014

SHEET TITLE

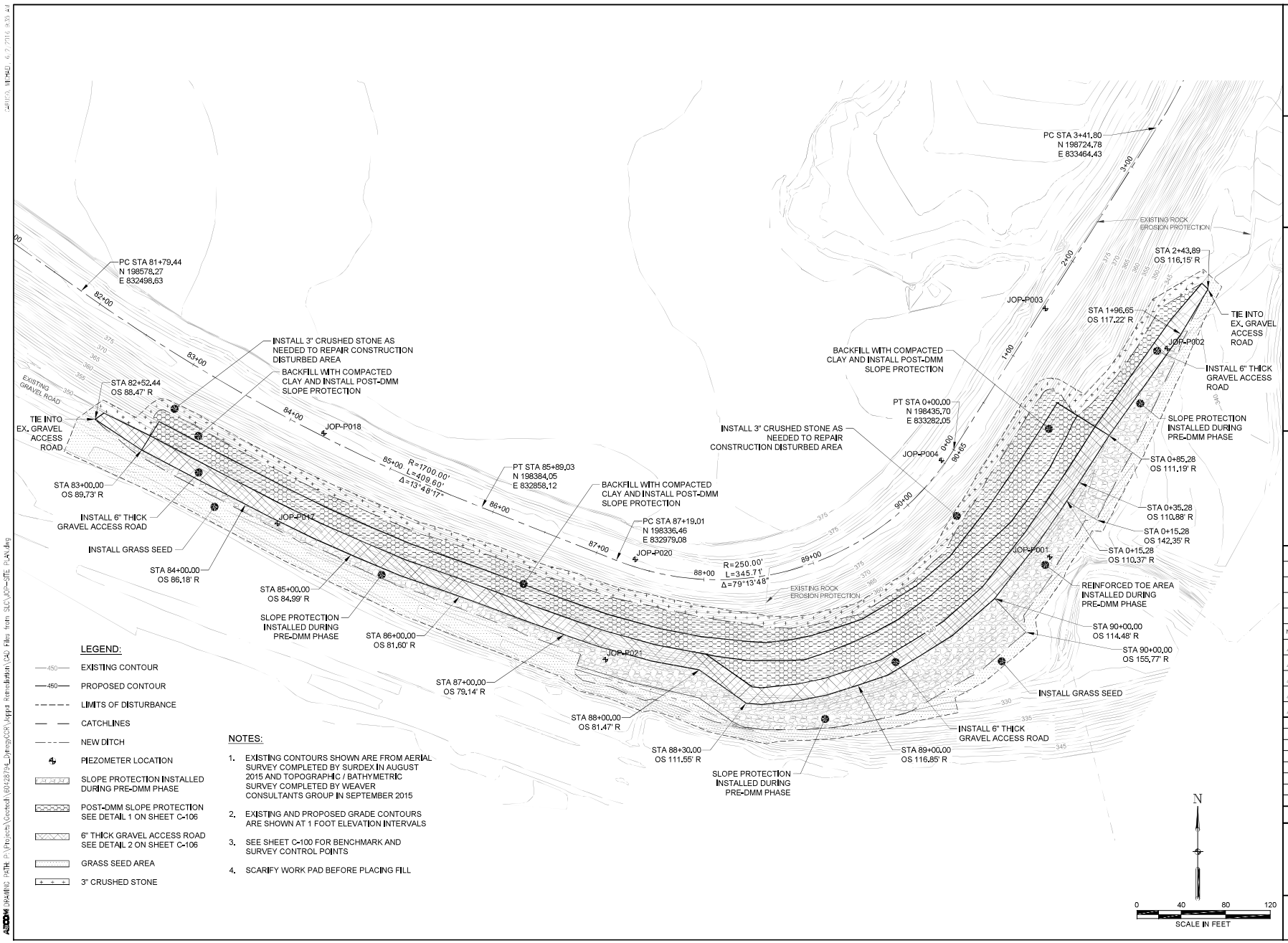
PRE-DMM DETAILS

C-104

SHEET 8 OF 14

AECOM DRAWING PATH: P:\Projects\Geotech\60439794_DynegyCCR\Appd Remediation\CAD Files from SLC\JOP-DETAILS.dwg
PLOTTED: 6/2/2016 8:51:44

R000586



LEGEND:

- 450 EXISTING CONTOUR
- 450 PROPOSED CONTOUR
- LIMITS OF DISTURBANCE
- CATCHLINES
- NEW DITCH
- PIEZOMETER LOCATION
- SLOPE PROTECTION INSTALLED DURING PRE-DMM PHASE
- POST-DMM SLOPE PROTECTION SEE DETAIL 1 ON SHEET C-106
- 6" THICK GRAVEL ACCESS ROAD SEE DETAIL 2 ON SHEET C-106
- GRASS SEED AREA
- 3" CRUSHED STONE

NOTES:

1. EXISTING CONTOURS SHOWN ARE FROM AERIAL SURVEY COMPLETED BY SURDEX IN AUGUST 2015 AND TOPOGRAPHIC / BATHYMETRIC SURVEY COMPLETED BY WEAVER CONSULTANTS GROUP IN SEPTEMBER 2015
2. EXISTING AND PROPOSED GRADE CONTOURS ARE SHOWN AT 1 FOOT ELEVATION INTERVALS
3. SEE SHEET C-100 FOR BENCHMARK AND SURVEY CONTROL POINTS
4. SCARIFY WORK PAD BEFORE PLACING FILL

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING — DATE BY

ISSUED FOR CONSTRUCTION 05/24/16 VAM — DATE BY

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/13/2016
PLOT DATE:	6/2/2016
SCALE:	1" = 40'
ACAD VER:	2014

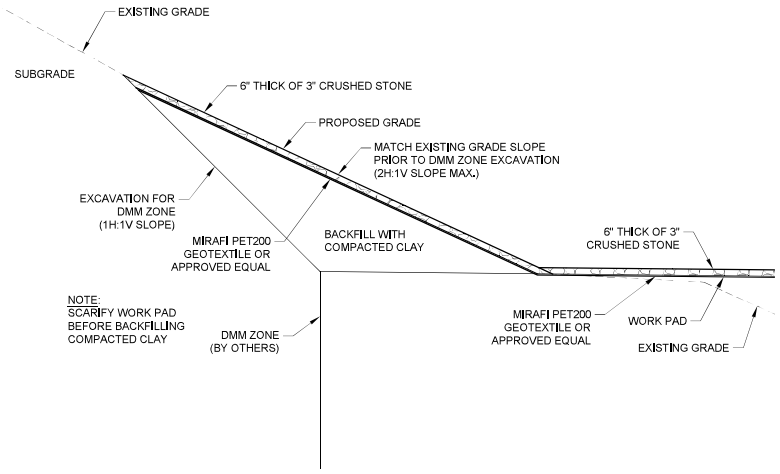
SHEET TITLE

POST-DMM SITE RESTORATION PLAN

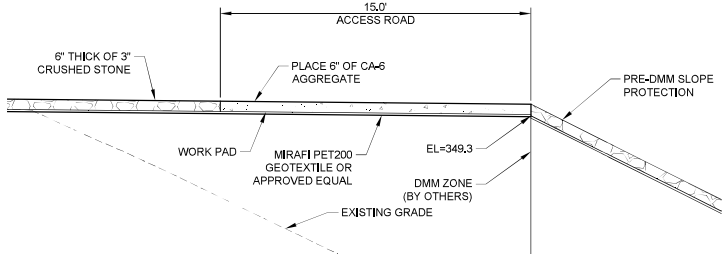
C-105

SHEET 9 OF 14

R000587



1 / C-105 TYPICAL POST-DMM SLOPE PROTECTION
SCALE 1" = 5'



2 / C-105 TYPICAL ACCESS ROAD
SCALE 1" = 3'

AECOM
1001 Highlands Plaza
Drive West, Suite 300
St. Louis, MO 63110-1337
314-429-0100 (phone)
314-429-0462 (fax)

ELECTRIC ENERGY, INC.
2100 PORTLAND ROAD
JOPPA, IL 62953

WORK PAD AND SITE RESTORATION
EAST ASH POND

ISSUED FOR CONSTRUCTION

ISSUED FOR BIDDING — DATE BY

ISSUED FOR CONSTRUCTION 05/24/16 VAM — DATE BY

REVISIONS

NO.	DESCRIPTION	DATE
1	ADDED TRAFFIC PLAN	6/2/2016
2		
3		
4		
5		

AECOM PROJECT NO:	60440155
DRAWN BY:	MJC
DESIGNED BY:	MJC
CHECKED BY:	LPC
DATE CREATED:	4/25/2016
PLOT DATE:	6/2/2016
SCALE:	AS SHOWN
ACAD VER:	2014

SHEET TITLE

POST-DMM DETAILS

C-106

SHEET 10 OF 14

R000588

AECOM

Appendix C: Joppa East Ash Pond Piezometer and Boring Locations

NOTES

1. Plan adapted from an aerial photograph courtesy of Google Earth.

LEGEND

Boring Location

A A' Slope Stability Cross Section

N

0 180 360

SCALE IN FEET

Drawn By: SLC	Ck'd By: SLC	App'vd By: RBP
Date: 08-12-10	Date: 09/20/10	Date: 9/20/10

GEOTECHNOLOGY INC.
ENGINEERING AND ENVIRONMENTAL SERVICES
ST. LOUIS • COLLINSVILLE • KANSAS CITY

Electric Energy Inc. Facility
Joppa, Illinois

AERIAL PHOTOGRAPH OF SITE AND BORING LOCATIONS

Project Number J017150.02	PLATE 2

R0000590

EXPLORATION METHOD (B=BORING, C=CPT, P=PIEZOMETER)

XXX-X###

ID NUMBER

STATION ABBREVIATION

SOURCE:
MAP PROVIDED BY GOOGLE EARTH PRO 2015

LEGEND

PIEZOMETER LOCATION

CCR UNIT BERM ALIGNMENT

N

0 300

APPROXIMATE SCALE FEET

Electric Energy, Inc.

PROJECT NO. 60440155

AECOM

DRN. BY: djd October 2015
DSGN. BY: eg
CHKD. BY: eg

Joppa East Ash Pond
Piezometer Locations

FIG. NO. 2A

File: P:\PROJECTS\GEOTECH\60429794_DYNEGY\CCR\04TASKS\00 PROGRAM TASKS\1.0 TASK 1 INITIAL UNIT ASSESSMENT\CCR FACT SHEETS\SITE MAPS\FIGURE 2A PIEZOMETER LOCATION PLAN (JOPPA).DWG Last edited: NOV. 04, 15 @ 1:20 p.m. by: david_deguire

R000591

AECOM

Appendix D: Ash Pond Embankment Instability, Hanson Professional Services Inc. (2011)

HANSON
Engineering | Architecture | Planning | Allied Services

Hanson Professional Services Inc.
1525 South 6th Street
Springfield, IL 62703
(217) 788-2450
Fax: (217) 788-5241
www.hanson-inc.com

April 29, 2011

Mr. Mike Mercer
Electric Energy Inc.
P.O. Box 158
Joppa, Illinois 62953

RE: Ash Pond Embankment Instability
Joppa Ash Pond
Hanson No. 11E0054

Dear Mr. Mercer:

On April 26, 2011 the Joppa ash pond embankment was inspected by James Knutelski, P.E. from Hanson, and Mike Mercer from Electric energy Inc. (EEI) after instability in several areas of the downstream embankment slope was observed on April 25, 2011 by EEI personnel. The locations of the areas of instability that were observed during the April 26, 2011 inspection are shown on the aerial photograph that is attached to this letter. We understand that storms produced 4.75 in. of rain at the Joppa Power Station between April 22 and April 25, 2011.

Existing drawing indicate that the embankment was originally constructed in 1985 using local cohesive soils (ML or CL materials) with 1.5H:1.0V and 2.0H:1.0V exterior slopes. The embankment height varies between 15 ft and 40 ft. The design crest width was 20 ft. EEI employees reported that the completed embankment crest width was less than 20 ft and on the order of 10 ft or less in some areas. Between 1985 and 2011, the configuration of the embankment has been changed using flyash produced at the Joppa Power Station. Generally, fly ash has been placed over the downstream slope from the embankment crest in order to widen the embankment crest width in some areas. At some locations as much as 3 ft of additional embankment (flyash) has reportedly been added to the downstream embankment slope.

There have been previous reports of instability of the pond embankment on the northern portion of the west embankment. These areas of instability were repaired using riprap materials in a bench arrangement in order to provide more resistance to sliding in the affected areas. These areas appeared to be stable during the April 26, 2011 inspection.

During the inspection, sloughs at eight areas of instability were observed. The areas of instability are shown on the attached photographs. The sloughs appeared to be relatively shallow. The length of scarp varied from as little as 25 ft in length to as much as 150 ft in length. The scarps generally began at the top of the slope and extended to between one-half of the embankment height and the full embankment height. The embankment soils exposed by the slide were observed to be firm to hard at a shallow depth (less than 1 ft in most instances) when probed with a thin steel rod (drain tile probe).

The sloughs observed on the northern ash pond (#1 through #6) and one of two slough areas on the southern ash pond (area #7) appeared to be mainly due to sliding at the interface between ash materials apparently added to the downstream embankment slope and the original cohesive soil embankment constructed in 1985. Water infiltration through the ash materials that did not infiltrate the cohesive soils appears to have reduced the friction between these materials and caused sloughing. The sloughed material appeared to be composed of partially hydrated flyash and was generally hard and brittle.

Slide area #8 was observed on the southern portion of the eastern embankment. It appeared to be a shallow failure about 50 ft long with a scarp about 8 in. deep. In general, the slide appeared to consist of only topsoil and organic material. Infiltration of water through the topsoil that was trapped between the topsoil and cohesive embankment probably provided the failure mechanism in this area. There were no observations made that would indicate why this area failed and other areas with similar surface condition and slope did not.

Until more favorable weather conditions exist, the areas of instability may continue to slough, sloughs may propagate into areas adjacent to existing sloughs, and new sloughs may develop.

Repair of these areas may be completed using local cohesive soils, or riprap materials similar to those used to repair other areas of sliding. The use of local cohesive soil for repair will probably be the more economic alternative if repairs are made, but will require more favorable weather conditions and soil moisture control as described below.

Repair of the embankment with local cohesive soil should consist of stripping the affected area of all sloughing soil, ash, and vegetative cover; placement of new compacted soil embankment; and establishment of vegetative cover on the repaired embankment. Repair of these areas with soil should not be started until weather conditions allow compaction of thin lifts (8 in. maximum compacted thickness) of soil to be placed and compacted to 95% of the maximum dry density obtained using ASTM Test Method D648 (Standard Compaction Test).

The new embankment materials should be constructed by benching into the existing embankment deep enough to remove all soft or wet soils encountered. The maximum vertical bench height should be limited to 2 ft. The average slope of the benched area within the existing embankment should be no steeper than 1.5H:1.0V during construction of repairs. In order to construct repairs and maintain stability of the existing embankment materials, it will probably be necessary to increase the width of the embankment toe and construct a slope flatter than the 1.5H:1.0 V and 2.0H:1.0V slopes that were originally constructed. It is recommended that slopes no steeper than 2.5H:1.0V be constructed for repairs with local cohesive soils since one area of instability in the 2.0H:1.0V existing slope was observed during the inspection. A typical soil repair section is shown on the attached sheet.

Repair of the embankment with riprap material should consist of stripping the affected area of all sloughing soil, ash, and vegetative cover and placement of riprap materials.

The riprap materials should be constructed by benching into the existing embankment deep enough to remove all soft or wet soils encountered. The average slope of the benched area within the existing embankment should be no steeper than 1.5H:1.0V during construction of repairs. The maximum vertical bench height should be limited to 2 ft. The riprap materials may be placed in a single slope configuration or benched. The riprap should be placed in lifts not exceeding 2 ft in height and tracked in with the equipment used for construction. The single slope should be no steeper than 2.5H:1.0V. For a benched slope, the average slope of the

riprap materials should be no steeper than 2.5H:1.0V. The slope of the benches should match the slope of the adjacent embankment materials. A typical benched riprap slope is shown on the attached sheet.

The above repair recommendations should also be considered for areas of the pond embankment that have not experienced instability in order to prevent instability under similar wet weather conditions in the future. The ash materials that have been placed on the embankment slope appear to have created a mechanism for failure by trapping water between the ash and embankment soil. In addition, flattening the slope of the embankment where ash materials are not present should be considered since instability of the slope under extremely wet weather conditions has been experienced.

As discussed, an alternative to the above repair recommendations is to discontinue use of the pond for water detention. The risk of a breach in the embankment would be greatly reduced if water detention and storage were eliminated. This could be accomplished by grading the ash materials within the pond to drain to a low point (either the existing outfall structure, or a designed breach within the perimeter embankment). One requirement for this alternative would be that the ash be graded to be able to discharge runoff from the pond interior to the pond outlet with minimal water detention.

We have been pleased to provide the information within this letter. Feel free to call me at (217) 747-9437 if you have any questions.

Sincerely,

HANSON PROFESSIONAL SERVICES INC.

James P. Knutelski, PE
Geotechnical Engineer

jpk

Enclosures

Slide Area #1

Slide Area #2

Slide Area #3

Slide Area #4

Slide Area #5

Slide Area #6

Slide Area #7

Slide Area #8

By: JPK Date: 4/27/11

Checked by: _____ Date: _____

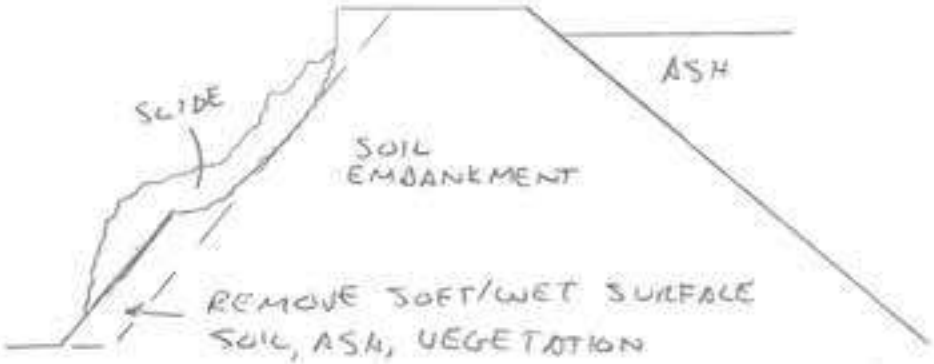
HANSON Engineering | Architecture | Planning | Allied Services

Sheet No.: 1 of: _____

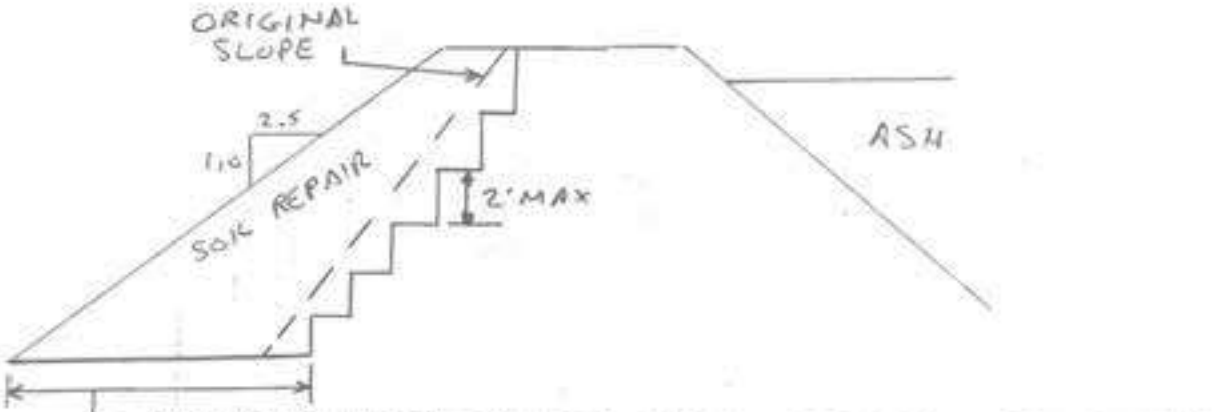
Project No.: 11E0054

JOPPA ASH POND - SHALLOW FAILURE REPAIR

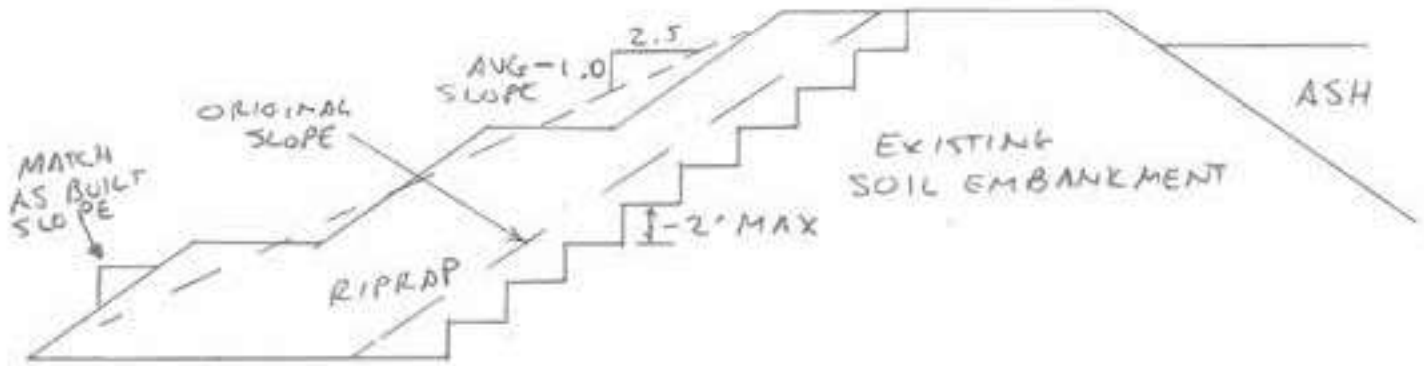
TYPICAL SHALLOW SLIDE



SOIL REPAIR



RIPRAP REPAIR



AECOM

Appendix E: Photos of Slope Repairs

AECOM

Figure E.1: Photo of stripping the affected area of all sloughing soil, ash, and vegetative cover.

Figure E.2: Photo of benching into the existing embankment.

ATTACHMENT C

October 2021

Joppa Power Plant - East Ash Pond's Chemical Constituents

In accordance with 35 I.A.C. 845.230(d)(2)(C), EEI is submitting available/existing analyses of "the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained in" the CCR impoundment, East Ash Pond.

A list of the chemical constituents' analyses contained in the EEI surface impoundment can be found in Appendix A. As determined through antidegradation studies, this list contains chemical constituents found in the surface free liquid and the subsurface free liquids. EEI is also including a list of chemical additives, sorbent materials and waste streams that were submitted in the facility's NPDES permit applications to IEPA within the past ten years at a minimum and/or listed in the current NPDES permit (IL0001554) in Appendix B.

Appendix A: Chemical Constituents Contained in the Ash Pond

Pollutant	Units	Surface Free Liquids Average Concentration	Subsurface Free Liquids Average Concentration
Ammonia	mg/L	< 0.10	3.3
Arsenic	mg/L	0.0014	0.189
Barium	mg/L	0.1585	0.45
Boron	mg/L	0.208	9.0
Cadmium	mg/L	< 0.0005	0.0007
Chloride	mg/L	20.6	11.7
Chromium	mg/L	0.00395	0.00024
Chromium (hexavalent)	mg/L	0.00315	0.0182
Copper	mg/L	0.00305	0.0260
Cyanide	mg/L	< 0.005	< 0.0050
Fluoride	mg/L	< 0.12	0.28
Iron	mg/L	0.2114	0.62
Iron, Dissolved	mg/L	< 0.05	6.7
Lead	mg/L	0.0007	0.039
Manganese	mg/L	0.0084	0.278
Mercury	mg/L	2.7E-06	0.000063
Nickel	mg/L	0.0014	0.0223
Nitrate as N	mg/L	1.2	0.09
Oil and Grease	mg/L	< 1.85	6.1
pH*	SU	8.8	8.3
Phenols	mg/L	< 0.05	< 0.05
Selenium	mg/L	< 0.0005	1.52
Silver	mg/L	< 0.0005	0.0063
Sulfate	mg/L	59.55	0.0004
TDS	mg/L	238	848.9
TSS	mg/L	9.9	1726
Zinc	mg/L	< 0.01	65

*Used https://calstormcompliance.com/ph-averaging-tool

Appendix B: List of Chemical Additives, Waste Streams and Sorbent Materials

Chemical Additives
Buckman 8812 or equivalent -- Anti Scalant
Calcium Bromide*
Bualab 5494 – Dust Suppression*
Sulfuric acid (93%)
Sodium hydroxide (50%)
Buckman 8862 or equivalent -- Biocide
Buckman 8854 or equivalent – high pH Cleaner
Buckman 8893 or equivalent – low pH Cleaner

* Only a very small percentage of these chemicals would enter the ash pond. A high majority of the product would be consumed in the combustion process. Varying products may be used.

Waste Streams and Sorbent Materials*
Bottom Ash & Fly Ash Sluice water
Demineralizer Regeneration Waste
Central Water Treatment Bldg Floor Drains
Settling Lagoon and Intake Dredging
Air Heater Wash Water
Reverse Osmosis and Demineralizer System Blowdown
Non-Chemical Metal Cleaning Waste

*No sorbent materials

DYNEGY

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	ASTM Class C Fly Ash
Synonyms:	Coal Fly Ash, Pozzolan
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Relevant Identified Uses:	Component of wallboard, concrete, roofing material, bricks, cement kiln feed.
Uses Advised Against:	None known.

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Dynegy, Inc.
Street Address:	601 Travis Street, Suite 1400
City, State and Zip Code:	Houston, TX 77002
Customer Service Telephone:	800-633-4704

Section 2
Hazards Identification

2.1 Classification of the Substance

GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):

- Eye Irritant, Category 2A
- STOT-SE, Category 3 (Respiratory Irritation)
- Carcinogen, Category 1A
- STOT-RE, Category 1 (Lungs)
- Toxic to Reproduction, Category 2

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	**DANGER**
Hazard Statement(s):	*Causes serious eye irritation.* *May cause damage to lungs after repeated/prolonged exposure via inhalation.* *May cause respiratory irritation.* *May cause cancer of the lung.* *Suspected of damaging fertility or the unborn child.*
Precautionary Statement(s):	*Obtain special instructions before use.* *Do not handle until all safety precautions have been read and understood.* *Avoid breathing dust.* *Wear protective gloves/protective clothing/eye protection/face protection.* *Wash thoroughly after handling.* *Do not eat drink or smoke when using this product.* *Use outdoors or in a well-ventilated area.* *If exposed or concerned: Get medical advice/attention.* *Store in a secure area.* *Dispose of product in accordance with local/national regulations.*

** Fly ash and other coal combustion products (CCPs) are UVCB substances (unknown or variable composition or biological). Various CCPs, noted as ashes/ash residuals; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Waste solids, ashes under TSCA are defined as: "The residuum from the burning of a combination of carbonaceous materials. The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." Ashes including fly ash and fluidized bed combustion ash are identified by CAS number 68131-74-8. The exact composition of the ash is dependent on the fuel source and flue additives composed of many constituents. The*

classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [Yes] **Other:** **(ACGIH)** [Yes]

Section 3
Composition/Information on Ingredients

Substance	***CAS No.***	***Percentage (%)***	***GHS Classification***
Crystalline Silica	*14808-60-7*	*30 - 60%*	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Silica, crystalline respirable (RCS)	*14808-60-7*	***See Footnote 1***	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Aluminosilicates	*71243-67-9* *1327-36-2*	*30 - 60%*	*Single Exposure STOT, Category 3*
Iron oxide	*1309-37-1*	*1 - 10%*	*Not Classified*
Calcium oxide (CaO)	*1305-78-8*	*20 - 30%*	*Skin Irritant, Category 2* *Eye Irritant, Category 1* *Single Exposure STOT, Category 3*
Magnesium oxide	*1309-48-4*	*2 - 10%*	*Not Classified*
Phosphorus pentoxide (P_2O_5)	*1314-56-3*	*≤2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Sodium oxide	*1313-59-3*	*1-8%*	*Not Classified*
Potassium oxide (K_2O)	*12136-45-7*	*≤1%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Titanium dioxide (TiO_2)	*13463-67-7*	*<3%*	*Not Classified*
Bromide salt (calcium)	*7789-41-5*	*See Footnote 2*	*Toxic to Reproduction, Category 2*

Footnote 1: *The percentage of respirable crystalline silica has not been determined. Therefore, a GHS classification of Carcinogen, Category 1A has been assigned.*

Footnote 2: *Analytical data are not available to demonstrate that the concentration of bromide salt is <0.1%; therefore, a GHS classification of Toxic to Reproduction, Category 2 has been assigned.*

DYNEGY

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse copiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute Effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.

Chronic Effects: Chronic exposure may cause lung damage from repeated exposure. Prolonged inhalation of respirable crystalline silica above certain concentrations may cause lung diseases, including silicosis and lung cancer. Repeated exposure to dusts containing inorganic bromide salts may affect fertility and/or result in effects to the unborn child.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing. Get medical advice if inhalation occurs and respiratory symptoms persist.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising from the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.2.2 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental Precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Calcium oxide		5	2	2	2
Particulates Not Otherwise Regulated	Total	15	15	10	10
	Respirable	5	5	3	5
Respirable Crystalline Silica	Respirable Crystalline Silica	0.05	0.05	0.025	0.05
Titanium dioxide	Total	15	2.4 (fine) 0.3 (ultrafine)	10	10
Manganese dioxide (as manganese compounds)	Total	5 (Ceiling)	1 3 (STEL)	0.1	0.2
	Respirable	-	-	0.02	-

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless[1]	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C) (in water): Not Determined	**Specific gravity or relative density:** 2.2 – 2.9
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point/boiling range (°C): NA	**Partition coefficient: n-octane/water:** NA
Flash point (°C): Not determined	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

[1] The use of urea or aqueous ammonia injected into the flue gas to reduce nitrogen oxides (NOx) emissions may result in the presence of ammonium sulfate or ammonium bisulfate in the ash at less than 0.1%. When ash containing these substances becomes wet under high pH (>9), free ammonia gas may be released resulting in objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces.

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is an inert, inorganic material primarily composed of elemental oxides.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is a relatively stable, inert material; however, when ash containing ammonia becomes wet under high pH (>9), free ammonia gas may be released resulting in an objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces. Polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Does not meet the classification criteria but may cause slight skin irritation. Product dust can dry the skin which can result in irritation.
Eye damage/irritation	Causes serious eye irritation. Positive scores for conjunctiva irritation and chemosis in 2/3 animals based on average of 24, 48 and 72-hour scores with irritation clearing within 21 days; No corneal or iritis effects observed.
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer.
Germ cell mutagenicity	Not mutagenic in in-vitro and in-vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by OSHA, NTP, ACGIH and IARC.
Reproductive toxicity	No developmental toxicity was observed in available animal studies. Reproductive studies on CCPs showed either no reproductive effects, or some effects on male and female reproductive organs and parameters but without a clear dose response. Inorganic bromide salts have been shown to have adverse effects on reproductive parameters in some animal studies.
STOT-SE	CCPs when present as a nuisance dust may result in respiratory irritation.
STOT-RE	In a 180-day inhalation study with fly ash dust, no effects were observed at the highest dose tested. NOEC = 4.2 mg/m^3; it is not possible to assess the level at which toxicologically significant effects may occur. Repeated inhalation exposures to high levels of respirable crystalline silica may result in lung damage (i.e., silicosis).
Aspiration Hazard	Not applicable based product form.

Section 12
Ecological Information

12.1 Toxicity

Fly Ash C (CAS# 68131-74-8)	
Toxicity to Fish	LC50 > 100 mg/L
Toxicity to Aquatic Invertebrates	Data indicates that the test substance is not toxic to *Daphnia magna* (EC50 undetermined).
Toxicity to Aquatic Algae and Plants	EC50 = 10 mg/L

Calcium oxide CAS# 1305-78-8	
Toxicity to Fish	LC50 = 50.6 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Invertebrates	EC50 = 49.1 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Algae and Plants	NOEC =48 mg/L @ 72 hours based on $Ca(OH)_2$ The initial pH of the test medium was not directly related to the biologically relevant effects. The formation of precipitates is likely the result of the reaction between CO_2 dissolved in the medium.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

This material does not contain any compounds that would bioaccumulate up the food chain.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

This material does not contain any compounds classified as “persistent, bioaccumulative or toxic” nor as “very persistent/very bioaccumulative”.

12.6 Other Adverse Effects

None known.

Section 13

Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate industrial hygiene practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65.

  The following substances are known to the State of California to be carcinogens and/or reproductive toxicants:

  - Respirable crystalline silica

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Ammonium bisulfate	7803-63-6	No	Yes	No	No
Ammonium sulfate	7783-20-2	Yes	No	Yes	No
Calcium oxide	1305-78-8	Yes	Yes	Yes	No
Iron oxide	1309-37-1	Yes	Yes	Yes	No
Magnesium oxide	1309-48-4	No	Yes	No	No
Manganese oxide-as manganese compounds	1313-13-9; Various	No	No	Yes	Yes
Phosphorus pentoxide (or phosphorus oxide)	1314-56-3	Yes	Yes	Yes	No
Potassium oxide	12136-45-7	No	Yes	No	No
Silica-crystalline (SiO2), quartz	14808-60-7	Yes	Yes	Yes	No
Sodium oxide	1313-59-3	No	Yes	No	No
Titanium dioxide	13463-67-7	Yes	Yes	Yes	Yes

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: February 23, 2018

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- CA: California
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFR: Code of Federal Regulations
- EPA: Environmental Protection Agency

- GHS: Globally Harmonized System of Classification and Labelling
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit
- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological
- U.S.: United States
- U.S. DOT: United States of Department of Transportation

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	2*	**Flammability:**	0	**Physical Hazards:**	0	**Personal protection:****	

** Chronic Health Effects*
*** Appropriate personal protection is defined by the activity to be performed.*
See Section 8 for additional information.

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

Bottom Ash
SDS Number: 0.0
Revision Date: 03/2018

DYNEGY

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	ASTM Bottom Ash
Synonyms:	Ash; Ashes; Ash residues; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Coal Fly Ash; Pozzolan; Waste solids.
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Relevant Identified Uses:	Component of wallboard, concrete, roofing material, bricks, cement kiln feed.
Uses Advised Against:	None known.

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Dynegy, Inc.
Street Address:	601 Travis Street, Suite 1400
City, State and Zip Code:	Houston, TX 77002
Customer Service Telephone:	800-633-4704

Section 2
Hazards Identification

2.1 Classification of the Substance

GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):

- Eye Irritant, Category 2A
- STOT-SE, Category 3 (Respiratory Irritation)
- Carcinogen, Category 1A
- STOT-RE, Category 1 (Lungs)
- Toxic to Reproduction, Category 2

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	**DANGER**
Hazard Statement(s):	*Causes serious eye irritation.* *May cause respiratory irritation.* *May cause damage to lungs after repeated/prolonged exposure via inhalation.* *May cause cancer of the lung.* *Suspected of damaging fertility or the unborn child.*
Precautionary Statement(s):	*Obtain special instructions before use.* *Do not handle until all safety precautions have been read and understood.* *Avoid breathing dust.* *Wash thoroughly after handling.* *Do not eat drink or smoke when using this product.* *Wear protective gloves/protective clothing/eye protection/face protection.* *Use outdoors or in a well-ventilated area.* *If exposed or concerned: Get medical advice/attention.* *Store in a secure area.* *Dispose of product in accordance with local/national regulations.*

** Fly ash and other coal combustion products (CCPs) are UVCB substances (unknown or variable composition or biological). Various CCPs, noted as ashes/ash residuals; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Waste solids, ashes under TSCA are defined as: "The residuum from the burning of a combination of carbonaceous materials. The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." Ashes including fly ash and fluidized bed combustion ash are identified by CAS number 68131-74-8. The exact composition of the ash is dependent on the fuel source and flue additives composed of many constituents. The classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.*

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [Yes] **Other:** **(ACGIH)** [Yes]

Section 3
Composition/Information on Ingredients

Substance	***CAS No.***	***Percentage (%)***	***GHS Classification***
Crystalline Silica	*14808-60-7*	*20 - 40%*	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Silica, crystalline respirable (RCS)	*14808-60-7*	***See Footnote 1***	*Repeat Dose STOT, Category 1* *Carcinogen. Category 1A*
Aluminosilicates[2]	***Various, see Footnote 2***	*10 - 60%*	*Single Exposure STOT, Category 3*
Calcium oxide (CaO)	*1305-78-8*	*10 - 30%*	*Skin Irritant, Category 2* *Eye Irritant, Category 1* *Single Exposure STOT, Category 3*
Iron oxide	*1309-37-1*	*1 - 10%*	*Not Classified*
Manganese dioxide (MnO_2)	*1313-13-9*	*<2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Magnesium oxide	*1309-48-4*	*2 - 10%*	*Not Classified*
Phosphorus pentoxide (P_2O_5)	*1314-56-3*	*≤2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Sodium oxide	*1313-59-3*	*1 - 10%*	*Not Classified*
Potassium oxide (K_2O)	*12136-45-7*	*≤1%*	*Skin Irritant Category 2* *Eye Irritant Category 2B*
Titanium dioxide (TiO_2)	*13463-67-7*	*<3%*	*Not Classified*

[1] *The percentage of respirable crystalline silica has not been determined. Therefore, a GHS classification of Carcinogen 1A has been assigned.*

[2] *Aluminosilicates (CAS# 1327-36-2) may be in the form of mullite (CAS# 1302-93-8); aluminosilicate glass; pozzolans (CAS# 71243-67-9); or calcium aluminosilicates such as tricalcium aluminate (C3A), or calcium sulfoaluminate (C4A3S). The form is dependent on the source of the coal and or the process used to create the CCP. Pulverized coal combustion would be more likely to create high levels of pozzolans. Aluminosilicates may have inclusions of calcium, titanium, iron, potassium, phosphorus, magnesium and other metal oxides.*

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse copiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute Effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.

Chronic Effects: Chronic exposure may cause lung damage from repeated exposure. Prolonged inhalation of respirable crystalline silica above certain concentrations may cause lung diseases, including silicosis and lung cancer.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing. Get medical advice if inhalation occurs and respiratory symptoms persist.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising from the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.2.2 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental Precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Calcium oxide		5	2	2	2
Particulates Not Otherwise Regulated	Total	15	15	10	10
	Respirable	5	5	3	5
Respirable Crystalline Silica	Respirable	0.05	0.05	0.025	0.05
Manganese dioxide (as manganese compounds)	Total	5 (Ceiling)	1 3 (STEL)	0.1	0.2
	Respirable	-	-	0.02	-

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

DYNEGY

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless[1]	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C) (in water): 8 - 11	**Specific gravity or relative density:** 2.2 – 2.9
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point and boiling range (°C): Not applicable	**Partition coefficient: n-octane/water:** Not determined
Flash point (°C): Not determined	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

[1] The use of urea or aqueous ammonia injected into the flue gas to reduce nitrogen oxides (NOx) emissions may result in the presence of ammonium sulfate or ammonium bisulfate in the ash at less than 0.1%. When ash containing these substances becomes wet under high pH (>9), free ammonia gas may be released resulting in objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces.

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is an inert, inorganic material primarily composed of elemental oxides.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is a relatively stable, inert material; however, when ash containing ammonia becomes wet under high pH (>9), free ammonia gas may be released resulting in an objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces. Polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Does not meet the classification criteria but may cause slight skin irritation. Product dust can dry the skin which can result in irritation.
Eye damage/irritation	Causes serious eye irritation. Positive scores for conjunctiva irritation and chemosis in 2/3 animals based on average of 24, 48 and 72-hour scores with irritation clearing within 21 days; no corneal or iritis effects observed.
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer.
Germ cell mutagenicity	Not mutagenic in in-vitro and in-vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by OSHA, NTP, ACGIH and IARC.
Reproductive toxicity	No developmental toxicity was observed in available animal studies. Reproductive studies on CCPs showed either no reproductive effects, or some effects on male and female reproductive organs and parameters but without a clear dose response.
STOT-SE	CCPs when present as a nuisance dust may result in respiratory irritation.
STOT-RE	In a 180-day inhalation study with fly ash dust, no effects were observed at the highest dose tested. NOEC = 4.2 mg/m^3; it is not possible to assess the level at which toxicologically significant effects may occur. Repeated inhalation exposures to high levels of respirable crystalline silica may result in lung damage (i.e., silicosis).
Aspiration Hazard	Not applicable based product form.

Section 12
Ecological Information

12.1 Toxicity

Fly Ash (CAS# 68131-74-8)	
Toxicity to Fish	LC50 > 100 mg/L
Toxicity to Aquatic Invertebrates	Data indicates that the test substance is not toxic to *Daphnia magna* (EC50 undetermined)
Toxicity to Aquatic Algae and Plants	EC50 = 10 mg/L
Calcium oxide CAS# 1305-78-8	
Toxicity to Fish	LC50 = 50.6 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Invertebrates	EC50 = 49.1 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Algae and Plants	NOEC =48 mg/L @ 72 hours based on $Ca(OH)_2$ The initial pH of the test medium was not directly related to the biologically relevant effects. The formation of precipitates is likely the result of the reaction between CO_2 dissolved in the medium.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

This material does not contain any compounds that would bioaccumulate up the food chain.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

This material does not contain any compounds classified as “persistent, bioaccumulative or toxic” nor as “very persistent/very bioaccumulative”.

12.6 Other Adverse Effects

None known.

Section 13
Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate industrial hygiene practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65

  The following substances are known to the State of California to be carcinogens and/or reproductive toxicants:

  - Respirable crystalline silica
  - Titanium dioxide

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Ammonium bisulfate	7803-63-6	No	Yes	No	No
Ammonium sulfate	7783-20-2	Yes	No	Yes	No
Calcium oxide	1305-78-8	Yes	Yes	Yes	No
Iron oxide	1309-37-1	Yes	Yes	Yes	No
Magnesium oxide	1309-48-4	No	Yes	No	No
Phosphorus pentoxide (or phosphorus oxide)	1314-56-3	Yes	Yes	Yes	No
Potassium oxide	12136-45-7	No	Yes	No	No
Silica-crystalline (SiO_2), quartz	14808-60-7	Yes	Yes	Yes	No
Sodium oxide	1313-59-3	No	Yes	No	No
Titanium dioxide	13463-67-7	Yes	Yes	Yes	Yes

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: February 23, 2018

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- CA: California
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFR: Code of Federal Regulations
- EPA: Environmental Protection Agency
- GHS: Globally Harmonized System of Classification and Labelling
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit
- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological
- U.S.: United States
- U.S. DOT: United States of Department of Transportation

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	2*	**Flammability:**	0	**Physical Hazards:**	0	**Personal protection:****	

** Chronic Health Effects*
*** Appropriate personal protection is defined by the activity to be performed.*
See Section 8 for additional information.

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

ATTACHMENT D

October 2021

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 Ill. Admin. Code Part 845 - Fault Area Location Demonstration for East Ash Pond at the Joppa Power Plant

Electric Energy, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois. The Joppa East Ash Pond is an existing surface impoundment storing coal combustion residuals (CCR). The requirements for the Joppa East Ash Pond are found in 35 Ill. Admin. Code (I.A.C.) 845 (Part 845).

This memorandum addresses the requirements of Section 845.320 Fault Areas, which states:

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).*

Pursuant to 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.

The previous fault area demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.62. The requirements described in 40 C.F.R. § 257.62 are nearly identical to the requirements contained in I.A.C. Section 845.320. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed fault area demonstration is included in Attachment D.

HALEY & ALDRICH, INC.
6500 Rockside Road
Suite 200
Cleveland, OH 44131
216.739.0555

MEMORANDUM

16 October 2018
File No. 129788

SUBJECT: Location Restriction Demonstration - Fault Areas
Joppa Power Station
East Ash Pond
Joppa, Illinois

Electric Energy, Inc. operates the coal-fired Joppa Power Station (Plant) located near Joppa, Illinois. The East Ash Pond (Unit) is an existing coal combustion residuals (CCR) surface impoundment. This demonstration addresses the requirements of 40 CFR §257.62 *(Fault Areas)* of the U.S. Environmental Protection Agency's (EPA) rule entitled *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities.* 80 Fed. Reg. 21,302 (Apr. 17, 2015) (promulgating 40 CFR §257.62); 83 Fed. Reg. 36,435 (July 30, 2018) (amending 40 CFR §257.62).

§257.62(a): New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units 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 by the dates specified in paragraph (c) of this section that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the CCR unit.

A review of available data from the U.S. Geologic Survey, the Illinois State Geological Survey, and other available information was completed for this demonstration. The Joppa Power Station is located within the Lusk Creek Fault Zone (LCFZ), and the nearest known mapped fault in the LCFZ is located approximately 1,120 feet northwest of the East Ash Pond. The timeframe of the most recent activity on faults within the LCFZ is estimated to be older than 75,000 years. Based on the available published geologic data and information reviewed, there are no active faults or fault damage zones that have had displacement in Holocene time reported or indicated within 200 feet of the Unit.

Joppa

§257.62(b): The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer or approval from the Participating State Director or approval from EPA where EPA is the permitting authority stating that the demonstration meets the requirements of paragraph (a) of this section.

I, Steven F. Putrich, 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 demonstration that the CCR Unit is not located within 60 meters (200 feet) of the outermost damage zone of a fault that has had a displacement in Holocene time as included in the CCR Rule Location Restrictions Evaluation memorandum dated 12 October 2018 meets the requirements of 40 CFR §257.62(a).

Signed: _____
Consulting Engineer

Print Name:	Steven F. Putrich
Illinois License No.:	62048779
Title:	Vice President
Company:	Haley & Aldrich, Inc.

Professional Engineer's Seal:

Joppa

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 Ill. Admin. Code Part 845 - Placement Above the Uppermost Aquifer Location Demonstration for East Ash Pond at the Joppa Power Plant

Electric Energy, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois. The Joppa East Ash Pond is an existing surface impoundment storing coal combustion residuals (CCR). The requirements for the Joppa East Ash Pond are found in 35 Ill. Admin. Code (I.A.C.) 845 (Part 845).

This memorandum addresses the requirements of Section 845.300 Placement Above the Uppermost Aquifer, which states:

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).*

Pursuant to 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.

The previous upper aquifer demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.60. The requirements described in 40 C.F.R. § 257.60 are nearly identical to the requirements contained in I.A.C. Section 845.300. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed upper aquifer demonstration is included in Attachment D.

HALEY & ALDRICH, INC.
6500 Rockside Road
Suite 200
Cleveland, OH 44131
216.739.0555

MEMORANDUM

16 October 2018
File No. 129788

SUBJECT: Location Restriction Demonstration – Placement Above Uppermost Aquifer
Joppa Power Station
East Ash Pond
Joppa, Illinois

Electric Energy, Inc. (EEI) operates the coal-fired Joppa Power Station (Plant) located near Joppa, Illinois. The East Ash Pond (Unit) is an existing coal combustion residuals (CCR) surface impoundment. This demonstration addresses the requirements of 40 CFR §257.60 *(Placement above the uppermost aquifer)* of the U.S. Environmental Protection Agency's (EPA) rule entitled *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities*. 80 Fed. Reg. 21,302 (Apr. 17, 2015) (promulgating 40 CFR §257.60); 83 Fed. Reg. 36,435 (July 30, 2018) (amending 40 CFR §257.60).

§257.60(a): New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must be constructed with a base that is located no less than 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 unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table). The owner or operator must demonstrate by the dates specified in paragraph (c) of this section that the CCR unit meets the minimum requirements for placement above the uppermost aquifer.

O'Brien & Gere (OB&G) evaluated groundwater conditions and prepared a Top of Uppermost Aquifer contour map (TOA Map) figure dated 28 November 2017 where the upper limit of the uppermost aquifer is mounded near the middle of the unit with a gradually sloping surface generally from northeast to southwest ranging in elevation from 315+/- feet to 280+/- feet across the southern portion of the unit while a gradually sloping surface generally from southwest to northeast ranging in elevation from 315+/- feet to 300+/- feet across the northern portion of the unit.

Haley & Aldrich reviewed available information provided by Vistra including historic record drawings and design drawings and identified drawing sets that provided information regarding the base of the unit and EEI East Ash Pond Plan, Section and Details C-106 drawing dated 11 September 1973 (1973 North Pond drawing) and EEI's Joppa, IL East Ash Pond 4229-8211 drawing dated 12 June 1986 (1986 South Pond drawing). Critical low point pre-construction elevations within the unit were identified on the EEI drawings and confirmed by borings performed by AECOM in 2015 (AECOM Borings).

Joppa

When the critical low points at the base of unit were compared to the corresponding contours on the TOA Map, the resulting minimum separation was determined to exceed the 5.0 feet minimum separation requirement of §257.60(a).

§257.60(b): The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer or approval from the Participating State Director or approval from EPA where EPA is the permitting authority stating that the demonstration meets the requirements of paragraph (a) of this section.

I, Steven F. Putrich, 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 demonstration regarding the location of the base of the CCR Unit no less than 1.52 meters above the upper limit of the uppermost aquifer as included in the CCR Rule Locations Restrictions Evaluation memorandum dated 12 October 2018 meets the requirements of 40 CFR §257.60(a).

Signed: _____
Consulting Engineer

Print Name:	Steven F. Putrich
Illinois License No.:	62048779
Title:	Vice President
Company:	Haley & Aldrich, Inc.

Professional Engineer's Seal:

Joppa

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 Ill. Admin. Code Part 845 – Seismic Impact Zone Location Demonstration for East Ash Pond at the Joppa Power Plant

Electric Energy, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois. The Joppa East Ash Pond is an existing surface impoundment storing coal combustion residuals (CCR). The requirements for the Joppa East Ash Pond are found in 35 Ill. Admin. Code (I.A.C.) 845 (Part 845).

This memorandum addresses the requirements of Section 845.330 Seismic Impact Zones, which states:

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).*

Pursuant to 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.

The previous seismic impact zone demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.63. The requirements described in 40 C.F.R. § 257.63 are nearly identical to the requirements contained in I.A.C. Section 845.330. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed seismic impact zone demonstration is included in Attachment D.

HALEY & ALDRICH, INC.
6500 Rockside Road
Suite 200
Cleveland, OH 44131
216.739.0555

MEMORANDUM

16 October 2018
File No. 129788

SUBJECT: Location Restriction Demonstration – Seismic Impact Zone
Joppa Power Station
East Ash Pond
Joppa, Illinois

Electric Energy, Inc. operates the coal-fired Joppa Power Station (Plant) located near Joppa, Illinois. The East Ash Pond (Unit) is an existing coal combustion residuals (CCR) surface impoundment. This demonstration addresses the requirements of 40 CFR §257.63 *(Seismic Impact zones)* of the U.S. Environmental Protection Agency's (EPA) rule entitled *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities*. 80 Fed. Reg. 21,302 (Apr. 17, 2015) (promulgating 40 CFR §257.63); 83 Fed. Reg. 36,435 (July 30, 2018) (amending 40 CFR §257.63).

§257.63(a): New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in seismic impact zones unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section 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.

The results of our evaluation indicate that the Unit is in compliance with 40 CFR §257.63(a). Although the Unit is located in a seismic impact zone, it satisfies the demonstration requirements of 40 CFR §257.63(a). The AECOM report entitled "CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Control System Plan for the East Ash Pond at Joppa Power Station" dated October 2016 (AECOM Report), includes engineering analysis, calculations, and findings that support the requirements of 40 CFR §257.63(a), and provides documentation that those requirements have been evaluated by AECOM for the subject CCR unit.

Joppa

§257.63(b): The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer or approval from the Participating State Director or approval from EPA where EPA is the permitting authority stating that the demonstration meets the requirements of paragraph (a) of this section.

I, Steven F. Putrich, 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, that the CCR Unit is located in a seismic impact zone as included in the CCR Rule Location Restrictions Evaluation memorandum dated 12 October 2018 and satisfies all requirements of 40 CFR §257.63(a).

By providing this certification demonstration statement, we are not stating or inferring that we have verified or certified the details, assumptions, calculations and/or site condition models developed by AECOM in the subject report; those elements of the report are considered the professional opinions and determinations of AECOM.

Signed: _____
Consulting Engineer

Print Name:	Steven F. Putrich
Illinois License No.:	62048779
Title:	Vice President
Company:	Haley & Aldrich, Inc.

Professional Engineer's Seal:

Joppa

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 Ill. Admin. Code Part 845 – Unstable Areas Location Demonstration for East Ash Pond at Joppa Power Plant

Electric Energy, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois. The Joppa East Ash Pond is an existing surface impoundment storing coal combustion residuals (CCR). The requirements for the Joppa East Ash Pond are found in 35 Ill. Admin. Code (I.AC.) 845 (Part 845).

This memorandum addresses the requirements of Section 845.340 Unstable Areas which states:

Section 845.340 Unstable Areas

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)*

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).*

Demonstration of compliance with Section 845.340(a) and (b) – Unstable Areas:

Pursuant to 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.

The previous unstable area demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.64. The requirements described in 40 C.F.R. § 257.64 are nearly identical to the requirements contained in I.A.C. Section 845.340. Pursuant to Section 845.210(d)(2), a certification is not required for the unstable area demonstration. The previously completed unstable area demonstration is included in Attachment D.

HALEY & ALDRICH, INC.
6500 Rockside Road
Suite 200
Cleveland, OH 44131
216.739.0555

MEMORANDUM

16 October 2018
File No. 129788

SUBJECT: Location Restriction Demonstration – Unstable Areas
Joppa Power Station
East Ash Pond
Joppa, Illinois

Joppa

Electric Energy, Inc. operates the coal-fired Joppa Power Station (Plant) located near Joppa, Illinois. The East Ash Pond (Unit) is an existing coal combustion residuals (CCR) surface impoundment. This demonstration addresses the requirements of 40 CFR §257.64 *(Unstable Areas)* of the U.S. Environmental Protection Agency's (EPA) rule entitled *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities*. 80 Fed. Reg. 21,302 (Apr. 17, 2015) (promulgating 40 CFR §257.64); 83 Fed. Reg. 36,435 (July 30, 2018) (amending 40 CFR §257.64).

§257.64(a): An existing or new CCR landfill, existing or new CCR surface impoundment, or any lateral expansion of a CCR unit must not be located in an unstable area unless the owner or operator demonstrates by the dates specified in paragraph (d) of this section that recognized and generally accepted good engineering practices have been incorporated into the design of the CCR unit to ensure that the integrity of the structural components of the CCR unit will not be disrupted.

§257.64(b): The owner or operator must consider all of the following factors, at a minimum, when determining whether an area is unstable:

(1) On-site or local soil conditions 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).

Determination of compliance with §257.64(b)(1) - Conditions associated with the potential for significant differential settlement due to liquefaction were not identified in the area where the Plant is located. A separate report completed by AECOM entitled "CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Control System Plan for the East Ash Pond at Joppa Power Station" dated October 2016 concluded that the coarse-grained soils beneath the Unit are not susceptible to liquefaction and soft clays beneath the Unit were susceptible to cyclic softening (strength loss). The post-earthquake stability analysis performed by AECOM to model the stability of the impoundment slopes following an earthquake and soil strength loss produced acceptable factors of safety.

Determination of compliance with §257.64(b)(2) - Based on available United States Geological Survey (USGS), Illinois State Geological Survey (ISGS) information, and communication with Vistra representatives familiar with the Plant's history, karst topography or physiographic features such as

sinkholes, vertical shafts, sinking streams, caves, large springs, or blind valleys do not exist at the Plant. To evaluate the susceptibility of landslides, we reviewed readily available USGS and ISGS data. The USGS data indicates that the Plant is in an area of high landslide susceptibility and low landslide incidence, however more detailed ISGS data indicates that there has not been a documented landslide occurrence at the Unit. The closest ISGS documented landslide occurrence is located more than 10 miles from the site. Accordingly, it is our opinion that the Unit is not located in an area that has high susceptibility to landslides.

Determination of compliance with §257.64(b)(3) - There are no documented surface or subsurface anthropogenic activities that would be indicative of creating unstable foundation conditions.

§257.64(c): The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer or approval from the Participating State Director or approval from EPA where EPA is the permitting authority stating that the demonstration meets the requirements of paragraph (a) of this section.

I, Steven F. Putrich, 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 demonstration indicating the CCR Unit is not located in an unstable area as included in the CCR Rule Location Restrictions Evaluation memorandum dated 12 October 2018 meets the requirements of 40 CFR §257.64(a).

Signed: _____
Consulting Engineer

Print Name:	Steven F. Putrich
Illinois License No.:	62048779
Title:	Vice President
Company:	Haley & Aldrich, Inc.

Professional Engineer's Seal:

HALEY ALDRICH

Joppa

Luminant

Office Memorandum

Date: October 17 2020

To: Cynthia Vodopivec

Charles Koudelka
cc: Phil Morris

From: Vic Modeer

Electric Energy, Inc.
Joppa Power Station
Subject: East Ash Pond Floodplain Certification

Electric Energy, Inc. (EEI) is the owner of the Joppa Power Plant, located in Massac County near Joppa, Illinois. The East Ash Pond is an active surface impoundment storing coal combustion residuals (CCR). Requirements for the East Ash Pond are located in 35 Ill. Admin. Code Part 845 (Part 845). With respect to the floodplain location restriction, Part 845 provides as follows:

Section 845.340 (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.

The boundaries of the East Ash Pond were determined in 2020 by a survey conducted by a professional surveyor licensed in the State of Illinois. The boundaries and elevations of the East Ash Pond were compared to the existing 1983 and 2008 FEMA floodplain maps, and it was determined that East Ash Pond is not located within the base flood elevation or 100-year floodplain (Figures 1 and 2, respectively).

Under Section 845.340(d), the owner or operator of the CCR surface impoundment must obtain a certification from a qualified professional engineer stating that the floodplain demonstration meets the requirements of Section 845.340(c).

I, Victor Modeer, being a Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief that this floodplain demonstration meets the requirements of 35 Ill. Adm. Code 845.340(c).

Sincerely,

Vic Modeer, PE, D.GE
(IL, MO, IN, KY, OH, LA)
Engineering Manager

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: 35 I.A.C. Admin. Code Part 845 - Wetland Location Demonstration for East Ash Pond at Joppa Power Plant

Electric Energy, Inc. operates the coal fired Joppa Power Plant located in Massac County, Illinois. The Joppa East Ash Pond is an existing surface impoundment storing coal combustion residuals (CCR). The requirements for the Joppa East Ash Pond are found in 35 Ill. Admin. Code (I.A.C.) 845 (Part 845).

This memorandum addresses the requirements of Section 845.310 Wetlands, which states:

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* [that the requirements listed in 845.310(a)(1) through (5) are met.]

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).*

Pursuant to 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.

The previous wetlands demonstration was certified by a qualified professional engineer stating that the demonstration meets the requirements of 40 C.F.R. § 257.61. The requirements described in 40 C.F.R. § 257.61 are nearly identical to the requirements contained in I.A.C. Section 845.310. Pursuant to Section 845.210(d)(2), a certification is not required for this demonstration. The previously completed wetlands demonstration is included in Attachment D.

HALEY & ALDRICH, INC.
6500 Rockside Road
Suite 200
Cleveland, OH 44131
216.739.0555

MEMORANDUM

16 October 2018
File No. 129788

SUBJECT: Location Restriction Demonstration - Wetland Areas
Joppa Power Station
East Ash Pond
Joppa, Illinois

Electric Energy, Inc. operates the coal-fired Joppa Power Station (Plant) located near Joppa, Illinois. The East Ash Pond (Unit) is an existing coal combustion residuals (CCR) surface impoundment. This demonstration addresses the requirements of 40 CFR §257.61 *(Wetlands)* of the U.S. Environmental Protection Agency's (EPA) rule entitled *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities*. 80 Fed. Reg. 21,302 (Apr. 17, 2015) (promulgating 40 CFR §257.61); 83 Fed. Reg. 36,435 (July 30, 2018) (amending 40 CFR §257.61.

§257.61(a): New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in wetlands, as defined in §232.2 of this chapter, unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that the CCR unit meets the requirements of paragraphs (a)(1) through (5) of this section.

Based on a review of the U.S. Fish and Wildlife Service's National Wetland Inventory mapping, 0.5-meter resolution aerial imagery (2017) and the results of on-site field assessments, the Unit is not located in wetlands as defined by 40 CFR §232.2.

Joppa

§257.61(b): The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer or approval from the Participating State Director or approval from EPA where EPA is the permitting authority stating that the demonstration meets the requirements of paragraph (a) of this section.

I, Steven F. Putrich, 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 CCR Unit is not located in wetlands as included in the CCR Rule Location Restrictions Evaluation memorandum dated 12 October 2018 and, therefore, meets the requirements of 40 CFR §257.61(a).

Signed: _____
Consulting Engineer

Print Name:	Steven F. Putrich
Illinois License No.:	62048779
Title:	Vice President
Company:	Haley & Aldrich, Inc.

Professional Engineer's Seal:

Joppa

ATTACHMENT E

October 2021

JOPPA EAST
ASH POND
ID #: W1270100004-02
ELECTRIC
ENERGY, INC.
DANGER
OVERHEAD
POWER LINES

JOPPA EAST
ASH POND
ID #: W1270100004-02
ELECTRIC
ENERGY, INC.

ATTACHMENT F

October 2021

Electric Energy, Inc.

JOPPA POWER PLANT
JOPPA, MASSAC COUNTY, ILLINOIS

Emergency Action Plan (EAP)

40 C.F.R. § 257.73(a)(3), Ill. Adm. Code 845.520
Coal Combustion Residual (CCR) Impoundment
& Related Facilities

- East Ash Pond (NID # IL50714) (IEPA # W1270100004-02)

Revision Date: September 16, 2021

Qualified Professional Engineer Certification; Emergency Action Plan for the Joppa Power Plant East Ash Pond

In accordance with 40 C.F.R. § 257.73(a)(3)(iv) and 35 Ill. Adm. Code 845.520(e), the owner or operator of a CCR unit that is required to prepare a written Emergency Action Plan under 40 C.F.R. § 257.73(a)(3) and 35 Ill. Adm. Code 845.520(a) must obtain a certification from a qualified professional engineer stating that the written Emergency Action Plan meets the requirements of 40 C.F.R. § 257.73(a)(3) and 35 Ill. Adm. Code 845.520.

I, Phil Morris, being a Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief that:

1. the information contained in this Emergency Action Plan was prepared in accordance with the accepted practice of engineering; and

2. this Emergency Action Plan meets the requirements of 40 C.F.R. § 257.73(a)(3) and 35 Ill. Adm. Code 845.520.

Phil Morris
Senior Director, Corporate Environmental

9/27/21
Date

JOPPA POWER PLANT

EMERGENCY ACTION PLAN
CCR IMPOUNDMENT & RELATED FACILITIES

TABLE OF CONTENTS

Section Page

PART I – EAP NARRATIVE AND EXHIBITS

1 STATEMENT OF PURPOSE 1

2 COMMUNICATION 4

3 EAP ROLES AND RESPONSIBILITIES 8

4 EAP RESPONSE 9

5 PREPAREDNESS 14

6 FACILITY/IMPOUNDMENT DESCRIPTION 15

7 BREACH INUNDATION MAP AND POTENTIAL IMPACTS 17

List of Tables

Table Page

Table 2-1. EAP Emergency Responders 7
Table 3-1. Summary of EAP Roles 8
Table 4-1. Guidance for Determining the Response Level 9
Table 4-2. Impoundment Trigger Elevations 11
Table 4-3. Step 3: Emergency Actions 11
Table 5-1. Emergency Supplies and Equipment 14

List of Figures

Figure Page

Figure 1-1. Joppa Power Plant Location Map 2
Figure 1-2. Joppa Power Plant CCR Impoundment & Related Facilities 3
Figure 2-1. Summary/Sequence of Tasks 4-Step Incident Response Process 4
Figure 2-2. Notification Flowchart 5
Figure 2-3. EAP Response Process Decision Tree 6
Figure 6-1. Joppa East Ash Pond Inundation Map 18

JOPPA POWER PLANT
EMERGENCY ACTION PLAN
CCR IMPOUNDMENT & RELATED FACILITIES

PART I – EAP NARRATIVE AND EXHIBITS

1 STATEMENT OF PURPOSE

The Joppa Power Plant (Power Plant) is located near Joppa in Massac County, Illinois. The location is shown in Figure 1-1. The Power Plant is a coal-fired electricity producing power plant owned and operated by Electric Energy, Inc., a subsidiary of Dynegy. This Emergency Action Plan (EAP) covers the following Coal Combustion Residual (CCR) surface impoundment located at the site:

- Joppa East Ash Pond (NID # IL50714) (IEPA # W1270100004-02)

The location of the impoundment is shown in Figure 1-2. Section 6 of this EAP includes a description of the impoundment.

The purpose of this Emergency Action Plan (EAP) is to:

1. Safeguard the lives, as well as to reduce property damage, of citizens living within potential downstream flood inundation areas of the CCR impoundment and related facilities at the Joppa Power Plant.
2. Define the events or circumstances involving the CCR impoundment and related facilities at the Joppa Power Plant that represent atypical operating conditions that pose a safety hazard or emergency and how to identify those conditions.
3. Define responsible persons, their responsibilities, and notification procedures in the event of a safety emergency.
4. Provide contact information of emergency responders.
5. Identify emergency actions in the event of a potential or imminent failure of the impoundment.
6. Identify the downstream area that would be affected by failure of the impoundment.
7. Provide for effective facility surveillance, prompt notification to local Emergency Management Agencies, citizen warning and notification responses, and preparation should an emergency occur.

Information provided by Electric Energy, Inc. was utilized and relied upon in preparation of this report.

0 3,000 6,000 Feet

1:60,000 (At original document size of 11x17)

Stantec DYNEGY

Project Location
Latitude: 37.21438
Longitude: -88.85292
Massac County, Illinois

175605019
Prepared by RMGB on 3/29/2017
Technical Review by MM on 3/29/2017
Independent Review by MH on 3/29/2017

Client/Project
Joppa Power Station
Emergency Action Plan

Figure No.
1-1

Title
Location Map

Notes
1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Aerial Source: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User

Disclaimer: Stantec assumes no responsibility for data supplied in electronic format. The recipient accepts full responsibility for verifying the accuracy and completeness of the data. The recipient releases Stantec, its officers, employees, consultants and agents, from any and all claims arising in any way from the content or provision of the data.

X:\1735\Temporary Users\Vistalites\Work Dynegy\Joppa\GIS\Site_overview_fig1-1_20170322.mxd Revised: 2017-04-13 By: tbranch

R0000666

Legend

CCR Surface Impoundment Boundary

0 1,000 2,000 Feet

1:20,000 (At original document size of 11x17)

Stantec DYNEGY

Project Location 175605019
Latitude: 37.21438 Prepared by RMGB on 3/29/2017
Longitude: -88.85292 Technical Review by MM on 3/29/2017
Massac County, Illinois Independent Review by MH on 3/29/2017

Client/Project
Joppa Power Station
Emergency Action Plan

Figure No.
1-2

Title
CCR Impoundment

Notes

1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Aerial Source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community2015 NAIP Imagery

Disclaimer: Stantec assumes no responsibility for data supplied in electronic format. The recipient accepts full responsibility for verifying the accuracy and completeness of the data. The recipient releases Stantec, its officers, employees, consultants and agents, from any and all claims arising in any way from the content or provision of the data.

V:\1735\temporary\users\nfisher\Work\Dynegy\Joppa\01.5_ccr_impoundments_fig1-2_20170322.mxd Revised: 2017-04-13 By: rbranch

R000667

2 COMMUNICATION

To facilitate understanding among everyone involved in implementing this EAP, four response levels are used to identify the condition of an impoundment. These are:

Response Levels:

- **Level 0:** Normal conditions and routine operations, including surveillance and initial investigation of unusual conditions and effects of storm events.
- **Level 1:** Potentially hazardous condition exists, requiring investigation and possible corrective action.
- **Level 2:** Potential failure situation is developing; possible mode of failure is being assessed; corrective measures are underway.
- **Level 3:** Failure is occurring or is imminent, public protective actions are required.

The 4-Step Incident Response Process is outlined in Figure 2-1. This should be used in conjunction with the Notification Flowchart (Figure 2-2) and EAP Decision Tree (Figure 2-3). Section 4 provides guidance tables for determining Response Levels and a table providing emergency actions to be taken given various situations. Table 2-1 lists contact information for the emergency responders.

Figure 2-1. Summary/Sequence of Tasks 4-Step Incident Response Process

Step 1: Detection, Evaluation, and Response Level Determination

Sequence of Tasks:

- Notify EAP Coordinator, Plant Manager, and Dam Safety Manager of unusual condition detected and confer on next steps needed.
- Conduct technical evaluation of conditions as needed.
- Determine Response Level based on evaluation. **(Table 4-1)**
- Reset Response Level as revised evaluations warrant.

Step 2: Notification

Sequence of Tasks:

- Notify authorities, designated personnel, and external response partners of change in Response Level, using the Notification Flowchart. **(Figure 2-2)**
- *Re-notify authorities, designated personnel, and external response partners as Response Level is changed*.

Step 3: Emergency Actions

Sequence of Tasks:

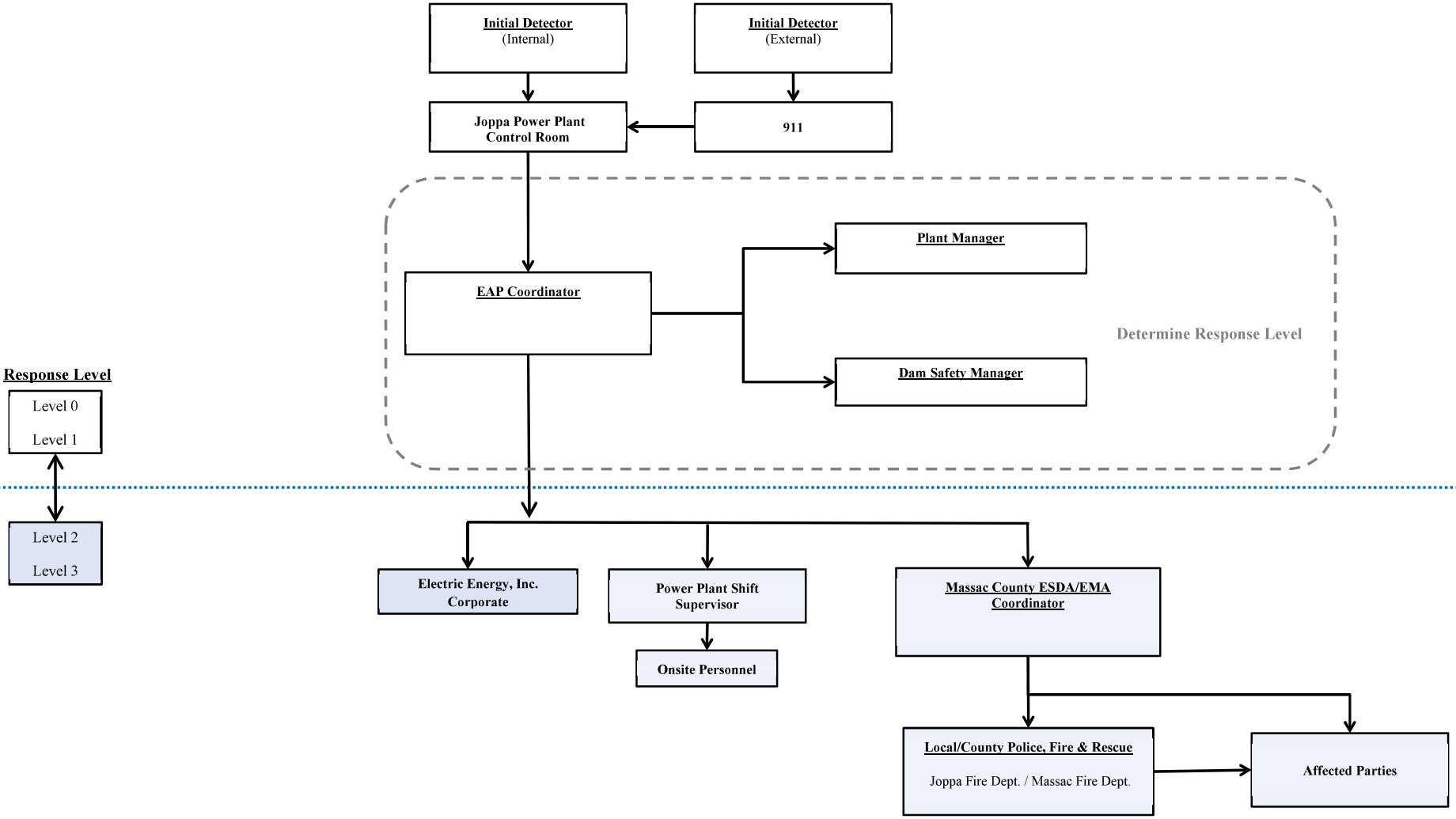
- Perform emergency actions with goal of saving the impoundment and minimizing impacts to life, property, and environment**. (Table 4-3)**
- Take continuous actions to include situation assessment, information sharing, remediation, and public safety advisories or warnings, as warranted.
- *Revise action plan as changes in conditions warrant*.

Step 4: Follow-up

Sequence of Tasks:

- Document conditions and decisions in the Emergency Incident Log.
- Notify authorities, designated personnel, and external response partners that condition is stabilized; limit incident termination declarations to conditions at the site.
- Conduct and document after-action review of incident and response.

Figure 2-2. Notification Flowchart



R000669

Figure 2-3. EAP Response Process Decision Tree

Note: At any given below, if failure is imminent or actively occurring **CALL 911 IMMEDIATELY** to notify emergency responders and then continue with process afterwards.

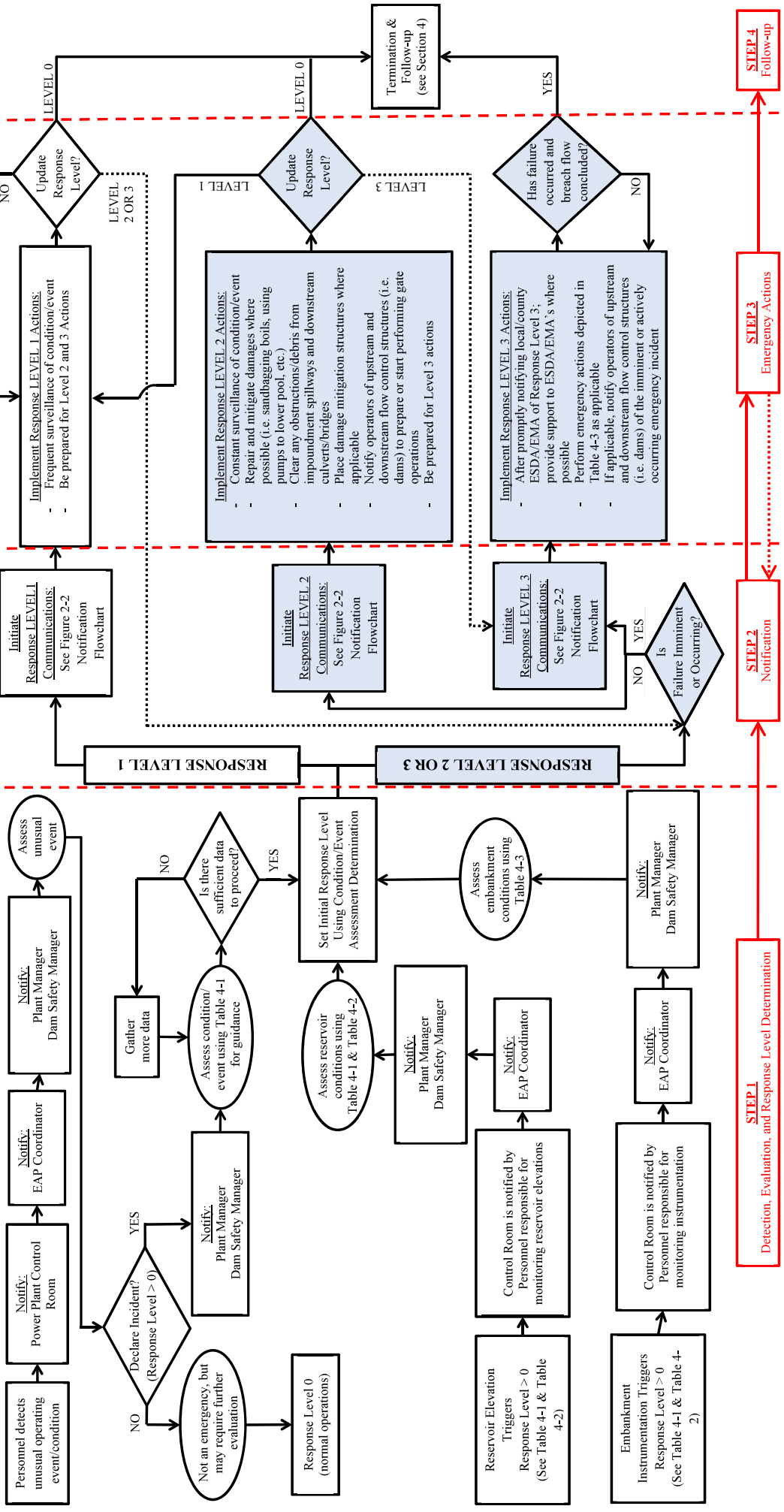


Table 2-1. EAP Emergency Responders

Position / Entity	Contact Information
Internal Contacts	
Joppa Power Plant	**Phone #**
Plant Manager	
EAP Coordinator	(618) 543-3458
Control Room	(618) 543-3301
Electric Energy, Inc. Corporate Operations	
Dam Safety Manager	(618) 792-8488
External Contacts	
Local/County ESDA/EMA, Police, & Fire	**Phone #**
Massac County ESDA/EMA Coordinator	(618) 524-2002
Massac County Sheriff Department	(618) 524-2912
Joppa Fire Department	(618) 543-7320
Massac County Fire Department	(618) 524-3200
State Emergency Management Agencies & Organizations	
IDNR-OWR Dam Safety Section Manager	(217) 782-4427
Illinois Conservation Police	(618) 638-6204
Illinois State Police	(309) 833-4046

3 EAP ROLES AND RESPONSIBILITIES

Table 3-1 provides a summary of the EAP roles during an emergency event.

Table 3-1. Summary of EAP Roles

Entity	Role Description
Emergency Response Team (ERT)	**ERT:** Personnel responsible for EAP implementation, distribution, updates/maintenance, and training activities. The *ERT* is comprised of the following roles; 1. **Corporate:** corporate entity, committee, team, or position with relevant responsibility for a given generating power plant. 2. **Plant Manager:** Personnel responsible for day-to-day operation and management of the Power Plant. 3. **Dam Safety Manager:** Personnel that is most knowledgeable about the design and technical operation of facilities at a given power plant. 4. **EAP Coordinator:** Personnel responsible for implementing the EAP and associated activities. **Emergency Event – EAP Responsibilities** 1. Respond to emergencies at the Power Plant. 2. Verify and assess emergency conditions. 3. Notify and coordinate as appropriate with participating emergency services disaster agencies or emergency management agencies (ESDA/EMA's), emergency responders, regulatory agencies, and all other entities involved or affected by this EAP. 4. Take corrective action at the Power Plant. 5. Declare termination of emergencies at the Power Plant.
Massac County ESDA/EMA	1. Receive Response Level reports from *Corporate* through *EAP Coordinator*. 2. Coordinate emergency response activities with local/county authorities: police, fire and rescue, etc. 3. Coordinate notification of public as necessary through established channels, which may include door-to-door contact. 4. Coordinate notification activities to affected parties within inundation areas. 5. Evaluate risk to areas beyond the inundation areas, communicate needs to the *Corporate* and/or *EAP Coordinator*, and coordinate aid as appropriate. 6. Responsible for declaring termination of an emergency condition off-site upon receiving notification of an emergency status termination from the *Corporate*. 7. If necessary, coordinate with *State ESDA/EMA*.
Local/County Police, Fire & Rescue	1. Receive alert status reports from the *ERT* or the Massac County *ESDA/EMA*. 2. If necessary, notify affected parties and general public within inundation areas (see Section 7). 3. Render assistance to Massac County *ESDA/EMA*, as necessary. 4. Render assistance to *Corporate*, and *Power Plant Management*, as necessary.

4 EAP RESPONSE

The 4-Step Incident Response Process is shown in Figure 2-1. The Decision Tree shown in Figure 2-3 provides a flowchart for the various elements of the response process. Upon reaching Step 4 of the response process (termination and follow-up), the EAP Coordinator is responsible for notifying the ESDA/EMA's that the condition of the dam/impoundment has been stabilized. The purpose of this section is to provide specific information that can be used during a response. This information is provided in the following tables:

- Table 4-1 provides guidance for determining the response level.
- Table 4-2 provide impoundment pool level trigger elevations.
- Table 4-3 lists emergency actions to be taken depending on the situation.

Table 4-1. Guidance for Determining the Response Level

Event	Situation	Response Level
Spillway flow (See Table 4-2 for relevant elevations)	Primary spillway flow is not causing active erosion and impoundment water surface elevation is below auxiliary spillway crest elevation (if equipped).	Level 0
	Impoundment water surface elevation is at or above auxiliary spillway crest elevation (if equipped). No active erosion caused by spillway flow.	Level 1
	Spillway flow actively causing minor erosion that is not threatening the control section or dam/impoundment stability.	Level 2
	Spillway flow that could result in flooding of people downstream if the reservoir level continues to rise.	Level 2
	Abnormal operation of the spillway system due to blockage or damage that could lead to flooding.	Level 2
	Spillway flow actively eroding the soil around the spillway that is threatening the control section (e.g. undermining) or dam/impoundment stability.	Level 3
	Spillway flow that is flooding people downstream.	Level 3
Embankment Overtopping (See Table 4-2 for relevant elevations)	Impoundment water surface elevation at or below typical normal pool fluctuation elevation.	Level 0
	Impoundment water surface elevation above typical high pool fluctuation elevation.	Level 1
	Impoundment water surface elevation within 2 feet of the embankment crest elevation.	Level 2
	Impoundment water surface elevation at or above embankment crest elevation.	Level 3
Seepage	New seepage areas in or near the dam/impoundment with clear flow.	Level 1
	New seepage areas with cloudy discharge or increasing flow rate.	Level 2
	Heavy seepage with active erosion, muddy flow, and/or sand boils.	Level 3
Sinkholes	Observation of new sinkhole in impoundment area or on embankment.	Level 2
	Rapidly enlarging sinkhole and/or whirlpool in the impoundment.	Level 3
	New cracks in the embankment greater than ¼ inch wide without seepage.	Level 1

Table 4-1. Guidance for Determining the Response Level

Event	Situation	Response Level
Embankment cracking	Any crack in the embankment with seepage.	Level 2
	Enlarging cracks with muddy seepage.	Level 3
Embankment movement	Visual signs of movement/slippage of the embankment slope.	Level 1
	Detectable active movement/slippage of the embankment slope or other related effects (tension cracking, bulges/heaves, etc.) that could threaten the integrity of the embankment.	Level 2
	Sudden or rapidly proceeding slides of the embankment slopes.	Level 3
Embankment Monitoring Equipment (piezometers, inclinometers, surface displacement mounts, etc.)	Instrumentation readings beyond historic normal.	Level 1
	Instrumentation readings indicate the embankment is susceptible to failure.	Level 2
	Instrumentation readings indicate embankment is at threshold of failure or is currently failing.	Leve 3
Earthquake or other event	Measurable earthquake felt or reported on or within 100 miles of the impoundment.	Level 1
	Earthquake or other event resulting in visible damage to the impoundment or appurtenances.	Level 2
	Earthquake or other event resulting in uncontrolled release of water or materials from the impoundment.	Level 3
Security threat	Verified bomb threat or other physical threat that, if carried out, could result in damage to the impoundment.	Level 2
	Detonated bomb or other physical damage that has resulted in damage to the impoundment or appurtenances.	Level 3
Sabotage/ vandalism	Damage to impoundment or appurtenance with no impact to the functioning of the impoundment.	Level 1
	Modification to the impoundment or appurtenances that could adversely impact the functioning of the impoundment. This would include unauthorized operation of spillway facilities.	Level 2
	Damage to impoundment or appurtenances that has resulted in seepage flow.	Level 2
	Damage to impoundment or appurtenances that has resulted in uncontrolled water release.	Level 3

Table 4-2. Impoundment Trigger Elevations

Impoundment	Embankment Crest Elevation	Auxiliary Spillway Crest Elevation	Normal Pool Fluctuation	
			Typical	High
Joppa East Ash Pond	380 ft.	N/A	374 ft.	377 ft.

Notes:
Estimated from DEM in GIS and USA Topo Map – Typical Embankment Crest Elevation – 380 ft

Table 4-3. Step 3: Emergency Actions

Condition	Description of Condition	Action to be Taken
High Water Level/ Large Spillway Release	See Table 4-1 and Table 4-2 for elevations and triggering water levels associated with the impoundments and spillways covered by this EAP.	1. Assess cause of increased reservoir stage, especially during fair weather conditions. 2. Determine Response Level. 3. Make proper notifications as outlined in the Figure 2-2 Notification Flowchart. 4. Perform additional tasks as determined through consultation with the ERT. 5. Make notifications if condition worsens such that downstream flooding is imminent. **Response Level 0**: require enhanced surveillance 3 times per day **Response Level 1**: contact internal chain of command and external response partners as necessary; inspect impoundment minimum 1 time per hour **Response Level 2**: contact internal chain of command; notify ESDA/EMA's and notify external response partners. ESDA/EMA's notify affected parties. **Response Level 3**: contact internal chain of command; notify ESDA/EMA's and notify external response partners. ESDA/EMA's notify affected parties of emergency incident.
Seepage	Localized new seepage or boil(s) observed along downstream face / toe of earthen embankment with muddy discharge and increasing but controllable discharge of water.	1. Measure and record feature dimensions, approximate flow rate, and relative location to existing surface features. Take photos. Document location on a site plan and in inspection notes. 2. Determine Response Level. 3. Make proper notifications as outlined in the Figure 2-2 Notification Flowchart. 4. ERT (with Dam Safety Manager as lead) to determine mitigation actions. The following actions may apply: a) Place a ring of sand bags with a weir at the top towards the natural drainage path to monitor flow rate. If boil becomes too large to sand bag, place a blanket filter over the area using non-woven filter fabric and pea gravel. Attempt to contain flow in such a manner (without performing any excavations) that flow rates can be measured. Stockpile gravel and sand fill for later use, if necessary. b) Inspect the embankment and collect piezometer, water level and seepage flow data daily unless otherwise instructed by the Dam Safety Manager. Record any changes of conditions. Carefully observe embankment for signs of depressions, seepage, sinkholes, cracking or movement.

Table 4-3. Step 3: Emergency Actions

Condition	Description of Condition	Action to be Taken
		c) Maintain continuous monitoring of feature. Record measured flow rate and any changes of condition, including presence or absence of muddy discharge. 5. Make notifications as outlined in the lower portion of the Notification Flowchart (Figure 2-2) if condition worsens such that failure is imminent.
Sabotage and Miscellaneous Other Issues	Criminal action with significant damage to embankment or structures where significant repairs are required and the integrity of the facility is compromised—condition appears stable with time.	1. Contact law enforcement authorities and restrict all access (except emergency responders) to impoundment. Restrict traffic on embankment crest to essential emergency operations only. 2. Determine Response Level. 3. Make internal notifications as outlined in the upper portion of the Notification Flowchart (Figure 2-2). 4. In conjunction with the Dam Safety Manager, assess extent of damage and visually inspect entire embankment and ancillary structures for additional less obvious damage. Based on inspection results, confirm if extent of damage to various components of the impoundment warrants a revised Response Level and additional notifications. 5. Perform additional tasks as directed by the ERT. 6. Make notifications if conditions worsen.
Embankment Deformation	**Cracks:** New longitudinal (along the embankment) or transverse (across the embankment) cracks more than 6 inches deep or more than 3 inches wide or increasing with time. New concave cracks on or near the embankment crest associated with slope movement.	1. Measure and record feature dimensions, approximate flow rate, and relative location to existing surface features. Take photos. Document location on a site plan and in inspection notes. 2. Restrict traffic on embankment crest to essential emergency operations only. 3. Determine Response Level. 4. Make notifications as outlined in the Figure 2-2 Notification Flowchart 5. ERT (with Dam Safety Manager as lead) to determine mitigation actions. The following actions may apply: a) Place buttress fill against base of slope immediately below surface feature. Stock pile additional fill. b) Place sand bags as necessary around crack area to divert any storm water runoff from flowing into crack(s). 6. As directed by the Dam Safety Manager, additional inspection and monitoring of the dam may be required. Items may include; inspect the dam on a schedule determined by the engineers; collect piezometer and water level data; and record any changes of condition. Carefully observe dam for signs of depressions, seepage, sinkholes, cracking or movement. 7. Make notifications as outlined in the Figure 2-2 Notification Flowchart if conditions worsen such that failure is imminent.
Embankment Deformation (cont.)	**Slides / Erosion:** Deep slide / erosion (greater than 2 feet deep) on the embankment that may also extend beyond the embankment toe but does not encroach onto the embankment crest and appears stable with time.	1. Measure and record feature dimensions, approximate flow rate, and relative location to existing surface features. Take photos. Document location on a site plan and in inspection report. 2. Restrict traffic on embankment crest to essential emergency operations only. 3. Determine the Response Level. 4. Make notifications as outlined in the Figure 2-2 Notification Flowchart. 5. ERT (with Dam Safety Manager as lead) to determine mitigation actions. Additional actions may include the following items. a) Place sand bags as necessary around slide area to divert any storm water runoff from flowing into slide(s). b) Increase inspections of the dam; collect piezometer and water level data; and record any changes of condition. During inspections,

Table 4-3. Step 3: Emergency Actions

Condition	Description of Condition	Action to be Taken
		carefully observe dam for signs of depressions, seepage, sinkholes, cracking or movement. 6. Make notifications as outlined in the Figure 2-2 Notification Flowchart if conditions worsen such that failure is imminent.
	Sinkholes: Small depression observed on the embankment or within 50 feet of the embankment toe that is less than 5 feet deep and 30 feet wide or which is increasing with time.	1. Slowly open drain gates to lower pool elevation. 2. Measure and record feature dimensions, approximate flow rate, and relative location to existing surface features. Take photos. Document location on a site plan and in inspection notes. 3. Restrict traffic on embankment crest to essential emergency operations only. 4. Determine Response Level. 5. Make notifications as outlined in the Figure 2-2 Notification Flowchart. 6. ERT (with Dam Safety Manager as lead) to determine mitigation actions. Additional actions may include the following items: a) Backfill the depression with relatively clean earth fill (free of organic materials) generally even with surrounding grade and slightly mounded (6 to 12 inches higher) in the center in order to shed storm water away from the depression. Stock pile additional fill. b) Increase inspections of the dam; collect piezometer and water level data daily unless otherwise instructed by engineer; and record any changes of condition. Carefully observe dam for signs of depressions, seepage, sinkholes, cracking or movement. 7. Make notifications as outlined in the Figure 2-2 Notification Flowchart if conditions worsen such that failure is imminent.
Gate Malfunction or Failure	Sluice gate damaged structurally (sabotage, debris, etc.) with uncontrolled release of water at a constant volume. Condition appears stable.	1. Close any other gates, if open. 2. Determine Response Level. 3. Make notifications as outlined in the Figure 2-2 Notification Flowchart. 4. Obtain instructions from the Engineer to determine if there are other methods to stop or slow down the flow of water. 5. If conditions worsen such that failure is imminent, make notifications as outlined in the lower portion of the Figure 2-2 Notification Flowchart.

5 PREPAREDNESS

The intent of this section is to provide information that will be utilized during a response. Established emergency supplies and locations, suppliers, and equipment are provided in Table 5-1.

A coordination meeting shall be conducted annually between representatives of the Electric Energy, Inc. and local emergency responders. This meeting may be in the form of a face-to-face meeting, tabletop exercise, or additional training regarding the EAP.

Table 5-1. Emergency Supplies and Equipment

Item	On-site (Yes/No/Occasionally)	Remarks
Flashlights	Yes	Contact Shift Supervisor for location(s).
Generator	Yes	Contact Shift Supervisor for location(s).
Extension Cords	Yes	Contact Shift Supervisor for location(s).
Fire extinguishers	Yes	Contact Shift Supervisor for location(s).
Floodlights	Yes	Contact Shift Supervisor for location(s).
Backhoe	Yes	Contact Shift Supervisor for location(s).
Dozer	Yes	Contact Shift Supervisor for location(s).
Large Equipment (Rental – including excavating equipment, pumps, lighting)	No	
Dump Truck	Yes	Contact Shift Supervisor for location(s).
Pump and Hoses	Yes	Contact Shift Supervisor for location(s).
Sandbags and Sand	Yes	Contact Shift Supervisor for location(s).
Fill (Stone, aggregate, sand)	Yes	Contact Shift Supervisor for location(s).
Concrete/grout	No	
Geotextile Filter Fabric	Yes	Contact Shift Supervisor for location(s).
Plastic Sheeting	No	
Rope	Yes	Contact Shift Supervisor for location(s).
Personal Flotation Devices	Yes	Contact Shift Supervisor for location(s).

6 FACILITY/IMPOUNDMENT DESCRIPTION

The impoundment included in this EAP is described as follows and illustrated in Figure 1-2. Table 6-1 contains additional geometric details for the impoundment.

The Joppa Power Plant is in Massac County, Illinois approximately 18 miles downstream of the confluence of the Tennessee River and the Ohio River. The plant is located on the northern bank of the Ohio River, adjacent to the village of Joppa. The East Ash Pond is located to the north of the main facility.

Joppa East Ash Pond has a surface area of approximately 103 acres with 32 acres holding water. The remaining area is filled with coal combustion residual materials. The maximum embankment height is approximately 45 feet. The crest of the pond is at approximate elevation 380 feet with a normal pool of approximately 374 feet. The East Ash Pond includes two subbasins, the north basin and south basin. There is a 24-inch corrugated metal pipe (CMP) through the central dike that connects the northern and southern subbasins to manage flow between the subbasins, which is not controlled. The southern subbasin's primary outlet structure is a 24-inch steel "T" structure connected to a 24-inch pipe that passes through the eastern embankment. The northern subbasin discharges through a 30-inch pipe that passes through the most northern embankment. Flow from the northern and southern subbasins ultimately discharge to an open channel then through a concrete culvert under Joppa Power Plant's coal-delivery railroad before discharging into the Ohio River 2,400 feet downstream of the railroad.

Table 6-1. Power Plant Impoundment Characteristics

Feature/Parameter	Joppa East Ash Pond
Maximum Embankment Height	45 ft.
Length of Dam	9100 ft.
Crest Width	10 ft.
Crest Elevation	380 ft.
Reservoir Area at Top of Dam	103 acres
Storage Capacity at Top of Dam	1077 acre-ft.
Primary Spillway Type	24” Steel “T” Structure
Primary Spillway Crest Elevation	N/A
Storage Capacity at Primary Spillway Elevation	N/A
Reservoir Area at Normal Water Surface Elevation	N/A
Auxiliary Spillway Type	N/A
Auxiliary Spillway Crest Elevation	N/A

Notes:
Estimated from DEM in GIS and USA Topo Map

7 BREACH INUNDATION MAP AND POTENTIAL IMPACTS

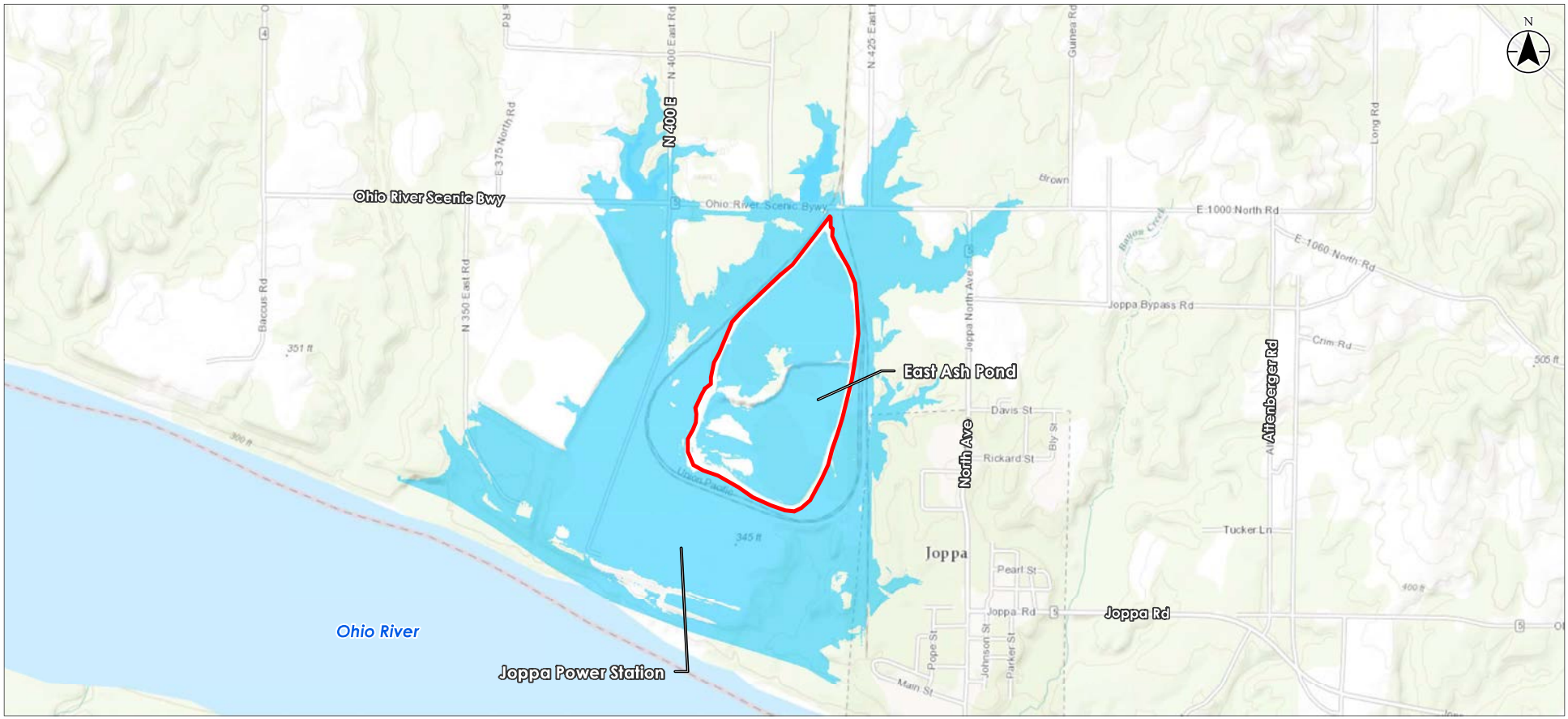
An inundation map for Joppa East Ash Pond potential breach scenarios is provided in this section. It is the Joppa / Massac County ESDA/EMA's responsibility to keep a current list of affected parties/properties to contact in the case of emergencies that result in Response Level 2 or 3. This list should encompass all properties within and adjacent to the probable inundation extents shown in the provided maps.

The methodology used to identify probable inundation extents for potential breach scenarios varied as a function of the impoundment size, location, surrounding topography, and surrounding structures/facilities/waterbodies.

For breach inundation mapping, the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS), version 5.0.1, computer program was used to perform hydraulic routing calculations. The HEC-RAS breach simulation was configured as an unsteady flood routing model. A two-dimensional flood routing model was selected for simulating potential breach impacts along the embankment of the East Ash Pond.

The breach scenario evaluated for the East Ash Pond was a piping breach during the Probable Maximum Precipitation (PMP) event. The East Ash Pond is perched and inflow from the storm events would consist of rainfall falling directly on the Pond. The freeboard for the Pond is greater than the PMP volume, therefore the pool elevation for the breach scenario was the normal pool plus the volume of the PMP event (38-inch depth across 103 AC footprint). Since the PMP event does not overtop the crest of the East Ash Pond, a piping breach was evaluated instead of an overtopping breach. Six breach locations were selected around the East Ash Pond. These locations include: one to the north, two breaches to the west, one breach to the south, and two breaches to the east. The total inundation extents were a combination of the six breach scenarios.

Approximate inundation area is illustrated in Figure 7-1.



Legend

- CCR Surface Impoundment Boundary
- Expected Breach Inundation Area

0 1,000 2,000 Feet

1:20,000 (At original document size of 11x17)

Stantec DYNEGY

Project Location
Latitude: 37.21438
Longitude: -88.85292
Massac County, Illinois

175605019
Prepared by RMGB on 3/29/2017
Technical Review by MM on 3/29/2017
Independent Review by MH on 3/29/2017

Client/Project
Joppa Power Station
Emergency Action Plan

Figure No.
7-1

Title
Inundation Map
East Ash Pond

Notes
1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Aerial Source: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User

Disclaimer: Stantec assumes no responsibility for data supplied in electronic format. The recipient accepts full responsibility for verifying the accuracy and completeness of the data. The recipient releases Stantec, its officers, employees, consultants and agents, from any and all claims arising in any way from the content or provision of the data.

X:\1735\Temporary Users\Websites\Work Dynegy\Joppa\GIS\Inundation_Mxd\Fig-1a_20170323.mxd Revised: 2017-04-13 By: rbranch

R000682

ATTACHMENT G

October 2021

CCR Fugitive Dust Control Plan

for

Joppa Power Plant

Prepared for:

Electric Energy, Inc.

Joppa Power Plant
2100 Portland Road
Joppa, IL 62953

Prepared by:

Burns & McDonnell
Kansas City, Missouri

Amendment 1

October 2021

Table of Contents

1 Introduction 1-1
1.1 Facility Information 1-1
1.2 Certification 1-1
2 CCR Fugitive Dust Control Measures and Appropriateness 2-1
2.1 Management of CCR in the CCR Units 2-1
2.2 Handling of CCR 2-2
2.2.1 Conditioning of CCR Prior to Emplacement in CCR Landfill 2-3
2.3 Transportation of CCR 2-4
3 Procedures for Periodic Assessment of the Plan 3-1
4 Recordkeeping, Notification, Internet Site 4-1
5 Procedures to Log Citizen Complaints 5-1
6 Amendments 6-1

List of Tables

Table 2-1. Control Measures for CCR Management in CCR Units 2-1
Table 2-2. Control Measures for Handling CCR 2-2
Table 2-3. Control Measures for Transportation of CCR 2-4
Table 6-1. CCR Fugitive Dust Control Plan Amendments 6-1

1 Introduction

This Coal Combustion Residuals (CCR) fugitive dust control plan has been prepared for the Joppa Power Plant, located in Massac County, Illinois. This plan addresses the air criteria in 40 C.F.R. § 257.80 of the United States Environmental Protection Agency's CCR rule, which requires the owner or operator of a CCR unit to "adopt measures that will effectively minimize CCR from becoming airborne at the facility" and to "prepare and operate in accordance with a CCR fugitive dust control plan." The plan also addresses the air criteria in 35 I.A.C. 845.500 of the Illinois Environmental Protection Agency's CCR rule, which contains similar requirements to the federal CCR rule.

1.1 Facility Information

- Facility Name: Joppa Power Plant
- Facility Address: 2100 Portland Road, Joppa, IL 62953
- Owner/Operator: Electric Energy, Inc.
    - Met-South, Inc., a wholly owned subsidiary of Electric Energy, Inc., operates the facility's Landfill and Fly Ash Handling Operations

1.2 Certification

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 40 C.F.R. § 257.80 and 35 I.A.C. 845.500. See 40 C.F.R. § 257.80(b)(7); 35 I.A.C. 845.500(b)(7).

I certify under penalty of law that, to the best of my knowledge, this plan meets the requirements of 40 C.F.R. § 257.80 and 35 I.A.C. 845.500. This certification is based on my review of the document and conditions at the site and on my inquiry of the person or persons who managed the preparation of this document.

John R. Hesemann
Printed Name of Qualified Professional Engineer

John R. Hesemann 9/09/2021
Signature of Qualified Professional Engineer and Date

062.058523 – Illinois – Expires 11/30/2021
Registration Number and State

2 CCR Fugitive Dust Control Measures and Appropriateness

CCR fugitive dust has the potential to become airborne at the facility during periods of CCR management in the CCR units, CCR handling and CCR transport. Areas at the facility that have the potential for airborne CCR fugitive dust are CCR surface impoundments, an existing CCR landfill, CCR handling equipment and CCR transport in trucks. The CCR landfill has not yet received CCR. This section identifies and describes the control measures selected and adopted by the facility to minimize CCR from becoming airborne at the facility and explains how the selected measures are applicable and appropriate for site conditions. The control measures may be adjusted or modified based on observed effectiveness of minimizing CCR from becoming airborne and weather conditions.

2.1 Management of CCR in the CCR Units

The facility currently manages CCR in surface impoundments. The facility also will manage CCR in its landfill once the landfill begins receiving CCR. Table 2-1 below identifies CCR fugitive dust control measures that have been selected for use by the facility during CCR management in the CCR units, including placement of CCR into the CCR unit, and explains how the selected measures are applicable and appropriate for site conditions. The facility will use the identified measures during CCR management in the CCR units to minimize CCR from becoming airborne at the facility.

CCR Activity	CCR Fugitive Dust Control Measure	Applicability and Appropriateness of Control Measure
Management of CCR in the facility's CCR units	Condition CCR to be emplaced in the landfill as needed before loading into vehicles for transport to the landfill.	Conditioning CCR to be placed in the landfill allows CCR to bind together and thus minimizes the potential for CCR fugitive dust generation when CCR is managed in the landfill. The added moisture content will prevent wind dispersal of the CCR but will not result in free liquids. Use of conditioned CCR also achieves at least equivalent performance to conventional daily cover in terms of preventing wind entrainment.
	Wet management of CCR in CCR surface impoundments.	Wet management of CCR minimizes the potential for CCR fugitive dust generation.
	Water areas of exposed CCR in CCR units, as necessary.	Water will be applied to areas of exposed CCR to maintain moisture content to minimize the potential for CCR fugitive dust generation in excessively dry or windy conditions. Wetting activities will not generate "free liquids" within the landfill.
	Naturally occurring grass vegetation in areas of exposed CCR in CCR surface impoundments.	Vegetation provides a wind screen and/or cover and reduces wind entrainment of CCR.
	Apply chemical dust suppressant on areas of exposed CCR in CCR units, as necessary.	Mixing an appropriate chemical dust suppressant with water and applying to areas of exposed CCR will minimize the potential for CCR fugitive dust generation in excessively dry or windy conditions.
	Reduce or halt operations during high wind events, as necessary.	Reducing or halting operations during high wind events minimizes the potential for CCR fugitive dust generation.

Table 2-1. Control Measures for CCR Management in CCR Units

2.2 Handling of CCR

CCR is regularly removed from the boiler system and conveyed to the CCR handling system, which includes silos and truck loading areas. CCR fly ash is pneumatically conveyed in an enclosed system from the boiler system to storage silos. When unloading the CCR fly ash silos for transport to and emplacement in the surface impoundments, a pug mill is used to condition the CCR fly ash as it is loaded into trucks. The pug mill will be used to condition CCR fly ash as it is loaded into trucks for transport to and emplacement in the landfill. Dry fly ash can also be unloaded dry into trucks using a telescoping chute. CCR bottom ash is wet sluiced into CCR surface impoundments. Fly ash from another Vistra facility is also unloaded from trucks into silos contained with bin vent filters. Bottom ash is periodically removed from the CCR surface impoundments and remains sufficiently wet during and after handling activities, including dewatering, associated with transfer of the CCR. Table 2-2 below identifies CCR fugitive dust control measures that have been selected for use by the facility during handling of CCR and explains how the selected measures are applicable and appropriate for site conditions. The facility will use the identified measures when handling CCR to minimize CCR from becoming airborne at the facility.

CCR Activity	CCR Fugitive Dust Control Measure	Applicability and Appropriateness of Control Measure
Handling of CCR at the facility	Wet sluice CCR bottom ash to CCR surface impoundments.	Wet sluicing CCR minimizes the potential for CCR fugitive dust generation.
	CCR bottom ash removed from CCR surface impoundments and loaded into trucks for transport remains conditioned during handling.	Conditioned CCR allows CCR to bind together and thus minimizes the potential for CCR fugitive dust generation when CCR is handled.
	Pneumatically convey dry CCR fly ash to storage silos in an enclosed system.	Conveying CCR fly ash in an enclosed system minimizes the potential for CCR fugitive dust generation.
	Condition CCR fly ash to be emplaced in the landfill before loading into trucks for transport to the landfill, as needed.	Conditioning allows CCR to bind together and thus minimizes the potential for CCR fugitive dust generation while loading CCR into trucks (and during transport and emplacement in the landfill).
	Condition CCR fly ash to be placed in the surface impoundments before loading into trucks for transport to the surface impoundments.	Conditioning allows CCR to bind together and thus minimizes the potential for CCR fugitive dust generation while loading CCR into trucks (and during transport and placement in the surface impoundments).
	Load CCR dry fly ash to transport trucks from the CCR fly ash silos using a chute or telescoping chute, when applicable.	Use of a chute, specifically a telescoping chute reduces the drop height from the end of the chute into the truck and minimizes the potential for CCR fugitive dust to become airborne.
	Perform housekeeping, as necessary, in the fly ash loading area.	Good housekeeping measures, such as sweeping or wetting the loading area, minimizes the potential for CCR fugitive dust generation during handling activities.
	Operate fly ash handling system in accordance with good operating practices.	Operation in accordance with good operating practices minimizes the potential for CCR fugitive dust generation.
	Maintain and repair as necessary dust controls on the fly ash handling and truck load-out systems.	Perform maintenance and repairs as needed to maintain dust controls in good operating condition minimizes the potential for CCR fugitive dust generation.
	Reduce or halt operations during high wind events, as necessary.	Reducing or halting operations during high wind events minimizes the potential for CCR fugitive dust generation.

Table 2-2. Control Measures for Handling CCR

2.2.1 Conditioning of CCR Prior to Emplacement in CCR Landfill

Conditioned CCR is CCR that has been wetted with water or an appropriate chemical dust suppressant. Water or a chemical dust suppressant is added to raise the moisture content of the CCR to prevent wind dispersal but will not result in free liquids. Conditioning allows for the CCR to bind together, which minimizes the potential for CCR fugitive dust. All CCR generated on site that is placed into the facility's landfill will be conditioned in a pug mill or otherwise conditioned prior to loading into trucks for transport to the landfill. Therefore, all CCR that is added to the facility's landfill will be conditioned CCR.

2.3 Transportation of CCR

CCR is transported via truck at the facility using a combination of paved and unpaved facility roads. Table 2-3 below identifies CCR fugitive dust control measures that have been selected for use by the facility during transport of CCR. The facility will use the identified measures when transporting CCR to minimize CCR from becoming airborne at the facility.

CCR Activity	CCR Fugitive Dust Control Measure	Applicability and Appropriateness of Control Measure
Transportation of CCR at the facility	Condition CCR to be emplaced in the landfill before it is loaded into vehicles for transport to the landfill.	Conditioning CCR increases moisture content of the CCR and minimizes the potential for CCR fugitive dust generation during CCR transport (and emplacement in the landfill).
	Condition CCR fly ash to be placed in the surface impoundments before loading into trucks for transport to the surface impoundments	Conditioning CCR increases moisture content of the CCR and minimizes the potential for CCR fugitive dust generation during CCR transport (and placement in the surface impoundments).
	Cover or enclose trucks used to transport CCR onsite, as necessary.	Covering or enclosing trucks transporting CCR minimizes the potential for CCR fugitive dust generation from the CCR transport trucks.
	Limit the speed of vehicles to no more than 15 mph on facility roads.	Limiting the speed of vehicles traveling on facility roads minimizes the potential for CCR fugitive dust generation from the CCR transport trucks.
	Sweep or rinse CCR off of the outside of the trucks transporting CCR, as necessary.	Removing CCR present on the outside of the truck minimizes the potential for movement of the truck or wind to cause CCR fugitive dust to become airborne.
	Cover or enclose trucks used to transport CCR offsite.	Covering or enclosing trucks transporting CCR minimizes the potential for CCR fugitive dust generation from the CCR transport trucks.
	Condition CCR materials to be transported offsite before they are loaded into trucks, as necessary.	Conditioning CCR increases moisture content of the CCR and minimizes the potential for CCR fugitive dust generation during CCR transport.
	Condition CCR haul roads with water or dust suppressant, as necessary.	Watering CCR haul roads will minimize the potential for CCR fugitive dust generation in excessively dry or windy conditions.
	Remove CCR deposited on facility road surfaces during transport as necessary.	Removing CCR deposited on facility road surfaces as a result of transport minimizes the potential for CCR fugitive dust generation from vehicle traffic.
	Reduce or halt operations during high wind events, as necessary.	Reducing or halting operations during high wind events minimizes the potential for CCR fugitive dust generation.

Table 2-3. Control Measures for Transportation of CCR

3 Procedures for Periodic Assessment of Effectiveness of the Plan

The facility conducts inspections associated with CCR fugitive dust control. The facility also uses the procedures identified in section 5 of this plan to log every citizen complaint involving CCR fugitive dust events at the facility. These inspections and the investigations of citizen complaints will be used to periodically assess the effectiveness of the CCR fugitive dust control plan per 40 C.F.R. § 257.80(b)(4) and 35 I.A.C. 845.500(b)(3).

The facility routinely performs inspections to verify the effectiveness of the CCR fugitive dust control measures used at the facility. Inspections are conducted during daylight working hours and include observing for the presence of CCR fugitive dust emissions from vehicles transporting CCR on facility roads, CCR handling and CCR management activities, including CCR placement in CCR units. Inspection records include information such as the name of the person conducting the inspection, the date and time of the inspection, the results of the inspection, and any corrective action taken.

When a CCR fugitive dust event is observed or a citizen complaint involving a CCR fugitive dust event at the facility is received, current CCR management practices will be reviewed to see that the selected control measures are being properly implemented. If the control measures are not being properly implemented, relevant operating personnel will be notified and, as warranted, re-trained in the proper implementation of CCR fugitive dust control measures. If appropriate, use of revised and/or additional control measures will be evaluated. As warranted, revised and/or additional control measures found to be applicable and appropriate to control CCR fugitive dust emissions will be incorporated into an amended CCR fugitive dust control plan.

The plan also will be reassessed in the event of material changes in site conditions potentially resulting in CCR fugitive dust becoming airborne at the facility.

4 Recordkeeping, Notification, Internet Site

The written CCR fugitive dust control plan, any amendment of the written plan, and the annual CCR fugitive dust control report required by 40 C.F.R. § 257.80(c) and 35 I.A.C. 845.500(c) will be placed in the facility's written operating record and posted to the company's CCR website in accordance with 40 C.F.R. § 257.105(g), § 257.107(g) and 845.800(d)(7), (14) and 845.810(e). Notification of the availability of the CCR fugitive dust control plan, any amendment of the plan, and the annual CCR fugitive dust control report will be provided to IEPA in accordance with 40 C.F.R. § 257.106(g). Any amendment of the fugitive dust control plan will be submitted to IEPA in accordance with 845.500(b)(5).

Additionally, pursuant to 845.500(b)(6), this fugitive dust control plan is being placed in facility's operating record and posted to the company's CCR website prior to the submission of any permits for the Joppa Power Plant.

5 Procedures to Log Citizen Complaints

In the event the owner or operator of the facility receives a citizen complaint involving a CCR fugitive dust event at the facility, relevant information about the complaint will be logged. Information that will be recorded includes, as applicable:

- Date/Time the complaint is received
- Date/Time and duration of the CCR fugitive dust event
- Description of the nature of the CCR fugitive dust event
- Name of the citizen entering the complaint
- Address & phone number of citizen entering the complaint
- Name of the personnel who took the complaint
- All actions taken to assess and resolve the complaint

All citizen complaints involving CCR fugitive dust events at the facility will be investigated promptly. As deemed appropriate or necessary, corrective measures will be taken and a follow-up response will be provided to the complainant.

Pursuant to 35 I.A.C. 845.500(b)(2), quarterly reports will be submitted to IEPA no later than 14 days from the end of the quarter for all complaints received in that quarter. At a minimum, the quarterly report will include 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.

6 Amendments

The written CCR fugitive dust control plan may be amended at any time provided the revised plan is placed in the facility's operating record as required by 40 C.F.R. § 257.105(g)(1) and 845.500(b)(6). Any amendment of the fugitive dust control plan will be submitted to IEPA in accordance with 845.500(b)(5). The written CCR fugitive dust control plan must be amended whenever there is a change in conditions that would substantially affect the written plan in effect.

Amendment Number and Date	Pages or Section	Description of Amendment	Professional Engineer Certifying Plan
Version 0 October 2015	--	Initial Plan	Wendy M. Pennington
Amendment 1 October 2021	Various	Administrative Changes and adjustments to site condition controls as appropriate	John R. Hesemann

Table 6-1. CCR Fugitive Dust Control Plan Amendments

ATTACHMENT H

October 2021

Intended for
Electric Energy, Inc.

Date
October 25, 2021

Project No.
1940100806-006

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT

EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT EAST ASH POND

Project Name	**Joppa Power Plant East Ash Pond**
Project No.	**1940100806-006**
Recipient	**Electric Energy, Inc.**
Document Type	**Hydrogeologic Site Characterization Report**
Revision	**FINAL**
Date	**October 25, 2021**

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com

Nicole M. Pagano, PG
Senior Managing Engineer

Brian G. Hennings, PG
Senior Managing Hydrogeologist

Rachel A. Banoff, EIT
Environmental Engineer

Nathaniel R. Keller
Senior Hydrogeologist

CONTENTS

Executive Summary		**6**
1.	**Introduction**	**11**
1.1	Overview	11
1.2	Part 845 Description	11
1.3	Previous Investigations and Reports	11
1.4	Site Location and Background	13
1.5	Site History	13
2.	**Regional and Site Geology**	**14**
2.1	Topography	14
2.2	Regional Geomorphology	14
2.3	Soils	14
2.4	Regional Geology	15
2.4.1	Unlithified Materials	15
2.4.2	Bedrock	16
2.4.3	Structure	16
2.4.4	Seismic Setting	17
2.4.5	Mining Activities	17
2.4.6	Industrial Activities	17
2.5	Site Geology	18
2.5.1	Site Specific Unlithified Geology	18
2.5.1.1	Fill and CCR	18
2.5.1.2	Equality Formation	19
2.5.1.3	Peoria Silt / Roxana Silt / Loveland Silt	19
2.5.1.4	Metropolis Formation	19
2.5.1.5	McNairy Formation	20
2.5.2	Site Specific Bedrock Geology	21
3.	**Regional and Local Hydrogeology**	**22**
3.1	Regional Hydrogeology	22
3.1.1	Unlithified Deposits Hydrogeology	22
3.1.2	Bedrock Hydrogeology	22
3.2	Site Hydrogeology	23
3.2.1	Hydrostratigraphic Units	23
3.2.2	Uppermost Aquifer	24
3.2.3	Potential Migration Pathways	24
3.2.4	Water Table Elevation and Groundwater Flow	24
3.2.4.1	Vertical Hydraulic Gradients	25
3.2.4.2	Impact of Existing Ponds and Ash Saturation	25
3.2.4.3	Impact of Surface Water Bodies	26
3.2.5	Hydraulic Conductivity	26
3.2.5.1	Field Hydraulic Conductivity	26
3.2.5.2	Laboratory Hydraulic Conductivity	26
3.2.6	Horizontal Groundwater Gradients and Groundwater Flow Velocity	27
3.2.7	Groundwater Classification	27
3.3	Surface Water Hydrology	27
3.3.1	Climate	27

3.3.2	Surface Waters	28
4.	**Groundwater Quality**	**30**
4.1	Summary of Groundwater Monitoring Activities	30
4.1.1	40 C.F.R. § 257 Program Monitoring and Well Network	30
4.1.2	Part 845 Well Installation and Groundwater Monitoring	30
4.2	East Ash Pond Groundwater Monitoring Results and Analysis	31
4.2.1	Boron	31
4.2.2	Cobalt	32
4.2.3	pH	32
4.2.4	Radium 226 and 228 Combined	32
4.2.5	Sulfate	32
4.2.6	Thallium	33
5.	**Evaluation of Potential Receptors**	**34**
5.1	Water Well Survey	34
5.2	Surface Water	35
5.3	Nature Preserves, Historic Sites, Endangered/Threatened Species	35
6.	**Conclusions and Conceptual Site Model**	**37**
7.	**References**	**39**

TABLES (IN TEXT)

Table A Average Monthly Temperature Extremes and Precipitation for Dixon Springs, Illinois
Table B 40 C.F.R. § 257 Groundwater Monitoring Program Parameters
Table C Part 845 Groundwater Monitoring Program Parameters

TABLES (ATTACHED)

Table ES-1 Part 845 Requirements Checklist
Table 2-1 Geotechnical Results
Table 2-2 Ash Analytical Results
Table 2-3 Porewater Analytical Results
Table 2-4 Soil Analytical Results
Table 3-1 Monitoring Well Locations and Construction Details
Table 3-2 Vertical Hydraulic Gradients
Table 3-3 Field Hydraulic Conductivities
Table 3-4 Horizontal Hydraulic Gradients and Groundwater Flow Velocities
Table 4-1 Groundwater Analytical Results
Table 4-2 Groundwater Field Parameter Results

FIGURES (IN TEXT)

Figure A Daily Gage Height (feet) June 1, 2020 to June 1, 2021 for USGS Gaging Station 03612600 at the Ohio River at Olmsted, Illinois.

FIGURES (ATTACHED)

Figure 1-1 Site Location Map
Figure 1-2 Site Map
Figure 2-1 Site Topographic Map
Figure 2-2 Soil Survey Map

Figure 2-3 Surficial Geologic Deposits
Figure 2-4 Generalized Stratigraphic Column for the Joppa Area
Figure 2-5 Major Structural Features of Joppa Quadrangle
Figure 2-6 Field Investigation Locations
Figure 2-7 Geologic Cross Sections A-A'
Figure 2-8 Geologic Cross Sections B-B' & C-C'
Figure 3-1 Monitoring Well Location Map
Figure 3-2 Top of Uppermost Aquifer
Figure 3-3 Uppermost Aquifer Groundwater Elevation Contours, March 3 and 4, 2021
Figure 3-4 Uppermost Aquifer Groundwater Elevation Contours, April 13 and 14, 2021
Figure 3-5 Uppermost Aquifer Groundwater Elevation Contours, May 11 and 12, 2021

APPENDICES

Appendix A Historical Topographic Map (1967)
Appendix B Boring and Well Construction Logs
Appendix C Geotechnical Laboratory Reports
Appendix D Information Pertinent to 35 I.A.C. § 845.220(a)(3)
Appendix E Groundwater Contour Maps and Elevations
Appendix F Hydraulic Conductivity Test Data
Appendix G FEMA Flood Hazard Map

ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
40 C.F.R.	Title 40 of the Code of Federal Regulations
bgs	below ground surface
CCR	coal combustion residuals
cm/s	centimeters per second
CPT	cone penetrometer test
CSM	conceptual site model
DWW	IEPA Illinois Drinking Water Watch
EAP	East Ash Pond
ESRI	Environmental Systems Research Institute
Federal CCR Rule	40 C.F.R. § 257 Subpart D
FEMA	Federal Emergency Management Agency
ft/day	feet per day
ft/ft	feet per feet
g	horizontal acceleration
GMP	Groundwater Monitoring Plan
GWPS	groundwater protection standard
Hanson	Hanson Professional Services, Inc.
HCR	Hydrogeologic Site Characterization Report
HMP	Hydrogeologic Monitoring Plan
HUC	Hydrologic Unit Code
ID	identification
IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
ILMINES	Illinois Coal Mines
ILWATER	ISGS Illinois Water and Related Wells
ISAS	Illinois State Archaeological Survey
ISGS	Illinois State Geological Survey
ISWS	Illinois State Water Survey
JPP	Joppa Power Plant
LAU	lower aquifer unit
LCU	lower confining unit
mg/L	milligrams per liter
NAVD27	North American Vertical Datum of 1927
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NGWMN	USGS National Groundwater Monitoring Network
NID	National Inventory of Dams
No.	Number
NRT	Natural Resource Technology, Inc.

NRT/OBG	Natural Resource Technology, Inc., an OBG Company
OBG	O'Brien and Gere Engineers, Inc.
Part 845	Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
pcf	pounds per cubic foot
pCi/L	picoCuries per liter
PMP	potential migration pathway
PWS	public water system
Ramboll	Ramboll Americas Engineering Solutions, Inc.
RCRA	Resource Conservation and Recovery Act of 1976
SDWIS	USEPA Safe Drinking Water Information System
SI	surface impoundment
Site	East Ash Pond
SSURGO	Soil Survey Geographic database
SU	Standard Unit
TDS	total dissolved solids
UCU	upper confining unit
USCS	Unified Soil Classification System
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Services
USGS	United States Geological Survey

EXECUTIVE SUMMARY

This Hydrogeologic Site Characterization Report (HCR) for the East Ash Pond (EAP) expands upon the hydrogeology, groundwater quality data, and conceptual site model (CSM) in previous hydrogeologic investigation reports prepared for the EAP. This report has been assembled to satisfy the information and analysis requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.620 as summarized in **Table ES-1**. The CSM includes hydrogeologic and groundwater quality data specific to the EAP, which has been collected between 2015 and 2021.

The Joppa Power Plant (JPP) property is situated in an industrial/agricultural area, bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north, the Village of Joppa to the east, and the Ohio River to the south. Two coal combustion residuals (CCR) Units are present on the JPP property including the EAP (Vistra identification [ID] number [No.] 401, Illinois Environmental Protection Agency [IEPA] ID No. W1270100004-02, and National Inventory of Dams [NID] No. IL50714), and Landfill (Vistra ID No. 402). In addition, there is a former CCR disposal area, Joppa West, (Vistra ID No. 403, IEPA ID No. W1270100004-01) located west of the EAP. The EAP is located in the west half of Section 14, directly north of the JPP and is bounded immediately to the east by the railway right-of-way, which is adjacent to forested portions of residential property in the Village of Joppa.

In addition to the CCR present in the EAP, there are five layers of unlithified material present above the bedrock, which were categorized into three hydrostratigraphic units in this report. Underlying the constructed CCR unit, the four (including bedrock) hydrostratigraphic units in descending order are:

- **Upper Confining Unit (UCU):** Low permeability silt and clay of the Equality Formation, silts of the Peoria/Roxana/Loveland, and clay and silt of the Metropolis Formation are considered the UCU. This unit was encountered in all borings advanced on site and limits the vertical migration of CCR impacts into the uppermost aquifer.
- **Uppermost Aquifer:** High permeability sands with gravel, silt, and clay lenses of the Upper McNairy Formation. The uppermost aquifer was encountered at elevations ranging from 222.6 to 318.6 feet North American Vertical Datum of 1988 (NAVD88).
- **Lower Confining Unit (LCU):** Clay and silt of the Lower McNairy Formation that was encountered in all borings advanced to bedrock. Based on material description, continuous lateral extent, and observed vertical gradients, this unit is identified as the LCU.
- **Lower Aquifer Unit (LAU):** Lowermost unit identified at the site and underlies all unlithified deposits. This unit is comprised of the Salem Limestone, which is the uppermost lithified unit at the Site, and used as a potable and non-potable water supply in the vicinity of the JPP.

Groundwater flow direction and gradients have not changed significantly since the first hydrogeologic study of the EAP was completed in 2009, and recent data support the existing CSM, which has been refined to incorporate additional data as follows:

- Groundwater migrates downward through the UCU which is composed of the Equality Formation, Silt Unit, and Metropolis Formation into the uppermost aquifer.
- Groundwater migrates within high permeability sands and gravels of the McNairy Formation which comprise the uppermost aquifer generally south towards the Ohio River.

- Vertical gradients measured between the LAU and the uppermost aquifer indicate upward migration of groundwater from the LAU to the uppermost aquifer and into the Ohio River.

Part 845 parameters were monitored in the uppermost aquifer and LAU monitoring wells at the EAP as part of the groundwater quality investigations performed between 2015 and 2018. These data were supplemented with installation and sampling of additional locations installed in 2021. The results indicate that the following parameters were greater than the applicable 35 I.A.C. § 845.600 groundwater protection standards (GWPSs) and are considered potential exceedances:

- Boron - at five uppermost aquifer wells G06, G07, G08, G09, and G10
- Cobalt - at thirteen uppermost aquifer wells (G01D, G03, G05, G06S, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D), and at LAU well G09M
- pH – at two UCU wells (G54S and G151), and at thirteen uppermost aquifer wells (G01D, G02D, G03, G05, G06S, G07, G09, G10, G11, G51D, G52D, G53D, and G54D)
- Radium 226 and 228 combined – at uppermost aquifer well G02D
- Sulfate - at two uppermost aquifer wells G10 and G11
- Thallium – at uppermost aquifer wells G05 and G11

Concentration results for the above parameters were compared directly to 35 I.A.C. § 845.600 GWPSs to determine potential exceedances. Potential exceedances include results reported during the background groundwater monitoring or prior period that are greater than the GWPS. The results are considered potential exceedances because the results were compared directly to the standard and did not include an evaluation of background groundwater quality or the statistical methodologies proposed in the groundwater monitoring plan (GMP) provided in the Operating Permit application. Exceedances will be determined following IEPA approval of the GMP.

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Part 845 Reference	Individual Part 845 Components Reviewed for Completeness	Location of Information in HCR
845.620(b)	**The hydrogeologic site characterization shall include but not be limited to the following:**	--
845.620(b)(1)	Geologic well logs/boring logs;	Table 3-1 Figure 3-1 Appendix B
845.620(b)(2)	Climatic aspects of the site, including seasonal and temporal fluctuations in groundwater flow;	Sections 3.2.4.3 & 3.3.1 Figures 3-3, 3-4 & 3-5
845.620(b)(3)	Identification of nearby surface water bodies and drinking water intakes;	Sections 3.3.2 & 5.2 Appendix D
845.620(b)(4)	Identification of nearby pumping wells and associated uses of the groundwater;	Section 5.1 Appendix D
845.620(b)(5)	Identification of nearby dedicated nature preserves;	Section 5.3 Appendix D
845.620(b)(6)	Geologic setting;	Sections 2.4 & 2.5 Figures 2-3 & 2-4
845.620(b)(7)	Structural characteristics;	Section 2.4.3 Figure 2-5
845.620(b)(8)	Geologic cross-sections;	Figures 2-8 through 2-10
845.620(b)(9)	Soil characteristics;	Section 2.3 Figure 2-2
845.620(b)(10)	Identification of confining layers;	Section 3.2.1

RAMBOLL
R000705

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Part 845 Reference	Individual Part 845 Components Reviewed for Completeness	Location of Information in HCR
845.620(b)(11)	Identification of potential migration pathways;	Sections 3.2.1 & 3.2.3
845.620(b)(12)	Groundwater quality data;	Section 4.2 Table 4-1
845.620(b)(13)	Vertical and horizontal extent of the geologic layers to a minimum depth of 100 feet below land surface, including lithology and stratigraphy;	Section 2.5 Figures 2-8 through 2-10 Appendix B
845.620(b)(14)	A map displaying any known underground mines beneath a CCR surface impoundment;	Section 2.4.5 Appendix D
845.620(b)(15)	Chemical and physical properties of the geologic layers to a minimum depth of 100 feet below land surface;	Sections 2.5 & 3.2.1 Tables 2-1, 2-2 & 2-4 Appendix C
845.620(b)(16)	Hydraulic characteristics of the geologic layers identified as migration pathways and geologic layers that limit migration, including:	Section 3.2.3 Tables 3-2, 3-3 & 3-4 Appendices B, C & F
845.620(b)(16)(A)	water table depth;	Section 3.2.4 Table 4-2 Figures 3-3, 3-4 & 3-5
845.620(b)(16)(B)	hydraulic conductivities;	Section 3.2.5 Tables 2-1 and 3-3 Appendices C & F
845.620(b)(16)(C)	effective and total porosities;	Section 2.5.1 Table 2-1 Appendix C
845.620(b)(16)(D)	direction and velocity of groundwater flow; and	Sections 3.2.4 & 3.2.6 Tables 3-2, 3-3 & 3-4 Figures 3-3, 3-4 & 3-5

RAMBOLL
R000706

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Part 845 Reference	Individual Part 845 Components Reviewed for Completeness	Location of Information in HCR
845.620(b)(16)(E)	map of the potentiometric surface;	Figures 3-3, 3-4 & 3-5
845.620(b)(17)	Groundwater classification pursuant to 35 I.A.C. § 620; and	Section 3.2.7

Notes:

[O: CJC 08/24/21, U: CJC 8/27/21, C: LDC 08/27/21]

-- = reference to main regulation
35 I.A.C. § 620 = Title 35 of the Illinois Administrative Code, Part 620
HCR = Hydrogeologic Site Characterization Report

R000707

1. INTRODUCTION

1.1 Overview

In accordance with requirements of the Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: 35 I.A.C. § 845 (Part 845) (IEPA, April 15, 2021), Ramboll Americas Engineering Solutions, Inc. (Ramboll) has prepared this HCR on behalf of JPP (**Figure 1-1**), operated by Electric Energy, Inc. This report will apply specifically to the CCR Unit referred to as the EAP. However, information gathered to evaluate other CCR units in the vicinity of the EAP regarding geology, hydrogeology, and groundwater quality has been incorporated, where appropriate. The EAP is a 111-acre-foot existing unlined CCR surface impoundment (SI) used to manage CCR and non-CCR waste streams at the JPP. This HCR includes Part 845 content requirements specific to 35 I.A.C. § 845.620(b) (Hydrogeologic Site Characterization) for the EAP at JPP.

1.2 Part 845 Description

CCR is commonly referred to as coal ash, and CCR SIs are commonly referred to as coal ash ponds. Part 845 contains comprehensive rules for the design, construction, operation, corrective action, closure, and post closure care of these SIs. This rule includes GWPSs applicable at the waste boundary at each CCR SI and requires each owner or operator to monitor groundwater. IEPA's rule includes a permitting program as well as all federal standards for CCR SIs promulgated by the United States Environmental Protection Agency (USEPA). In addition, the rules include procedures for public participation, closure alternatives analyses, and closure prioritization, and provides access to records via public website. The rule also includes financial assurance requirements for CCR SIs.

A checklist summarizing the specific requirements of 35 I.A.C. § 845.620 is included in **Table ES-1**. The table provides references to sections, tables, and figures included in this document to locate the information that meets specific requirements of 35 I.A.C. § 845.620.

1.3 Previous Investigations and Reports

Numerous hydrogeologic investigations have been performed concerning the CCR Units located at the JPP. The information presented in this HCR includes data collected in support of the monitoring well network established for development of the GMP and supplements comprehensive data collection and evaluations from prior hydrogeologic investigation reports (recent to oldest), including, but not limited to, the following:

- ***Ramboll, January 31, 2021. 2020 Annual Groundwater Monitoring and Corrective Action Report – Joppa East Ash Pond.***
  Annual report prepared as required by Title 40 of the Code of Federal Regulations (40 C.F.R.) § 257.90(e) that documents the status of the Groundwater Monitoring and Corrective Action Program for the EAP.
- ***Natural Resource Technology, an OBG Company (NRT/OBG), October 17, 2017. Hydrogeologic Monitoring Plan – Joppa East Ash Pond.***
  A Hydrogeologic Monitoring Plan (HMP) prepared to provide background information in support of the groundwater monitoring system established to comply with 40 C.F.R. § 257.91 to regulate the disposal of CCR as solid waste under Subtitle D of the Resource Conservation

and Recovery Act of 1976 (RCRA) (40 C.F.R. § 257 Subpart D [Federal CCR Rule]; published in 80 FR 21302-21501, April 17, 2015) for the JPP EAP.

- ***AECOM, October 2016. CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Plan Control System Plan for East Ash Pond at Joppa Power Station.***
  A report documenting that the structural stability assessment, safety factor assessment, and inflow design flood control system plan meet the requirements specified in 40 C.F.R. § 257.73(d), 40 C.F.R. § 257.73(e), and 40 C.F.R. § 257.82, respectively, to support the certification required under each of those regulatory provisions for the JPP EAP.
- ***AECOM, January 2016. 30% Design Data Package for Dynegy, Joppa East Ash Pond.***
  A 30% design package including a geotechnical program consisting of installation of auger borings, cone penetrometer test (CPT) soundings, and vibratory wire piezometers to obtain information for compliance with requirements of the Federal CCR Rule design basis.
- ***Natural Resource Technology (NRT), July 2013. Phase I Hydrogeologic Assessment Report, Coal Combustion Product Impoundments, Joppa Generating Station, Joppa, IL.***
  A report to review hydrogeologic data pertinent to the site, groundwater quality data, the potential for off-site migration in the event of a release from one of the impoundments, and whether or not there are potential groundwater receptors in the event of a release. Included a survey to identify wells within 2,500 feet of the Site.
- ***Geotechnology, Inc., May 2013. Groundwater Monitoring Report, Second Quarter 2013, Electric Energy Incorporated, Joppa, Illinois.***
  A report documenting results of groundwater monitoring activities performed at the Site in the first quarter of 2013.
- ***Geotechnology, Inc., March 2013. Groundwater Monitoring Report, First Quarter 2013, Electric Energy Incorporated, Joppa, Illinois.***
  A report documenting results of groundwater monitoring activities performed at the Site in the second quarter of 2013.
- ***NRT, December 2012. Technical Memorandum No. 1, Class II Groundwater Designation and Replacement Wells, Joppa Ash Ponds.***
  A technical memorandum describing a proposal to reclassify groundwater within the clay unit at the Site from Class I to Class II designation and describing a proposal to modify the groundwater monitoring network.
- ***Geotechnology, Inc., October 2010. Well Installation and Groundwater Monitoring Report, Electric Energy, Inc., Joppa, IL.***
  A report documenting results of monitoring well installation and groundwater monitoring activities performed at the Site, as well as, summarizing field hydraulic conductivity testing and geotechnical soil testing results.
- ***Hanson Professional Services, Inc. (Hanson), August 2009. "Section 3 – Hydrogeologic Report" of Initial Facility Report, Landfill, CCB Management Facility, Joppa Generating Station, Massac County, Illinois.***
  A summary of the geology and hydrogeology of the Joppa Landfill.
- ***Hanson, October 2009. Ash Pond Hydrogeologic Assessment Plan, Joppa Power Station.***

A report to satisfy the IEPA request to characterize subsurface hydrogeology, evaluate potential contaminant migration, develop a groundwater monitoring plan and identify potable wells near the retired Joppa West and active EAP.

- ***SO-BI-CO Materials Testing Service, March 1973. Report of Soil Investigation and Recommendations, Proposed East Ash Pit, Joppa Power Plant, Joppa, IL.***
  A report documenting the results of a soils investigation and foundation evaluation completed to determine the nature of the soil deposits, determine the properties of available borrow soils and provide a basis for making recommendations regarding the stability and structural integrity of embankments for the proposed east ash pit at Joppa Power Plant.

A GMP meeting the requirements of Part 845 is being prepared for the EAP in conjunction with this report.

1.4 Site Location and Background

The JPP is west of the Village of Joppa in Massac County, Illinois, northeast of the Ohio River in Section 14, Township 15 South, Range 3 East (**Figure 1-1**). The JPP property is bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north and west, the Village of Joppa to the east, and the Ohio River to the south. The EAP is located in the west half of Section 14 directly north of the JPP and is bounded immediately to the east by the railway right-of-way, which is adjacent to forested portions of residential property in the Village of Joppa.

Figure 1-1 shows the location of the plant; **Figure 1-2** is a site map showing the location of the EAP as described in **Section 1.5**.

1.5 Site History

The JPP currently operates the EAP for management of CCR waste streams. Another inactive SI, referred to as Joppa West, is present in the western portion of the JPP property, and a permitted landfill is present in the northwestern portion of the JPP property. These other CCR units are not the subject of this HCR.

The EAP (Site) is classified as an existing unlined CCR SI which is used to manage both fly ash and bottom ash. The EAP was built in two phases. The northern portion (Phase I) was placed into service in late 1973, while the southern portion (Phase II) was permitted in May 1985, with completion of construction occurring in late 1985. These two sections are separated by a dividing dike (*i.e.,* Central Dike) and were referred to as the Northern and Southern Ponds. The pond embankment has not been raised since its construction in 1973, but material has been added in some areas to increase the width. The Northern Pond is diked over the length of its perimeter and the height of the dike varies from approximately 15 to 45 feet above the outboard toe of slope. The crest is at an approximate elevation of 380 feet NAVD88. The Southern Pond is also a diked earthen embankment structure with a height that varies from approximately 15 to 45 feet above its outboard toe. As with the Northern Pond, the crest is at an approximate elevation of 380 feet NAVD88 (O'Brien and Gere Engineers, Inc. [OBG], 2010).

2. REGIONAL AND SITE GEOLOGY

A report to summarize geologic and hydrogeologic conditions at the EAP was submitted to IEPA in 2013 (NRT, 2013). Since that submittal, several site characterization activities have been performed in the vicinity of the EAP including: 40 C.F.R. § 257 monitoring network installation in 2015, geotechnical investigations in 2016 (AECOM, 2016a), hydraulic conductivity testing in April 2017, and hydrogeologic investigation in 2021. This information (including information sourced from previous investigations and reports identified in **Section 1.3** of this HCR) has been incorporated and updated as needed to satisfy the content requirements specific to 35 I.A.C. § 845.620(b).

2.1 Topography

Topography in the vicinity of the EAP ranges from approximately 370 feet NAVD88 along the north end of the Site to 330 feet NAVD88 towards the south and east sloping toward the Ohio River (**Figure 2-1**). Based on the topographic map, the embankments are at an elevation of approximately 370 feet NAVD88, while CCR material within the Phase I area of the impoundment ranges from approximately 372 to 380 feet NAVD88, and in the Phase II it ranges from approximately 351 to 363 feet NAVD88. The height of the EAP is approximately 55 feet relative to surrounding grade.

A historic topographic map (**Appendix A**) indicates that a former drainage feature was present in the central portion of the EAP. Elevation contours indicate that the ground surface was approximately 320 feet North American Vertical Datum of 1927 (NAVD27) in the southeast corner of the pond prior to filling with CCR. The lower vertical limit of CCR identified within the lateral limits of the EAP is at an elevation of approximately 325.6 feet NAVD88 at AECOM boring location JOP-B019 (AECOM, 2016a, **Appendix B**).

2.2 Regional Geomorphology

The JPP lies at the southern boundary of the Illinois Basin and the northern edge of the Mississippi Embayment, a relatively low-lying area that is part of the Coast Plain Physiographic Province. The vicinity of the JPP generally has less than 6 meters (19.7 feet) of silty and clayey diamictons overlying Cretaceous sediments, silts, sands, etc. from depths of 6 to 15 meters (19 to 50 feet).

2.3 Soils

Surficial soils in the vicinity are shown on **Figure 2-2**, based on the soil survey data for Christian County available in the Soil Survey Geographic database (SSURGO) by the United States Department of Agriculture Natural Resources Conservation Service provided by the Environmental Systems Research Institute (ESRI) web-hosted layer. Soils underlying the JPP that are not identified as disturbed areas (Orthents #802D), are predominantly identified as Hosmer silt loam with percent slopes ranging from 2 to 18 percent (#214B, #214C2, #214C3, #214D2, and #214D3). The Hosmer series soils consist of moderately well drained soils on Loess hills. These soils formed in eolian deposits. This soil association is well suited for farmland.

Areas surrounding the EAP that are not designated Hosmer silt loam are predominantly classified as Stoy Silt Loam (#164A). The Stoy series consists of somewhat poorly drained soils on Loess hills. These soils formed in eolian deposits and are well suited for farmland.

2.4 Regional Geology

The EAP lies adjacent to and north to northeast of the Ohio River at the southern boundary of the Illinois Basin and the northern edge of the Mississippi Embayment, a relatively low-lying area that is part of the Coastal Plain Physiographic Province (Leighton et al., 1948). Based on stack-unit maps prepared by the Illinois State Geological Survey (ISGS) (Berg and Kempton, 1987) the area is characterized by less than 20 feet of silty and clayey diamictons overlying Cretaceous-age sediments, silts, sands, etc., from depths of 20 to 50 feet. The unlithified materials rest on Mississippian-age bedrock. The bedrock dips gently northward toward the center of the Illinois Basin.

2.4.1 Unlithified Materials

Regionally, the unlithified materials consist of diamictons and lacustrine/alluvial deposits. These deposits may exceed 100 feet in thickness. Four principal unlithified deposits exist in the vicinity of the EAP: (1) the Equality Formation; (2) Peoria Silt / Roxana Silt / Loveland Silt; (3) Metropolis Formation; and (4) McNairy Formation (**Figures 2-3 and 2-4**). Deposits displayed in **Figure 2-3** were mapped on a regional scale by the ISGS.

The Equality Formation is the uppermost material encountered in the vicinity of the EAP. The Equality Formation consists of silt, clay, and minor sand and gravel. The silt and clay are medium to dark gray to brown; less commonly they are greenish to bluish gray. Some reddish to orange-brown layers occur in the upper part of the unit. Consistency varies from stiff to soft, plastic "gumbo." Structure varies from massive to finely laminated or varved. Wood fragments and decomposed vegetation are common. This formation is interpreted as fine-grained fluvial overbank sediments and slack-water lacustrine deposits that accumulated during the Wisconsinan age (Nelson, 2007). Based on seventeen borings advanced as part of a subsurface geologic investigation approximately ¼ to 1 mile northwest of Joppa West (Hanson, 2009a), the thickness of the Equality ranges from 14 to 32 feet.

Contiguous with the Equality Formation but unmapped in this area are the Peoria Silt, Roxana Silt, and Loveland Silt. Based on descriptions by Nelson (2007) the Peoria Silt and Roxana Silt are both wind-blown (eolian) deposits of Wisconsinan age that are difficult to distinguish from one another. Their lower contacts are gradational. The Peoria Silt is a massive, slightly clayey silt with rare fine sand grains. The upper part is generally yellowish brown to dark brown, grading downward to mottled gray and yellowish brown. The Roxana Silt is medium dark brown to reddish brown that typically has uniform color with no mottling and higher clay content than the Peoria Silt. The Loveland Silt is of Illinoian age and is a massive silt, interpreted as an eolian deposit, with high clay content. The Loveland is strongly mottled in yellow, red, and orange and has prominent vertical gray streaks. It is strongly weathered and commonly displays root casts or traces. The Loveland is generally thin and lenticular and its lower contact is gradational to the Metropolis Formation but unconformable to older units.

Underlying the Equality Formation, or at some locations the Loveland Silt, is the Metropolis Formation, which consists of silt, sand, clay, and gravel. The Metropolis Formation is composed of silty sand and sandy silt in a clay matrix and contains scattered pebbles and lenses of gravel. Much of the unit may be classified as diamicton. These sediments are strongly mottled and streaked in shades of gray, yellowish brown, and yellowish orange. The lower part of the formation contains bright red and orange sand. Sediments are poorly sorted to unsorted and massive to weakly stratified. Gravel occurs as common scattered pebbles and as lenses up to 4

feet thick (Nelson, 2007). The Metropolis Formation, originally defined by Nelson et al. (1999a), borders the Ohio River, where it underlies a loess-capped terrace. The Metropolis Formation is interpreted as alluvial sediment deposited in the valley of the ancestral Tennessee River (Nelson et al., 1999a; Nelson et al., 1999b). The lower contact is unconformable on the McNairy in most places. Age is Pleistocene, Illinoian and older. Based on thirteen borings advanced approximately ¼ to 1 mile northwest of Joppa West (Hanson, 2009a), the thickness of the Metropolis Formation ranges from 25 to 40 feet.

The lowermost unlithified unit encountered in the vicinity of the JPP is the McNairy Formation, which consists of sands, silts, and clays. The McNairy Formation is Upper Cretaceous in age and consists of very fine- to medium-grained sand, mostly highly micaceous, and range from white and light gray to bright orange, red, and yellow in color. The silts and clays are light to dark gray and may be mottled in yellow, gray, and magenta. The lower contact is unconformable (Nelson, 2007). Based on one boring advanced to bedrock by Hanson (2009a) approximately 0.7 miles northwest of Joppa West, and confirmed by borings completed in 2021, the thickness of the McNairy Formation is approximately 76 feet. The drillers log for plant well 4 (which is 900 feet south of the EAP) indicates sand from a depth of 50 to 135 feet, suggesting that the McNairy Formation is 85 feet thick south of the CCP impoundments (NRT, 2013).

2.4.2 Bedrock

The regional bedrock consists of a sequence of Mississippian System sedimentary rocks hundreds of feet thick and consolidated prior to the Cretaceous Period. The bedrock dips gently northward toward the center of the Illinois Basin. The uppermost bedrock near the JPP generally consists of limestone. The total thickness of the Mississippian System in southern Illinois is greater than 3,200 feet (Willman et al., 1975).

The uppermost unit encountered in the vicinity of the JPP is the Salem Limestone (**Figure 2-4**). The Salem Limestone is described as fine-grained, fossiliferous limestone, and is approximately 200 to 500 feet thick in the area. The Salem Limestone overlies the Ullin Limestone; the Ullin Limestone is described as a light-colored fine- to coarse-grained limestone. The overall thickness of the Ullin Limestone near the JPP is approximately 200 feet. The Fort Payne Formation, which is overlain by the Ullin Limestone, is described as a very fine-grained, siliceous, cherty limestone, and is approximately 200 to 600 feet thick in the study area (Kolata, 2005; Willman et al., 1967; Willman et al., 1975).

2.4.3 Structure

The major geologic structural features around Illinois are shown on **Figure 2-5**. The JPP is located within the zone of the pre-Cretaceous structure of the Pascola Arch. The Pascola Arch was uplifted sometime after the middle of the Pennsylvanian Period and eroded, truncated, and buried beneath Upper Cretaceous and younger rocks in the Mississippi Embayment. The Embayment, as defined by the extent of Cretaceous rocks, reaches into southernmost Illinois and is a northern extension of the Gulf Coastal Plain. The Pascola Arch closes off the southwestern margin of the Illinois Basin between the Nashville and Ozark Domes. Cambrian rocks are directly overlain by Tuscaloosa Formation at the apex of the arch. The northeast dip of Paleozoic strata and southern closure of the Illinois Basin in southernmost Illinois are attributed to the Pascola Arch (Nelson, 1995).

2.4.4 Seismic Setting

Several fault zones cross the Joppa Quadrangle. These faults are part of the Fluorspar Area Fault Complex, an intricate array of fractures that affect a large area of southernmost Illinois and western Kentucky (Nelson and Masters, 2008). The Lusk Creek Fault Zone, **Figure 2-5**, is the westernmost major fault zone in the Fluorspar Area Fault Complex. This fault zone continues more than 30 miles northeast of Joppa into Pope County, where it merges with the east-west trending Rough Creek-Shawneetown Fault System.

Within the Joppa Quadrangle, the Lusk Creek Fault Zone is less than ¼ mile wide and trends about N35°E. Overall the evidence implies that the Lusk Creek Fault Zone underwent a pre-Cretaceous displacement of about 100 feet down to the southeast, offsetting Mississippian limestone. Post-Cretaceous tectonic activity produced narrow grabens that dropped as much as 200 feet. Small movements may have taken place as recently as the Pleistocene (Nelson and Masters, 2008). United States Geological Survey (USGS) seismic hazard maps show peak ground accelerations (g) of approximately 0.8 g to 0.6 g in the Lusk Creek Fault Zone vicinity.

35 I.A.C. § 845.330 requires that existing and new CCR SIs and lateral expansions of existing SIs must not be located in seismic impact areas, unless owners or operators demonstrate that the SI is designed to resist the maximum horizontal acceleration in lithified earth material. This requirement is identical to that in 40 C.F.R. § 257.63. The definition of a seismic impact zone is "areas having a 10 percent or greater probability that the maximum expected horizontal acceleration (g) in hard rock, expressed as a percentage of the earth's gravitation pull, will exceed 0.10 g in 50 years." These areas are identified on maps prepared by the USGS (Algermissen et al., 1982). Based on the data illustrated on Plate 2 (Algermissen et al., 1982), the Site vicinity exhibits a potential horizontal acceleration of approximately 0.11 g with a 90 percent probability of not being exceeded in 50 years. The Site is therefore within a seismic impact area, as currently defined in 40 C.F.R. § Part 257.63, and, by extension, 35 I.A.C. § 845.330.

Per 35 I.A.C. 845.460(a)(4), the calculated seismic factor of safety must equal or exceed 1.00. As a part of the Initial Safety Factor Assessment (AECOM, 2016a), factors of safety were calculated for seismic loading conditions. This calculation models the dike stability under short-term, seismic loading conditions during the design 2,500-year return period seismic event. Six cross sections were analyzed and the minimum calculated factor of safety of 1.01 exceeded the factor of safety requirement of 1.00. Therefore, the Site meets the requirements in 35 I.A.C. 845.460(a)(4).

2.4.5 Mining Activities

Based on the Illinois State Geological Survey (ISGS) Illinois Coal Mines (ILMINES) online database (ISGS, 2018), no surface or underground mines were identified within 1,000 meters of the EAP.

2.4.6 Industrial Activities

As indicated in **Section 1.4**, the surrounding areas include industrial activities to the west and north of the EAP with the village of Joppa to the east and the Ohio River to the south (**Figure 1-2**). The industrial properties include:

- LaFarge North America cement plant is located to the west of the EAP at 2500 Portland Road.

- Trunkline Gas Company-Joppa Compressor Station is located to the north and west of the EAP at 2101 Portland Rd. The compressor station is used for an approximately 2,000-mile natural gas pipeline system.

2.5 Site Geology

A field investigation was performed in 2021 to collect additional data for the discussion of vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet below ground surface (bgs) as specified in 35 I.A.C. § 845.620(b). Field investigation locations are shown on **Figure 2-6**.

2.5.1 Site Specific Unlithified Geology

The stratigraphy within and immediately surrounding the EAP consists of the following in descending order: fill material and CCR, the Equality Formation, Peoria Silt / Roxana Silt / Loveland Silt, Metropolis Formation, and McNairy Formation. Boring logs, monitoring well and piezometer construction forms obtained from investigations at the EAP are provided in **Appendix B**.

2.5.1.1 Fill and CCR

Non-CCR fill material was classified as clayey silt, well graded sand, gravelly sand, or sandy clay. In general, fill was encountered at depths of up to 5 feet bgs. Soil borings performed within the EAP (XPW01, XPW02, and XPW03) indicate CCR material consists of both fly ash and bottom ash and is encountered at depths up to 46 feet bgs. Based on borings and historical information, CCR material extends to an elevation of 327.7 feet NAVD88 (**Figures 2-7 through 2-8**).

No geotechnical samples were collected from non-CCR fill. Geotechnical analysis results of five CCR samples yielded Unified Soil Classification System (USCS) soil classifications of silty sand, silty lean clay, and sandy silt. These classifications are consistent with previous geotechnical analyses of samples from 1 to 5 feet bgs. The results of the geotechnical analysis are summarized below and in **Table 2-1** and the geotechnical laboratory report is included in **Appendix C**. The results of the geotechnical analysis of Fill and CCR indicated the following:

- The grain size distributions for the CCR samples indicate that the CCR material is on average approximately 7 percent gravel, 30 percent sand, and 63 percent fines. Although coarser grained material was identified in two samples with approximately 9 to 26 percent gravel, 45 to 74 percent sand, and only 17 to 28 percent silt and clay.
- The moisture content for CCR ranged from 31.7 percent (XPW-01 at 46-48 feet bgs) to 47.6 percent (XPW-02 at 24-26 feet bgs), with an average moisture content of approximately 41 percent.
- Laboratory hydraulic conductivity tests performed for samples from the CCR materials resulted in a range from 1.8×10^{-7} to 2.1×10^{-5} centimeters per second (cm/s); and a geometric mean vertical hydraulic conductivity of 1.0×10^{-6} cm/s.

In addition to geotechnical analyses, samples of CCR material were collected for chemical analysis. The results of these chemical analyses are summarized in **Table 2-2**.

Leachate wells (*i.e.,* XPW01, XPW02, and XPW03) installed within the ash were also sampled in 2021. The results of porewater samples collected from within the EAP are summarized in **Table 2-3**.

2.5.1.2 Equality Formation

The Equality Formation is the uppermost unlithified material encountered in the vicinity of the EAP. The Equality Formation was classified as silt and clay with minor amounts of sand and gravel in borings advanced on site. Thicknesses of the Equality Formation ranged from 14.0 feet at G06 to 28.0 feet at G03 and G09M (**Figures 2-7 through 2-8**). The silt and clay are medium to dark gray to brown; less commonly they are greenish to bluish gray. Based on interpretations of boring logs, this formation was found to extend from 320.60 to 356.2 feet NAVD88. A drillers log for plant well 4, located south of the EAP, indicates fine-grained deposits from the land surface to a depth of 50 feet. These deposits represent the combined thickness of the Equality and Metropolis Formations south of the EAP. The results of geotechnical analysis are summarized below and in **Table 2-1** and the geotechnical laboratory report is included in **Appendix C**. The results of the geotechnical analysis from the Equality Formation indicated the following:

- Moisture content of the samples ranged from 15.5 to 20.6 percent, with an average of 18.2 percent. These observations are at the lower end of the range observed during previous investigations (AECOM, 2016b) that indicate an average of 19.9 percent.
- The average total porosity (calculated) was 35 percent, with a range from 32 to 37 percent.
- The average dry density was 109.1 pounds per cubic foot (pcf) and ranged from 105.4 to 112.7 pcf. These observations are consistent with previous investigations (AECOM, 2016a) which indicated an average dry density of 106.1 pcf.
- The average specific gravity was 2.671 with a range of 2.659 to 2.688.
- The average grain size distribution was 0.2 percent gravel, 23.4 percent sand, and 76.4 percent silt and clay. Previous investigations identified the following grain size distribution: approximately 90 percent silt and clay and 10 percent gravel and sand.

2.5.1.3 Peoria Silt / Roxana Silt / Loveland Silt

Where present, the Peoria Silt, Roxana Silt, and Loveland Silt were not differentiated and are referred to as the Silt Unit in this Report. This unit was generally classified as silt with limited occurrences of sandy silt. The Silt Unit was encountered at locations G07 through G10 located around the south and southeast portions of the EAP with thicknesses ranging from 4.0 to 8.0 feet. No geotechnical or chemical samples were collected from this unit.

2.5.1.4 Metropolis Formation

Underlying the Equality Formation, or at some locations the Silt Unit, is the Metropolis Formation. At the EAP, the Metropolis Formation is composed of clay, sandy clay, and sandy silt with limited occurrences of silty sand and gravel. This unit was encountered in all borings advanced onsite and ranges in thickness from 4.0 feet at G08 to 39.3 feet at G04. These results are within the range of borings advanced approximately ¼ to 1 mile northwest of Joppa West (Hanson, 2009a), which indicate the thickness of the Metropolis Formation ranges from 25 to 40 feet. The percentages of sand/gravel, silt, and clay composition of a sample of the Metropolis Formation collected from G09M (46 to 48 feet bgs) indicates it is approximately 17 percent sand, and 83 percent silt and clay (**Table 2-1**) The geotechnical laboratory report is provided in **Appendix C**.

Samples collected from the Metropolis Formation were also submitted to an analytical laboratory for chemical analysis. The results of this chemical analysis are summarized in **Table 2-4**.

2.5.1.5 McNairy Formation

The McNairy Formation is the lowermost unlithified unit at the JPP and consists of sands, silts, and clay, and was encountered in all borings advanced in the vicinity of the EAP. The material was classified as well- and poorly-graded sand, and gravelly sand with limited lenses of silty sand, silt, or clay. Colors were variable and the material was generally described as light gray, tan, yellowish brown with several observations of yellowish red, strong brown, or reddish yellow in layers.

At the base of the McNairy, above the bedrock, lean clay was encountered with a thickness of 14 feet (G09M, approximately 222 feet NAVD88). This is consistent with JPP wells #2 (API# 121270005000) and #4 (API# 121270000100) which indicate silt or clay at depths of 130 feet and 125 feet, respectively. A former potable well log (API#121270005400, **Figure D-2** in **Appendix D**) also identifies a clay layer at a depth of 115 feet which appears consistent with these two three wells. In addition, a boring advanced to bedrock by Hanson (2009a) approximately 0.8 miles mile northwest of the Joppa West, encountered a white clay from approximately 242 to 222 feet NAVD88.

The McNairy Formation at the JPP has been divided into two units for discussion in **Section 3.2** based on composition of the materials onsite as follows:

- Upper McNairy Formation: consisting of sand and gravel with isolated lenses of silt and clay.
- Lower McNairy Formation: consisting of finer grained materials present at the bedrock surface which appear to be laterally continuous in the vicinity of the JPP.

The percentages of sand/gravel, silt, and clay composition of the McNairy Formation samples are summarized below and in **Table 2-1** and the geotechnical laboratory report is provided in **Appendix C**. The results of the geotechnical analysis from the McNairy Formation indicated the following:

- Moisture content of the samples ranged from 7.6 to 25.5 percent, with an average of 16.9 percent. These observations overlap with the range observed during previous investigations (AECOM, 2016b) that indicate a range of 14.2 to 44.4 percent, with an average of 19.7 percent.
- The average total porosity (calculated) was 41 percent, with a range from 34 to 48 percent.
- The average dry density was 99.0 pcf and ranged from 87.0 to 110.0 pcf. These observations are consistent with previous investigations (AECOM, 2016b) which indicated an average dry density of 107.5 pcf, and range from 92.6 to 113.1 pcf.
- The average specific gravity was 2.673 with a range of 2.661 to 2.686.
- The average grain size distribution was 6.3 percent gravel, 85.4 percent sand, and 8.3 percent silt and clay. Previous investigations identified the following grain size distribution: 74.0 percent silt and clay and 26.0 gravel and sand.

Samples collected from the McNairy Formation were also submitted to an analytical laboratory for chemical analysis. The results of this chemical analysis are summarized in **Table 2-4**.

Geologic cross-sections across of the study area are shown on **Figures 2-7 through 2-8**.

2.5.2 Site Specific Bedrock Geology

The uppermost bedrock unit encountered in the vicinity of the EAP is the Mississippian Salem Limestone. Bedrock was encountered in G09M at an elevation of approximately 222 feet NAVD88 (**Figure 2-5**). This elevation is consistent with the JPP production wells and ISGS's *Geology of Joppa Quadrangle* report completed to evaluate structural geology of the area (Nelson and Masters, 2008). The bedrock was classified as limestone (specifically calcarenite), with a very pale brown color. A sample was collected from the bedrock at a depth of 142 to 144 feet bgs and submitted for chemical analysis. The results of this chemical analysis are summarized in **Table 2-4**.

3. REGIONAL AND LOCAL HYDROGEOLOGY

3.1 Regional Hydrogeology

3.1.1 Unlithified Deposits Hydrogeology

The McNairy-Nacatoch aquifer is in Upper Cretaceous deposits and is the lowermost hydrogeologic unit included in the Mississippi embayment aquifer system. The McNairy-Nacatoch aquifer is included in the aquifer system because of the local hydraulic connection between this aquifer and the overlying aquifers in Tertiary rocks in the northern part of the Mississippi Embayment where the Midway confining unit is thin (USGS, 1995).

The McNairy-Nacatoch aquifer primarily consists of the McNairy Sand but also includes the Nacatoch Sand. Other underlying sands of Late Cretaceous age, including the Coffee Sand and sand beds in the Demopolis, the Eutaw, and the Tuscaloosa Formations, are discontinuous in the region. The McNairy-Nacatoch aquifer thickens from less than 50 feet near its updip limit in southern Illinois to a maximum of more than 400 feet near its southern extent. Sand in the McNairy-Nacatoch aquifer is present as a single thick bed or as two or more thick sand beds separated by thin clay or marl layers. The sand facies is locally overlain by clay and marl of Late Cretaceous age, which, in turn, are overlain by clays of the Midway confining unit. The clean, fine sands change laterally to clay, marl, and limestone toward the southwest and are accompanied by calcareous cementation that fills the pore space between sand grains and greatly reduces the permeability of the sand. Wells completed in the McNairy-Nacatoch aquifer commonly yield from 50 to 500 gallons per minute, but yields might exceed 1,000 gallons per minute (USGS, 1995).

3.1.2 Bedrock Hydrogeology

Groundwater in bedrock occurs in limestone aquifers of Mississippian rocks. The uppermost limestone in the vicinity of the JPP is the Salem Limestone. In general, the limestone aquifers in this area are either flat lying or gently dipping and are capped by a layer of regolith that varies greatly in thickness. Typically, the limestone aquifers that yield the largest quantities of water to wells and springs are the Upper Mississippian Monteagle, the Ste. Genevieve, and the St. Louis Limestones. Where the Monteagle, the Ste. Genevieve, and the St. Louis are thin or missing, such as in the southwestern part of central Tennessee, the Warsaw Limestone (includes the Salem Limestone in Illinois) along with chert and limestone beds of the Fort Payne Formation are the principal aquifers (USGS, 1995).

In most places, the Mississippian aquifers are covered by regolith, which mostly consists of weathered material, or residuum. This material consists of clay, silt, sand, and pebble-sized particles of limestone or chert, which are derived mostly from weathering of the underlying bedrock. The hydraulic characteristics of the Mississippian aquifers vary greatly over short distances. For example, the ability of limestone with large, interconnected solution openings to transmit and yield water is several orders of magnitude greater than that of the almost impermeable blocks of limestone between solution openings, fractures, and bedding planes. Well yields commonly range from 2 to 50 gallons per minute, and reported maximum yields range from about 100 gallons per minute in Indiana to 1,000 gallons per minute in Illinois. Wells that penetrate large, saturated solution openings may yield several thousands of gallons per minute. However, such openings constitute only a small part of the rock and might be difficult to locate (USGS, 1995).

3.2 Site Hydrogeology

Prior to 2021, significant investigation had been completed to characterize the EAP, including CPT and installation of soil borings and monitoring wells. In 2015, a monitoring program consisting of six monitoring wells (G01D, G02D, G51D. G52D, G53D, and G54D) was established to comply with requirements of 40 C.F.R. § 257. In 2021, twelve additional monitoring wells (G03 through G11, G06S, G09M, and G54S) were installed to collect information to meet the requirements of Part 845. Construction details for monitoring wells and piezometers is provided in **Table 3-1** and locations are depicted in **Figure 3-1**. Boring logs, monitoring well, and piezometer construction forms are provided in **Appendix B**.

3.2.1 Hydrostratigraphic Units

Five water-bearing units have been identified in the vicinity of the EAP based on stratigraphic relationships and common hydrogeologic characteristics. The units are described as follows:

- **CCR:** CCR consisting of fly ash and bottom ash. Water elevations measured in early March 2021 within the EAP indicate the phreatic surface is approximately 370 to 374 feet. A maximum thickness of saturated fill and CCR of approximately 42 feet was observed at location XPW01 in April 2021. The amount of saturated fill and CCR in the EAP is generally consistent, ranging from 35 to 45 feet from March through August 2021, based on an estimated base of ash from 425 to 435 feet NAVD88 and the measured phreatic surface.
- **UCU:** The uppermost hydrostratigraphic unit is comprised of the Equality Formation, the Silt Unit, and Metropolis Formation deposits. The average thickness of this unit is 40.7 feet with a range of 8 to 58 feet. The UCU underlies the CCR fill in all locations and is thinnest in the southeast portion of the site. These deposits are predominantly fine-grained, comprised of clay, silt, and silty clay with limited intervals of sandy material. This hydrostratigraphic unit was encountered at all locations and extends down to the McNairy Formation, which was encountered at 34 feet bgs at location G06.
- **Uppermost Aquifer:** This unit consists of the Upper McNairy Formation which is composed of permeable sands and gravels with isolated lenses of finer grained material. This hydrostratigraphic unit at the site was 58 feet thick and is underlain by the LCU. The Upper McNairy Formation is composed of a significantly higher percentage of sand and gravel than the overlying Equality and Metropolis Formations.
- **LCU:** This unit consists of the Lower McNairy Formation which, in the vicinity of the EAP is composed of clay and silt overlying the Salem Limestone. The clay and silt of this unit was encountered in borings advanced to bedrock south and southeast of the EAP, as well as one boring located northwest of the site. The presence of this material at locations advanced to bedrock suggest it is laterally continuous in the vicinity of the JPP.
- **LAU:** This unit, composed of the Salem Limestone bedrock, is the lowermost hydrostratigraphic unit identified and is considered a potential migration pathway (PMP). The limestone bedrock is encountered at an elevation of approximately 200 feet NAVD88 below the EAP, slopes towards a syncline to the east (Nelson and Masters, 2008), and has a reported thickness of 200 to 500 feet. The Salem Limestone is used to supply water for various uses in the region and provides non-potable water for the JPP and potable water for the Village of Joppa (**Appendix D**).

3.2.2 Uppermost Aquifer

The uppermost aquifer is comprised of the sand and gravel, classified as the Upper McNairy Formation. The unit was encountered at its shallowest elevation (approximately 319 feet NAVD88) at G06 located on the east/ southeast edge of the EAP. This hydrostratigraphic unit at the site was approximately 58 feet thick (G09M) and extends down to the clay and silt of the Lower McNairy Formation. The lenses of clay and silt within the Upper McNairy are encountered at isolated locations and not interpreted to be laterally continuous. The base of the uppermost aquifer is the Lower McNairy Formation, comprised of clay and silt which overlies the Mississippian Aged Salem Limestone. **Figure 3-2** shows the top of the uppermost aquifer.

3.2.3 Potential Migration Pathways

The potential pathways for contaminant migration at the Site have been fully characterized and defined in **Section 3.2.1**. Based on a review of the lithology underlying the EAP, potential impacts to groundwater migrate downwards through the unconsolidated UCU into the uppermost aquifer (the Upper McNairy Formation). Further downward migration is limited by the Lower McNairy Formation, which is the LCU. Below the LCU is the LAU which is comprised of the Salem Limestone. The LAU has been identified as a PMP.

3.2.4 Water Table Elevation and Groundwater Flow

Groundwater flow is represented using groundwater elevation contour maps for several sampling events completed during 2021 (**Figures 3-3 through 3-5**). The EAP is located upgradient of the Ohio River and the groundwater elevation measured in wells surrounding the EAP range from 305.27 to 338.96 feet NAVD88 from March to July 2021. Groundwater elevation contours generally illustrate flow from northwest to southeast in the northern half of the EAP. In the southern half of the EAP, flow is southwest and southeast around an elevated measurement at G52D.

The elevations of water within the EAP (as observed in XPW01, XPW02, XPW03, and XSG01) are greater than the surrounding areas. The phreatic surface within the EAP from March to July 2021 averaged 369.85 feet NAVD88, ranging from 357.48 feet NAVD88 in XSG01 (eastern edge of EAP) to 373.84 feet NAVD88 in XPW03 (in the southwestern corner of the EAP) (**Figures 3-3 through 3-5**).

The groundwater elevation in wells within the UCU (G101, G151, G152B, G153, and G54S) from March to July 2021 averaged 322.75 feet NAVD88, with a range from 310.25 feet NAVD88 in G54S (southwest corner of the EAP) to 338.96 feet NAVD88 in G152B (southern edge of EAP). Well G152B, located south of the EAP, consistently recorded the highest groundwater elevation, with an average groundwater elevation of 335.58 feet NAVD88. The elevated groundwater here is assumed to be a result of well G152B screen being situated in low conductivity materials. Groundwater elevations at well G151 (along the western edge of the EAP) were also consistently higher than the remaining UCU wells, with an average groundwater elevation of 326.97 feet NAVD88.

The groundwater elevation in wells within the uppermost aquifer (G01D, G02D, G03, G04, G05, G06, G06S, G07, G08, G09, G10, G11, G51D, G52D, G53D and G54D) from March to July 2021 averaged 319.44 feet NAVD88, with a range from 311.02 feet NAVD88 in G09 (southern edge of EAP) to 327.46 feet NAVD88 in G52D (southern edge of EAP). Wells G11 and G51D (along the western edge of the EAP) were again consistently higher than the remaining uppermost aquifer

wells, with an average groundwater elevation of 322.02 feet NAVD88. Elevations measured in G52D do not appear to be consistent with other uppermost aquifer locations. The boring log from this location indicates more heterogenous geology, and as a result the well may have less hydraulic connection with the uppermost aquifer.

The groundwater elevation within the LAU well G09M from March to July 2021 averaged 319.32 feet NAVD88, with a range from 316.93 to 322.19 feet NAVD88.

Groundwater elevations are primarily controlled by river stage of the Ohio River near the JPP. Seasonal variation of groundwater levels has been observed, and the River has been observed at elevations higher than groundwater (**Figure 3-3**). Flow reversals associated with flooding of the Ohio River (**Appendix E**) have not been observed to extend northward beneath the EAP.

Groundwater elevations vary seasonally and may fluctuate by about 10 feet. Slight seasonal variation in groundwater flow directions ranging from southeast to southwest are also observed; however, the major component of groundwater flow direction is consistently south toward the Ohio River (**Figure 3-3 through 3-5**), which is the primary receiving body of water in the vicinity of the JPP (NRT, 2013).

3.2.4.1 Vertical Hydraulic Gradients

Vertical hydraulic gradients were calculated using available groundwater elevation data from early March to July 2021 at nested well locations within the UCU, the uppermost aquifer, and LAU (**Table 3-2**). The vertical gradients are summarized as follows:

- UCU to uppermost aquifer:
  - Consistent downward gradients were measured at well nests G151/G51D, and G152B/G52D. The gradients ranged from 0.10 to 0.83 feet/feet (ft/ft).
  - Variable gradients were measured at G101/G01D, G153/G53D, and G54S/G54D. On average, gradients were upward in G101/G01D and G54S/G54D, while they were flat at G153/G53D. In general, downward gradients were measured in July.
- Uppermost aquifer (within): Small downward gradients were measured in uppermost aquifer wells G06S/G06, with a range of 0.01 to 0.02 ft/ft.
- Uppermost aquifer to LAU:
  - At nested location G09/G09M, consistent upward vertical gradients (average of 0.06 ft/ft) were observed. Well G09M is screened in the bedrock below the LCU, while G09 is screened within the uppermost aquifer. Consistent upward gradients indicate that the Ohio River is a regional discharge point for the bedrock aquifer system and the LCU is continuous in the vicinity of G09.

3.2.4.2 Impact of Existing Ponds and Ash Saturation

The phreatic surface measured in the EAP ranges from approximately 370 to 375 feet NAVD88 while groundwater elevations measured in monitoring wells located around the EAP and screened within the UCU and uppermost aquifer range from approximately 311 to 327 feet NAVD88. Groundwater elevation contours indicate groundwater generally flows to the south, with no indication of radial flow. The elevation difference between the phreatic surface and groundwater elevations, in addition to no observations of radial flow, provide evidence that the EAP does not

impact groundwater flow directions. The amount of saturated fill and CCR in the EAP is generally consistent, ranging from 35 to 45 feet from March through August 2021.

3.2.4.3 Impact of Surface Water Bodies

The river basin typically experiences annual floods during the months of March, April, May, and occasionally June, while smaller floods occur less frequently in autumn (**Figure 3-3** and **Appendix E**). There have been no monitoring events (between 2015 and 2021) with observations that indicate groundwater flow reverses direction (*i.e.,* groundwater flows from the Ohio River north into the uppermost aquifer) beneath the EAP. Based on this timeframe it does not appear the Ohio River impacts groundwater flow; if it does, however, it is likely limited in extent and magnitude to the areas downgradient (*i.e.*, south) of the EAP.

3.2.5 Hydraulic Conductivity

3.2.5.1 Field Hydraulic Conductivity

Field hydraulic conductivity tests performed on the uppermost aquifer and LAU materials at the EAP were completed as part of the 2021 field investigation. Hydraulic conductivity test analyses and results are summarized in **Table 3-3** and provided in **Appendix F**. Field hydraulic conductivity tests indicated that the horizontal hydraulic conductivity for the Upper McNairy Formation sands and gravels at the site are variable, but mostly permeable with measured hydraulic conductivity ranging from 4.8×10^{-4} to 1.2×10^{-2} cm/s and a geometric mean of 3.1×10^{-3} cm/s (**Table 3-3**). This is higher than measurements of the uppermost aquifer calculated in 2017 (NRT/OBG, 2017), which resulted in a geometric mean conductivity of 3.4×10^{-4} cm/s.

Results of field hydraulic conductivity tests conducted in 2021 in the CCR Fill Unit wells (XPW02 and XPW03) ranged from 4.5×10^{-3} to 1.7×10^{-1} cm/s, with a geometric mean of 1.3×10^{-2} cm/s.

Slug testing was not completed at several wells (XPW01, G04, G05, G06S, and G54S), as these wells repeatedly went dry during well development. Hydraulic conductivity within the LAU as measured at well G09M, ranged from 2.7×10^{-4} to 5.8×10^{-4} cm/s, with a geometric mean of 4.0×10^{-4} cm/s. The hydraulic conductivity test analyses and results are provided in **Appendix F**.

3.2.5.2 Laboratory Hydraulic Conductivity

Falling head permeability tests (ASTM D5084 Method F) were performed in the laboratory on samples collected during the 2021 investigations. Sample locations are shown on **Figure 2-6**. The geotechnical laboratory report is provided in **Appendix C**. The results are summarized in **Table 2-1** and discussed below.

- Three samples were collected from CCR Fill unit borings at XPW01, XPW02, and XPW03. Laboratory falling head permeability test results in the CCR Fill unit indicated a geometric mean vertical hydraulic conductivity of 1.0×10^{-6} cm/s.
- Four UCU samples were collected from borings G03, G09M, and G11. Laboratory falling head permeability results in the UCU indicated a geometric mean vertical hydraulic conductivity of 1.7×10^{-7} cm/s.
- Laboratory hydraulic conductivity tests were not performed on samples from the uppermost aquifer or LAU.

3.2.6 Horizontal Groundwater Gradients and Groundwater Flow Velocity

Groundwater elevations have been measured quarterly since 2015. The Ohio River is the regional receiving body of water for groundwater. Under normal conditions at the EAP, groundwater flows from north to south discharging into the river as shown on **Figures 3-3** and **3-4**. Additional water table contour maps for 2019 through 2020 are available in **Appendix E**.

Horizontal hydraulic gradients and groundwater velocities for the uppermost aquifer were calculated based upon groundwater elevation measurements from March to July 2021 between G02D and G53D, G02D and G08, G11 and G54D, and G11 and G10 (**Table 3-4**). Horizontal hydraulic gradients are slight across the EAP and ranged from 0.0002 ft/ft between G02D and G53D in April 2021 to 0.0103 ft/ft between G11 and G54D in June 2021. The lower hydraulic gradients near the north of the EAP, between G02D and G53D, are consistent with previous calculations of horizontal hydraulic gradients at upgradient locations (NRT/OBG, 2017).

Horizontal hydraulic gradients calculated to the northeast of the EAP, between G02D and G53D, were on average 0.0008 ft/ft with an average groundwater velocity of 0.003 feet per day (ft/day). Horizontal hydraulic gradients calculated through the center of the EAP, between G02D and G08, were on average 0.0019 ft/ft with an average groundwater velocity of 0.046 ft/day. Horizontal hydraulic gradients calculated to the southwest of the EAP, between G11 and G54D, were on average 0.0053 ft/ft, with an average groundwater velocity of 0.23 ft/day. Horizontal hydraulic gradients calculated to the south of the EAP, between G11 and G10, were on average 0.0051 ft/ft with an average groundwater velocity of 0.19 ft/day. Horizontal hydraulic gradients and groundwater flow velocities are presented in **Table 3-4**.

3.2.7 Groundwater Classification

Per 35 I.A.C. § 620.210, groundwater within the uppermost aquifer at the EAP meets the definition of a Class I – Potable Resource Groundwater based on the following criteria:

- The groundwater is located more than 10 feet bgs and within an unconsolidated silty sand and gravel unit which is five feet or more in thickness and contains less than 12 percent of fines.
- Slug testing results identified a mean hydraulic conductivity of 3.1×10^{-3} cm/s, which exceeds the 1×10^{-4} cm/s criterion (**Table 3-4**).
- The groundwater does not underlie a previously mined area or a coal mine refuse disposal area.

3.3 Surface Water Hydrology

3.3.1 Climate

Average climatic data was obtained from the Illinois State Water Survey (ISWS). The data was recorded from 1989 to 2020 from Dixon Springs, Illinois, which is located approximately 15 miles northeast of the JPP. The data includes monthly maximum and monthly minimum daily temperatures (degrees Fahrenheit [°F]) and average rainfall for each month calculated from daily values collected over the 31-year period. The data is summarized in **Table A** below.

Table A: Average Monthly Temperature Extremes and Precipitation for Dixon Springs, Illinois.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Maximum Temperature (°F)	42.8	47.9	57.5	68.2	76.3	84.2	87.2	86.4	80.6	69.7	56.9	46.6	67.0
Minimum Temperature (°F)	25.9	29.4	37.2	46.2	55.5	63.7	65.4	65.4	57.8	46.4	36.9	29.7	46.8
Precipitation (inches)	3.88	3.41	4.52	4.84	4.66	3.95	4.22	2.93	3.33	3.74	4.28	4.47	48.2

3.3.2 Surface Waters

The predominant surface water body in the region is the Ohio River and associated lowland backwater lakes. The Ohio River is located directly adjacent to and down-gradient from the EAP. A USGS stream gage (#03612600) for the Ohio River at Olmsted, Illinois is located 12 river miles southwest (downstream) of the JPP. The gage datum elevation is 278.44 feet National Geodetic Vertical Datum of 1929 (NGVD29). Daily gage heights for the periods of June 1, 2020 to June 1, 2021 are shown in the following graph (USGS, 2021).

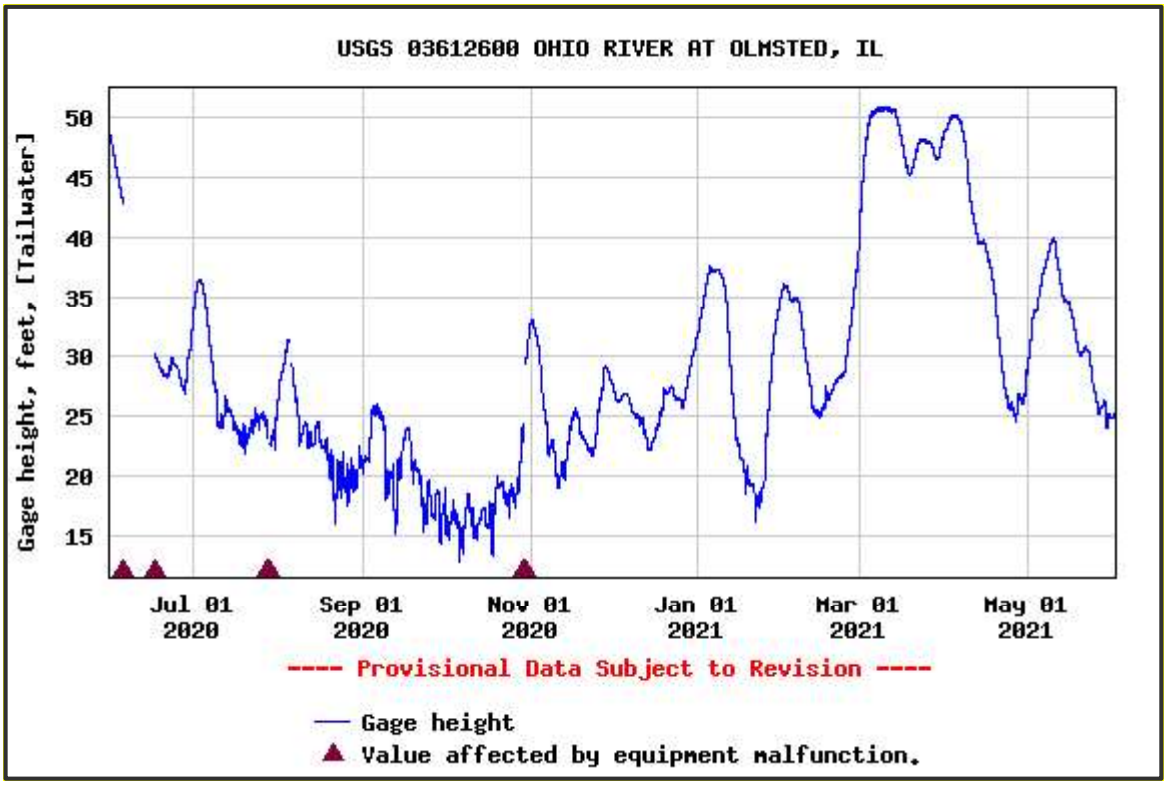


Figure A. Daily Gage Height (feet) June 1, 2020 to June 1, 2021 for USGS Gaging Station 03612600 at the Ohio River at Olmsted, Illinois.

The gage height of 15 feet, representing approximate base flow, occurs at an elevation of 278.62 feet NAVD88.

Other surface water in the vicinity includes Mermet Lake two miles north of the EAP, freshwater emergent wetlands to the east and west of the EAP, freshwater forested/shrub wetlands to the north and south of the EAP, and freshwater ponds spread around the EAP.

A Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map for Massac County (Map No. 1704670025B; Effective Date: July 5, 1983) is attached in **Appendix G** and can also be viewed online at: https://www.illinoisfloodmaps.org/dfirm.aspx?county=massac. None of the impoundment berms within the EAP occur below the base flood elevation value of 335 feet identified on the 2011 FEMA map. The EAP is outside the 100-year flood zone shown on the FEMA map. The flood hazard areas shown on the map are defined as those areas subject to inundation by the 1 percent annual chance flood (*i.e.,* 100-year flood), also known as the base flood, that has a 1 percent chance of being equaled or exceeded in any given year.

4. GROUNDWATER QUALITY

4.1 Summary of Groundwater Monitoring Activities

4.1.1 40 C.F.R. § 257 Program Monitoring and Well Network

The 40 C.F.R. § 257 well network for the EAP consists of six monitoring wells installed nearby and adjacent to the EAP within the unlithified uppermost aquifer. The EAP 40 C.F.R. § 257 well network consists of two upgradient (*i.e.,* background) monitoring wells (G01D and G02D) and four downgradient (*i.e.,* compliance) monitoring wells (G51D, G52D, G53D, and G54D). The boring logs, well construction forms, and other related monitoring well forms for the well network are included in **Appendix B** of this HCR.

Assessment monitoring of these wells was established on April 9, 2018. The 40 C.F.R. § 257 well network locations are shown on **Figure 3-1**. 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 the EAP (NRT/OBG, 2017).

Groundwater samples are collected semi-annually and analyzed for the following laboratory 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 total dissolved solids [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.

4.1.2 Part 845 Well Installation and Groundwater Monitoring

In 2021, twelve additional monitoring wells (G03, G04, G05, G06, G06S, G07, G08, G09, G09M, G10, G11, and G54S) were installed along the perimeter of the EAP to assess the vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet bgs as specified in 35 I.A.C. § 845.620(b). Additionally, three leachate monitoring wells (XPW01, XPW02, and XPW03) were installed within the EAP unit to characterize the CCR materials. These locations and samples were discussed in Section 2.5.1.1. The boring logs, well construction forms, and other related monitoring well forms for the well network are included in **Appendix C** of this HCR. The well locations are shown on **Figure 3-1**.

Prospective Part 845 monitoring wells were sampled for eight rounds from February to August 2021 and the results were assessed for selection of the EAP Part 845 monitoring well network

presented in the groundwater monitoring plan. Groundwater samples were collected and analyzed for 35 I.A.C. § 845.600 parameters summarized in **Table C** below. Part 845 groundwater monitoring results are included below in **Section 4.2**.

Table C. 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)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1]Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential were recorded during sample collection.

4.2 East Ash Pond Groundwater Monitoring Results and Analysis

Groundwater data collected from the 40 C.F.R. § 257 network monitoring wells between 2015 and 2021 were supplemented with sampling of additional locations in 2021 and evaluated with respect to standards included in 35 I.A.C. § 845.600(a)(1). This data set was selected because it includes parameters (total metals) consistent with the parameter list in 35 I.A.C. § 845.600(a)(1). Based on this data set there were no reported concentrations of antimony, arsenic, barium, beryllium, cadmium, chloride, chromium, fluoride, lead, lithium, mercury, molybdenum, selenium, or TDS greater than the GWPSs. Results indicate that the parameters discussed in the following sections were greater than the applicable 35 I.A.C. § 845.600(a)(1) standards and are considered potential exceedances [1]. A summary of the groundwater analytical data is provided in **Table 4-1**, and groundwater elevations and field parameters are included in **Table 4-2**.

4.2.1 Boron

Boron is a primary indicator parameter for CCR leachate impacts on groundwater quality. Boron was consistently detected greater than the GWPS (2 milligrams per liter [mg/L]) in five downgradient uppermost aquifer wells (G06, G07, G08, G09, and G10). Uppermost aquifer wells G06, G07, G08, and G10 had boron concentrations greater than the GWPS during all sampling events in 2021, while G09 had boron concentrations greater than the GWPS during 7 of 8 monitoring rounds. These wells are located on the south-southeast side of the EAP. Concentrations in these wells ranged from 0.282 to 5.25 mg/L with the most elevated concentrations occurring in G07 and G08 (median

[1] Potential exceedances include results reported during the eight rounds of baseline groundwater monitoring that are greater than the applicable 35 I.A.C. § 845.600(a)(1) standards. The results are considered potential exceedances because they were compared directly to the standard and did not include an evaluation of background groundwater quality or apply the statistical methodologies proposed in the Groundwater Monitoring Plan (GMP). For simplicity, "GWPS" will be used hereafter in discussing potential exceedances. Exceedances will be determined following IEPA approval of the GMP.

concentrations of 4.67 and 4.53 mg/L, respectively) located on the southeast corner near the pre-construction intermittent stream.

No UCU wells nor LAU wells had concentrations greater than the GWPS.

4.2.2 Cobalt

Twelve downgradient uppermost aquifer wells (G03, G05, G06S, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D) and one background well (G01D) had concentrations greater than the GWPS (0.006 mg/L) on at least one occasion between 2016 and 2021. Background well G03 and downgradient wells G07, G08, and G11 had cobalt concentrations greater than the GWPS during one or two of the initial sampling events in 2021. Conversely, no cobalt concentrations greater than the GWPS were reported at G51D, G52D, and G53D in 2020 or 2021, although there were concentrations greater than the GWPS between 2015 and 2019. Concentrations at G05, G06S, G10, and G54D have consistently been greater than the GWPS. The range of concentrations in these wells is 0.0045 to 0.0268 mg/L, with a median concentration of 0.012 mg/L.

LAU well G09M had cobalt concentrations greater than the GWPS only during the initial two events following installation in 2021. Concentrations at this well ranged from 0.00162 to 0.0097 mg/L, with a median concentration of 0.0055 mg/L.

4.2.3 pH

UCU wells G54S and G151 had measurements of pH consistently less than the lower limit GWPS (6.5 standard units [SU]). The measurements of pH ranged from 5.5 to 6.4 SU.

Measurements of pH were detected less than the lower limit GWPS in eleven uppermost aquifer wells (background wells G01D and G02D, and downgradient wells G03, G05, G06S, G07, G09, G10, G11, G51D, G52D, G53D, and G54D). All uppermost aquifer wells listed previously have consistently had measurements of pH less than the lower limit GWPS in 2021 with the exception of wells G01D, G04, G06, and G10.

No LAU wells had measurements of pH less than the lower limit GWPS or greater than the upper limit GWPS.

4.2.4 Radium 226 and 228 Combined

Radium 226 and 228 combined was detected at a concentration greater than the GWPS (5 picoCuries per liter [pCi/L]) in upgradient uppermost aquifer well G02D during September 2020. Concentrations in this well range from 0.12 to 5.93 pCi/L with a median of 0.693 pCi/L.

No UCU wells nor LAU wells had concentrations greater than the GWPS.

4.2.5 Sulfate

Sulfate is also a primary indicator parameter of CCR leachate impacts on groundwater quality. Sulfate was detected at concentrations greater than the GWPS (400 mg/L) in downgradient uppermost aquifer wells G10 and G11. Uppermost aquifer well G11 had concentrations greater than the GWPS during every event in 2021 with exception of the initial sampling event. Uppermost aquifer well G10 had concentrations greater than the GWPS during the June and July

2021 sampling events. Concentrations at these wells ranged from 401 to 761 mg/L. No other wells in the uppermost aquifer had concentrations greater than the GWPS.

No UCU wells nor LAU wells had concentrations greater than the GWPS.

4.2.6 Thallium

Thallium was detected at concentrations greater than the GWPS (0.002 mg/L) at downgradient uppermost aquifer wells G05 and G11. Concentrations at G05 were greater than the GWPS during the seventh sample event in July 2021, while concentrations at G11 were greater than the GWPS in the eighth sample event. There were no other detections of thallium in these or any other wells in 2021.

No UCU wells nor LAU wells had concentrations greater than the GWPS.

5. EVALUATION OF POTENTIAL RECEPTORS

Geosyntec completed field work in 2021 to obtain information pertinent to Part 845. This section originates from information provided by Geosyntec (2021) and has been supplemented where needed.

5.1 Water Well Survey

A potable water well inventory was completed in 2021 utilizing federal and state databases to assess nearby pumping wells, drinking water receptors, and other uses of water in the vicinity of the EAP.

The following sources of information were queried to identify well locations, drinking water receptors, and other uses of water within 1,000 meters of the EAP boundary:

- USGS National Groundwater Monitoring Network (NGWMN)[2]
- ISGS Illinois Water and Related Wells (ILWATER) Map[3]
- USEPA Safe Drinking Water Information System (SDWIS)[4]
- IEPA Illinois Drinking Water Watch (DWW)[5]

The EAP is located atop one or more water-bearing units (**Figure D-1** in **Appendix D**). According to the USGS NGWMN, the EAP is located on the Southeastern Coastal Plain Aquifer System, which is designated as a principal aquifer. A principal aquifer is defined as a regionally extensive aquifer or aquifer system that has the potential to be used as a source of potable water. According to the ISGS ILWATER Map, the southern portion of the EAP, and the area adjacent to the Ohio River is located atop a major sand and gravel aquifer (**Appendix D**).

A review of the USEPA SDWIS and IEPA DWW databases for drinking water intakes in the vicinity of the EAP yielded one result for public water systems (PWS) within 1,000 meters of the Site. The Joppa PWS (Water System ID IL1270100), which was reported to serve 462 people, was identified to be approximately 870 meters to the southeast and downgradient of the EAP. However, historical field verification has identified the actual location of the well at approximately 1,070 meters from the EAP. The Joppa PWS obtains drinking water from groundwater. Based on the well log, it is possible that potable wells of the Joppa PWS are hydraulically connected to the uppermost aquifers of the EAP.

A search of the ILWATER Map identified 17 wells, including two co-located wells, within 1,000 meters of the EAP (**Figure D-2** in **Appendix D**). Under normal conditions, five of the wells (121270005000, 121270000100, 121270005400, 121272094200, and 121270005500) are located downgradient from the EAP, eight are located side gradient (121270003100, 121270005300, 121270003000, 121270005100, 121270005200, 121272106100,

[2] USGS NGWMN: https://cida.usgs.gov/ngwmn/index.jsp
[3] ISGS ILWATER Map: https://prairieresearch.maps.arcgis.com/apps/webappviewer/index.html?id=e06b64ae0c814ef3a4e43a191cb57f87
[4] USEPA SDWIS: https://www.epa.gov/enviro/sdwis-search
[5] IEPA Illinois DWW: http://water.epa.state.il.us/dww/index.jsp

121270014600, and 121272103900), and the remaining four are located upgradient (121270015800, 121270011100, 121272067500, and 121272103000).

Five water wells within 1,000-meters of the EAP, including two downgradient wells (121270011100, 121272094200), one cross-gradient well (121272106100), and two upgradient wells (121270011100, 121272103000) were identified to have depths ranging from 65 feet to 94 feet bgs. Based on geologic cross-sections of the EAP, the sand layer beneath the EAP typically occurs from 50 to 100 feet bgs. Based on these depths the wells are likely to be hydraulically connected to the uppermost aquifer beneath the EAP.

5.2 Surface Water

A search was performed utilizing the United States Fish and Wildlife Service (USFWS) Wetlands Mapper[6] and the USGS National Map[7] for surface water bodies within 1,000 meters of the EAP.

The predominant surface water bodies near the EAP are the Ohio River, located to the south of the site, and Bayou Creek, located to the east of the site. A USGS stream gage for the Ohio River at Olmsted, Illinois (#03612600) is located 12 river miles southwest (downstream) of the JPP. The gage datum elevation is 278.44 feet NGVD29. Daily gage heights for the periods of June 1, 2020 to June 1, 2021 are shown on the graph in **Section 3.3.2**. The gage height of 15 feet, representing approximate base flow, occurs at elevation of about 278.62 feet NAVD88.

According to the USFWS Wetlands Mapper and USGS National Map, several small, scattered ponds are located in the vicinity of the EAP. In addition, freshwater emergent wetlands and freshwater forested/shrub wetlands were mapped along the banks of the Ohio River and on several areas to the north, west, and southeast of the EAP. Several unnamed streams were also identified to the east and southwest of the EAP, most of which connect to the Ohio River. A map of wetlands and surface waters in the vicinity of the EAP is presented in **Figure D-3** in **Appendix D**.

The USGS National Map places the EAP within the Bayou Creek-Ohio River Watershed (Hydrologic Unit Code [HUC] 12: 051402060701), which is part of the larger Lower Ohio River watershed (HUC 8: 05140206) and drains to the Ohio River. The HUC watershed location is presented in **Figure D-4** within **Appendix D**.

Based on groundwater elevation contour maps (**Figures 3-3 through 3-5** and **Appendix E**), between 2018 to 2021, groundwater predominantly flows to the south, towards the Ohio River. Due to the downgradient location and proximity of the Ohio River to the EAP, the Ohio River is likely to be hydraulically connected to the uppermost aquifer beneath the EAP.

5.3 Nature Preserves, Historic Sites, Endangered/Threatened Species

A comprehensive search of the Illinois Department of Natural Resources (IDNR) Natural Heritage Database[8] for natural areas and protected areas within 1,000 meters of the Site was performed. No natural or protected areas were identified within 1,000 meters of the EAP.

[6] USFWS Wetlands Mapper: https://www.fws.gov/wetlands/data/mapper.html
[7] USGS National Map: https://apps.nationalmap.gov/viewer/
[8] IDNR Natural Heritage Database: https://www2.illinois.gov/dnr/conservation/NaturalHeritage/Pages/NaturalHeritageDatabase.aspx

According to the Illinois Threatened and Endangered Species by County[9] database, 61 threatened and endangered species are located in Massac County, including 41 endangered and 20 threatened species (**Appendix D**). However, the habitats were identified at the county level only.

Additionally, a search of the IDNR Historic Preservation Division[10] database for historic sites in the vicinity of the Site yielded no results within 1,000 meters of the EAP. The Illinois State Archaeological Survey (ISAS)[11] databases were also searched and yielded no results within 1,000 meters of the EAP.

[9] Illinois Threatened and Endangered Species by County
[10] IDNR Historic Preservation Division: https://www2.illinois.gov/dnrhistoric/Pages/default.aspx
[11] ISAS: https://www.isas.illinois.edu/

6. CONCLUSIONS AND CONCEPTUAL SITE MODEL

Based on extensive site investigation and monitoring, the EAP has been characterized and a detailed CSM has been developed. Results of these hydrogeologic studies include geologic, hydrogeologic, and groundwater quality data collected with a focus on the EAP (Part 845 regulated CCR Unit and subject of this HCR). The data were summarized and evaluated for changes in groundwater conditions since the previous investigations; available groundwater quality data for the Ash Pond was compared to the Part 845 Standards.

The results of the hydrogeologic and groundwater quality evaluation are:

- There are five different unlithified materials in addition to the bedrock in the vicinity of the EAP as summarized below in descending order:
  - Fill (predominantly CCR within the EAP, but also including constructed berms and railroad embankments).
  - Equality Formation (clays and silts interbedded with thin sand lenses).
  - Silt Unit (undifferentiated silts of the Peoria, Roxana, and Loveland Formations).
  - Metropolis Formation (silt and clay, with interbedded sandy layers).
  - McNairy Formation (split into two units: the upper, which consists of predominantly sand with gravelly sand, clay and silt lenses, and the lower, which is composed of clay and silt).
- Bedrock underlying the EAP is the Mississippian bedrock which consists of the Salem Limestone.
- Five water bearing layers have been identified at the EAP based on stratigraphic relationships and common hydrogeologic characteristics, these include the following in descending order:
  - CCR: saturated CCR, consisting primarily of fly ash and bottom ash at thicknesses up to 50 feet.
  - UCU: low permeability clays, silts and sandy lenses within the Equality Formation, Silt Unit, and Metropolis Formation. This unit is thinnest in the southeast portion of the EAP.
  - Uppermost Aquifer: Predominantly composed of high permeability sands of the Upper McNairy Formation, with limited occurrences of silt, clay, and gravel layers within the unit. This unit is at the highest elevation and closest to the CCR fill near G06.
  - LCU: low permeability silt and clay of the Lower McNairy Formation that overlies bedrock at the site. Thicknesses range from 5 to 14 feet based on boring logs and potable well logs advanced to bedrock near the Site.
  - LAU: Bedrock composed of the Salem Limestone.
- The elevations of water within the EAP are greater than the surrounding areas but there is no evidence that the EAP is affecting groundwater flow directions.
- Groundwater flow in the uppermost aquifer is generally to the south toward the Ohio River with seasonal variations to the southeast and southwest. There have been no observations of groundwater flow direction beneath the EAP being impacted by the Ohio River based on measurements collected between 2015 and 2021.

- As determined by the detailed geologic information provided, and the hydrogeologic and groundwater quality data, groundwater within the uppermost aquifer at the Ash Pond is classified as Class I – Potable Resource Groundwater.
- Potential exceedances of 35 I.A.C. § 845.600 GWPSs were detected in monitoring wells downgradient of the EAP in the various hydrostratigraphic units as follows:
  - Boron – at five uppermost aquifer wells G06, G07, G08, G09, and G10.
  - Cobalt – at thirteen uppermost aquifer wells (G01D, G03, G05, G06S, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D), and at LAU well G09M.
  - pH – at two UCU wells (G54S, and G151), and at thirteen uppermost aquifer wells (G01D, G02D, G03, G05, G06S, G07, G09, G10, G11, G51D, G52D, G53D, and G54D).
  - Radium 226 and 228 combined – at uppermost aquifer well G02D.
  - Sulfate – at two uppermost aquifer wells G10 and G11.
  - Thallium – at uppermost aquifer wells G05, and G11.

This HCR satisfies Part 845 content requirements specific to 35 I.A.C. § 845.620(b) (Hydrogeologic Site Characterization) for the EAP at the JPP.

7. REFERENCES

AECOM, 2016a. CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Plan Control System Plan for East Ash Pond at Joppa Power Station. October 2016.

AECOM, 2016b. 30% Design Data Package for Dynegy, Joppa East Ash Pond. January 15, 2016.

Algermissen, S.T., Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.L., 1982. Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States. U.S. Geological Survey Open-File Report 82-1033, 99 p. (Plate 2).

Berg, R.C. and J.P. Kempton, 1987. Stack-Unit Mapping of Geologic Materials in Illinois to a Depth of 15 Meters. Illinois State Geological Survey Circular 542. Champaign, Illinois.

Geosyntec, 2021. Illinois Administrative Code Part 845 Data Gap Analysis, Joppa Power Plant, East Ash Pond, Joppa, IL. Certified 8/16/2021.

Hanson Professional Services Inc. (Hanson), 2009a. Hydrogeologic Report (Section 3.0), CCB Management Facility, Joppa Power Generating Station, June 2009.

Hanson Professional Services Inc. (Hanson), 2009b. Ash Pond Hydrogeologic Assessment Plan, Electric Energy, Inc., Joppa Power Station, October 2009.

Illinois Environmental Protection Agency (IEPA), 2021. In the Matter of: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Proposed New Title 35 Illinois Administration Code 845, Addendum. April 15, 2021.

Illinois State Geological Survey (ISGS), 2018. Illinois Coal Mines (ILMINES) https://prairieresearch.maps.arcgis.com/apps/webappviewer/index.html?id=e38e9769e1c04ec29e41d d5ba1c59bd7. Accessed 11 February 2021.

Kolata, D.R., 2005, Bedrock Geology of Illinois: Illinois State Geological Survey map, scale 1:500,000.

Leighton, M.M., G.E. Ekblaw, and L. Horberg, 1948. Physiographic Divisions of Illinois: Illinois State Geological Survey, Report of Investigations 129, 19 p.

Natural Resource Technology, Inc. (NRT), 2013. Phase I Hydrogeological Assessment Report, Coal Combustion Product Impoundments, Joppa Generating Station, Joppa, IL, July 23, 2013.

Natural Resource Technology, An OBG Company (NRT/OBG), 2017. Sampling and Analysis Plan. Joppa East Ash Pond, Joppa Power Station, Joppa Illinois, Project No. 2285, Revision 0, October 17, 2017.

Nelson, W.J., 1993. Structural Features in Illinois, Plates 1 and 2. Illinois State Geological Survey, Bulletin 100. Champaign, Illinois.

Nelson, W.J., 1995. Structural Features in Illinois. Illinois State Geological Survey, Bulletin 100. Champaign, Illinois.

Nelson, W.J., F.B. Denny, L.R. Follmer, and J.M. Masters, 1999a. Quaternary grabens in southernmost Illinois: Deformation near an active interplate seismic zone: Tectonophysics, v. 305, p. 381-397.

Nelson, W.J., J.M. Masters, and L.R. Follmer, 1999b. Evolution of lower Ohio and Tennessee Rivers, Miocene to Recent (abs.): Boulder, Colorado, Geological Society of America, Abstracts with Programs, Annual meeting, Denver, p. 48.

Nelson, W.J., 2007. Geology of the Bandana Quadrangle Pulaski and Massac Counties, Illinois: Illinois State Geological Survey.

Nelson, W.J. and Masters, J.M., 2008. Geology of Joppa Quadrangle, Massac County, Illinois. Illinois Department of Natural Resources. Illinois State Geological Survey. Champaign, Illinois.

O'Brien & Gere Engineers, Inc. (OBG), 2010. Dam Safety Assessment of CCW Impoundments. Joppa Plant, Prepared for: US Environmental Protection Agency, Washington, DC, September 24, 2010.

United States Geological Survey (USGS), 1995. Groundwater Atlas of the United States. Hydrologic Investigations Atlas 730-K, 1995.

United States Geological Survey (USGS). 2021. *National Water Information System data available on the World Wide Web (Peak Streamflow for Illinois, USGS 05558300, Ohio River at Olmsted, IL)*. Accessed 4 June 2021 at URL: https://waterdata.usgs.gov/il/nwis/uv?03612600

Willman, H.B., J.C. Frye, J.A. Simon, K.E. Clegg, D.H. Swann, E. Atherton, C. Collinson, J.A. Lineback, T.C. Buschbach, and H.B. Willman, 1967. Geologic Map of Illinois: Illinois State Geological Survey map, scale 1:500,000.

Willman, H.B., 1973. Geology Along the Illinois Waterway – A Basis for Environmental Planning. Illinois State Geological Survey, Circular 478. Champaign, Illinois.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975. Handbook of Illinois Stratigraphy, Bulletin 95, Illinois State Geological Survey, Urbana, IL, 261 pp.

TABLES

TABLE 2-1. GEOTECHNICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample ID	Field Location ID	Top of Sample (ft bgs)	Bottom of Sample (ft bgs)	Moisture Content (%)	Dry Density (pcf)	Specific Gravity	Calculated Porosity [1] (%)	Vertical Hydraulic Conductivity (cm/s)	LL	PL	PI	Laboratory USCS	Gravel (%)	Sand (%)	Fines (%)
Equality Formation															
SB-G03-(32-34)-20210202	G03	32	34	15.5	112.7	2.659	32.1	4.7E-07	27	16	11	SC	0.6	53.8	45.6
SB-G09M-(16-18)-20210127	G09M	16	18	20.6	105.4	2.666	36.7	8.3E-08	39	16	23	CL	0	5.0	95.0
SB-G11-(24-26)-20210119	G11	24	26	18.5	109.1	2.688	35.0	5.6E-08	36	15	21	CL	0	11.5	88.5
Metropolis Formation															
SB-G09M-(46-48)-20210127	G09M	46	48	19.8	105.7	2.715	37.6	3.5E-07	35	15	20	CL	0	17.2	82.8
McNairy Formation															
SB-G03-(60-62)-20210202	G03	60	62	20.0	- -	2.671	- -	- -	- -	- -	- -	SP	1.5	94.4	4.1
SB-G09M-(82-84)-20210127	G09M	82	84	7.6	100.0	2.686	40.4	- -	- -	- -	- -	SP	22.7	75.4	1.9
SB-G09M-(112-114)-20210127	G09M	112	114	25.5	87.0	2.675	47.9	- -	- -	- -	- -	- -	0.7	84.1	15.2
SB-G11-(56-58)-20210119	G11	56	58	14.4	110.0	2.661	33.8	- -	NP	NP	NP	SM	0.2	87.7	12.1
CCR															
SB-XPW01-(6-8)-20210120	XPW01	6	8	34.7	85.6	2.711	49.4	2.1E-05	NP	NP	NP	SM	26.3	45.4	28.3
SB-XPW01-(46-48)-20210120	XPW01	46	48	31.7	87.7	2.675	47.5	2.8E-07	25	20	5	CL-ML	0	18.7	81.3
SB-XPW02-(24-26)-20210120	XPW02	24	26	47.6	74.0	2.567	53.8	- -	NP	NP	NP	SM	9.3	74.1	16.6
SB-XPW03-(22-24)-20210121	XPW03	22	24	45.4	- -	2.410	- -	- -	- -	- -	- -	- -	0	4.2	95.8
SB-XPW03-(36-38)-20210121	XPW03	36	38	46.5	65.7	1.999	47.4	1.8E-07	46	31	15	ML	0	9.4	90.6

[O: NMP 08/19/21; U: CJC 08/24/21; C: LDC 08/27/21]

Notes:
[1] Porosity calculated as relationship of bulk density (p_b) to particle density (p_d) (n = 100[1- (p_b/p_d)])
- - = Not Applicable/Not Analyzed
% = Percent
bgs = below ground surface
CCR = coal combustion residuals
cm/s = centimeters per second
ft = foot/feet
LL = Liquid limit
NP = Non-Plastic
pcf = pounds per cubic foot
PI = Plasticity Index
PL = Plastic Limit

USCS = Unified Soil Classification System
CL = Lean Clay
CL-ML = Silty Lean Clay
SC = Clayey Sand
SM = Silty Sand
SP = Poorly-Graded Sand

RAMBOLL

R000739

TABLE 2-2. ASH ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Depth (ft BGS)	Sample Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Calcium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Lead (mg/kg)	Lithium (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)
XPW01	4-6	01/20/2021	2.8	16.4	3080	3.7	542	1.41	141000	49.4	22	34.2	30.9	0.758	7.42	8.29	<0.93
XPW01	46-48	01/20/2021	<0.38	8.77	105	0.72	35.1	<0.19	3280	18.3	8.46	15.1	12.2	0.015	32.2	<0.94	0.32
XPW02	4-6	01/20/2021	3.25	21.1	2690	3.18	536	1.61	152000	57.7	22.9	32	28.2	0.583	9.93	6.65	1.13
XPW02	24-26	01/20/2021	2.19	44.1	193	3.86	334	2.37	34600	55.8	11.8	22.4	10.4	<0.014	7.99	2.23	2.11
XPW03	6-8	01/21/2021	4.07	55.8	976	3.3	308	0.95	34700	44.8	11.8	60.3	16.2	0.029	11.6	2.15	1.33
XPW03	34-36	01/21/2021	0.41	52.7	149	1.49	92.6	0.65	4010	31.2	8.26	42.8	17.5	0.33	213	6.94	0.46

Notes:
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
BGS = below ground surface
ft = feet
mg/kg = milligrams per kilogram

generated 10/05/2021, 4:11:31 PM CDT

RAMBOLL

R000740

TABLE 2-3. POREWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)
XPW01	03/05/2021	<0.001	0.0243	0.165	<0.001	10.4	<0.001	162	10	<0.0015	<0.001	0.67	<0.001	<0.003	<0.0002	0.46	8.0	1.03	<0.001	345	<0.002
XPW01	03/24/2021	<0.001	0.0346	0.161	<0.001	9.58	<0.001	158	9	<0.0015	<0.001	0.55	<0.001	<0.003	<0.0002	0.36	8.4	0.746	<0.001	355	<0.002
XPW01	04/14/2021	<0.001	0.0362	0.154	<0.001	9.42	<0.001	156	7	<0.0015	<0.001	0.57	<0.001	<0.003	<0.0002	0.362	8.2	0.226	<0.001	355	<0.002
XPW01	05/12/2021	<0.002	0.0329	0.162	<0.001	10.2	<0.001	166	6	<0.001	<0.001	0.62	<0.001	<0.005	<0.0002	0.419	8.4	0.158	<0.001	309	<0.001
XPW01	07/21/2021	<0.001	0.0529	0.175	<0.001	10.1	<0.001	160	6	<0.0015	<0.001	0.54	<0.001	<0.003	<0.0002	0.448	7.3	1.16	<0.001	328	<0.002
XPW02	03/04/2021	0.001	0.0379	0.0342	<0.001	12.1	<0.001	591	130	<0.0015	<0.001	0.42	<0.001	0.0691	<0.0002	0.855	8.0	0.511	<0.001	2380	<0.002
XPW02	03/24/2021	<0.001	0.0366	0.0271	<0.001	12.2	<0.001	484	176	<0.0015	<0.001	0.45	<0.001	0.0647	<0.0002	1.03	8.0	0.474	<0.001	2830	<0.002
XPW02	04/14/2021	<0.001	0.0379	0.0283	<0.001	11.5	<0.001	551	110	<0.0015	<0.001	0.44	<0.001	0.0616	<0.0002	0.781	7.9	0.266	<0.001	2410	<0.002
XPW02	05/12/2021	<0.002	0.0415	0.0287	<0.001	10.8	<0.001	495	134	0.00116	<0.001	0.41	0.00127	0.063	<0.0002	0.846	7.8	0.783	<0.001	2410	<0.001
XPW02	07/21/2021	<0.001	0.0388	0.0226	<0.001	12	<0.001	494	179	<0.0015	<0.001	0.4	<0.001	0.0761	<0.0002	0.856	7.8	1.31	<0.001	2330	<0.002
XPW03	03/04/2021	0.0116	0.401	0.0116	<0.001	12.2	<0.001	17.3	25	<0.0015	<0.001	0.26	<0.001	0.168	<0.0002	0.362	10.5	0.071	0.0102	133	<0.002
XPW03	03/24/2021	0.0105	0.402	0.0124	<0.001	11.6	<0.001	15.9	25	<0.0015	<0.001	0.26	<0.001	0.16	<0.0002	0.322	10.6	0.298	0.0144	138	<0.002
XPW03	04/14/2021	0.0117	0.439	0.0118	<0.001	9.3	<0.001	15.1	27	<0.0015	<0.001	0.26	<0.001	0.157	<0.0002	0.334	10.5	0.0298	0.0156	152	<0.002
XPW03	05/12/2021	0.012	0.452	0.012	<0.001	11.7	<0.001	16.4	25	<0.001	<0.001	0.25	<0.001	0.163	<0.0002	0.358	10.7	0.0533	0.00688	155	<0.001
XPW03	07/21/2021	0.0103	0.467	0.0114	<0.001	11.6	<0.001	15.3	26	<0.0015	<0.001	0.26	<0.001	0.193	<0.0002	0.329	10.0	1.08	0.0171	148	<0.002

Notes:
Field readings are reported with as many significant figures as provided by analytical laboratory.
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
mg/L = milligrams per liter
pCi/L = picocuries per liter
SU = standard units
generated 10/05/2021, 4:26:51 PM CDT

RAMBOLL

R000741

TABLE 2-4. SOIL ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Geologic Unit	Sample Depth (ft BGS)	Sample Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Calcium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Lead (mg/kg)	Lithium (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)
G03	Equality Formation	30-32	02/02/2021	<0.37	2.59	347	0.71	<4.63	<0.18	1590	18.7	110	27.8	12.6	<0.012	0.38	<0.91	0.26
G03	McNairy Formation	58-60	02/02/2021	<0.37	0.3	6.01	<0.28	<4.72	<0.19	153	4.69	0.82	1.3	0.86	<0.012	<0.19	<0.94	<0.19
G09M	Equality Formation	10-12	01/26/2021	<0.39	3.34	93.6	0.46	<4.55	<0.18	1740	16.6	5.68	7.76	9.67	0.021	0.37	<0.91	<0.18
G09M	McNairy Formation	82-84	01/27/2021	<0.38	6.34	19.6	0.89	<4.55	<0.18	277	19.4	7.69	3.48	0.78	<0.012	1.04	<0.91	<0.18
G09M	McNairy Formation	110-112	01/27/2021	<0.38	4.44	11.5	<0.29	<4.9	<0.2	420	7.43	0.8	3.76	1.72	<0.012	0.51	<0.98	<0.2
G09M	Salem Limestone	142-144	01/28/2021	<0.38	1.88	41.9	<0.29	<4.81	2.75	333000	6.32	2.94	2.02	2.03	<0.027	0.24	<0.96	<0.19
G11	Equality Formation	22-24	01/19/2021	0.79	3.5	173	0.74	<4.55	0.43	1370	15.7	2.72	8.64	5.69	<0.011	0.36	<0.91	0.41
G11	McNairy Formation	58-60	01/19/2021	<0.37	1.15	21.6	0.3	<4.55	<0.18	430	6.05	1.29	3	2.03	<0.011	<0.18	<0.91	<0.18

Notes:
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
BGS = below ground surface
ft = foot or feet
mg/kg = milligrams per kilogram

generated 10/05/2021, 4:27:00 PM CDT

RAMBOLL

R000742

TABLE 3-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Well Number	HSU	Date Constructed	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)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
G01D	UA	08/14/2015	364.19	364.19	Top of Disk	361.50	54.19	63.85	307.31	297.65	64.40	297.10	9.7	2	37.220429	-88.857179
G02D	UA	08/13/2015	363.65	363.65	Top of Disk	360.82	62.21	71.84	298.61	288.98	72.40	288.50	9.6	2	37.220715	-88.853311
G03	UA	02/02/2021	357.87	357.87	Top of PVC	354.84	55.00	65.00	302.90	292.90	65.00	289.80	10	2	37.220682	-88.850376
G04	UA	02/02/2021	359.07	359.07	Top of PVC	356.15	50.00	60.00	309.10	299.10	60.00	296.20	10	2	37.21804	-88.849321
G05	UA	02/01/2021	361.21	361.21	Top of PVC	358.45	50.00	60.00	311.20	301.20	60.00	298.50	10	2	37.21719	-88.849014
G06	UA	01/29/2021	355.24	355.24	Top of PVC	352.60	75.00	85.00	280.20	270.20	85.00	267.60	10	2	37.212929	-88.848893
G06S	UA	01/28/2021	355.35	355.35	Top of PVC	352.47	30.00	40.00	325.30	315.30	40.00	312.50	10	2	37.212957	-88.84889
G07	UA	01/29/2021	353.53	353.53	Top of PVC	350.34	50.00	60.00	303.50	293.50	60.00	290.30	10	2	37.211001	-88.848969
G08	UA	01/28/2021	343.54	343.54	Top of PVC	341.72	75.00	85.00	268.50	258.50	85.00	256.70	10	2	37.210531	-88.851015
G09	UA	01/31/2021	351.70	351.70	Top of PVC	348.69	59.50	69.50	292.20	282.20	69.50	279.20	10	2	37.210336	-88.854116
G09M	LAU	01/28/2021	351.53	351.53	Top of PVC	348.60	145.00	155.00	206.50	196.50	155.00	193.60	10	2	37.210341	-88.85413
G10	UA	02/01/2021	353.49	353.49	Top of PVC	350.75	60.30	70.30	293.20	283.20	70.30	280.50	10	2	37.211272	-88.855841
G11	UA	01/19/2021	366.55	366.55	Top of PVC	363.38	55.70	65.70	310.90	300.90	65.70	297.70	10	2	37.214408	-88.85633
G51D	UA	08/18/2015	363.85	363.85	Top of PVC	361.10	49.61	59.27	311.49	301.83	59.90	301.20	9.7	2	37.216016	-88.855653
G52D	UA	08/19/2015	348.41	348.41	Top of PVC	345.88	69.85	79.55	276.03	266.33	80.01	265.90	9.7	2	37.209626	-88.852943
G53D	UA	08/21/2015	355.47	355.47	Top of PVC	352.16	47.29	56.89	304.87	295.27	57.33	294.20	9.6	2	37.215069	-88.849367
G54S	UCU	01/22/2021	356.57	356.57	Top of PVC	353.58	34.70	44.70	321.90	311.90	44.70	308.90	10	2	37.212291	-88.857497
G54D	UA	08/11/2015	357.03	357.03	Top of PVC	353.71	69.96	79.66	283.75	274.05	80.14	273.60	9.7	2	37.212264	-88.857485
G151	UCU	06/19/2010	363.38	363.38	Top of PVC	360.79	31.70	41.70	329.11	319.11	41.70	318.80	10	2	37.216047	-88.855649
G152	UCU	06/21/2010	351.07	351.07	Top of PVC	348.55	14.70	24.70	333.85	323.85	24.70	323.60	10	2	37.210848	-88.854907
G152B	UCU	01/30/2013	347.56	347.56	Top of PVC	345.84	34.40	44.40	311.34	301.34	44.60	301.20	10	2	37.209621	-88.852935
G153	UCU	06/18/2010	354.11	354.11	Top of PVC	351.56	29.70	39.70	321.98	311.98	39.70	311.70	10	2	37.215057	-88.849378
XPW01	CCR	01/20/2021	383.36	383.36	Top of PVC	380.75	48.70	53.70	334.70	329.70	53.70	327.10	5	2	37.216965	-88.852074

RAMBOLL

R000743

TABLE 3-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Well Number	HSU	Date Constructed	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)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
XPW02	CCR	01/21/2021	376.05	376.05	Top of PVC	373.23	24.70	29.70	351.30	346.30	29.70	343.60	5	2	37.215865	-88.855001
XPW03	CCR	01/21/2021	381.52	381.52	Top of PVC	378.65	31.70	36.70	349.80	344.80	36.70	342.00	5	2	37.212153	-88.85542
XSG01	CCR	--	--	371.78	Staff gauge	--	--	--	--	--	--	--	--	--	37.21517	-88.8498
SG02	SW	--	--	--	Staff gauge	--	--	--	--	--	--	--	--	--	37.207287	-88.860503

Notes:
All elevation data are presented relative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
-- = data not available
BGS = below ground surface
CCR = coal combustion residuals
ft = foot or feet
HSU = Hydrostratigraphic Unit
LAU = lower aquifer unit
PVC = polyvinyl chloride
SW = surface water
UA = uppermost aquifer
UCU = upper confining unit

generated 10/07/2021, 3:22:28 PM CDT

RAMBOLL

R000744

TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Date	G06S Groundwater Elevation (ft NAVD88)	G06 Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	UA	UA				
3/4/2021	317.76	317.63	0.13	45.16	0.003	down
3/24/2021	324.85	323.74	1.11	44.87	0.025	down
4/13/2021	323.95	323.14	0.81	44.87	0.018	down
5/11/2021	319.60	319.12	0.48	47.00	0.010	down
6/14/2021-6/15/2021	317.01	316.38	0.63	44.41	0.014	down
6/1/2021	317.66	317.08	0.58	45.06	0.013	down
7/6/2021	315.88	315.44	0.44	43.28	0.010	down
7/20/2021	315.80	315.42	0.38	43.20	0.009	down
			Middle of screen elevation G06S			317.5
			Middle of screen elevation G06			272.6

Date	G09 Groundwater Elevation (ft NAVD88)	G09M Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	UA	LAU				
3/4/2021	318.48	321.48	-3.00	85.59	-0.035	up
3/25/2021	322.65	324.08	-1.43	85.59	-0.017	up
4/14/2021	319.59	322.19	-2.60	85.59	-0.030	up
5/11/2021	316.57	321.42	-4.85	85.59	-0.057	up
6/1/2021	311.02	317.47	-6.45	85.59	-0.075	up
6/14/2021-6/15/2021	311.68	318.47	-6.79	85.59	-0.079	up
7/6/2021	313.60	316.93	-3.33	85.59	-0.039	up
7/21/2021	312.34	317.29	-4.95	85.59	-0.058	up
			Middle of screen elevation G09			284.2
			Middle of screen elevation G09M			198.6

TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Date	G101 Groundwater Elevation (ft NAVD88) UCU	G01D Groundwater Elevation (ft NAVD88) UA	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
3/24/2021	319.95	327.02	-7.07	11.87	-0.596	up
4/14/2021	319.74	325.92	-6.18	11.87	-0.521	up
5/12/2021	319.37	324.12	-4.75	11.87	-0.400	up
6/1/2021	323.24	320.46	2.78	11.87	0.234	down
6/14/2021-6/15/2021	318.91	322.10	-3.19	16.45	-0.194	up
7/6/2021	321.42	321.38	0.04	11.87	0.003	down
07/20/2021-07/21/2021	321.17	320.89	0.28	11.87	0.024	down
			Middle of screen elevation G101			314.3
			Middle of screen elevation G01D			302.5

Date	G151 Groundwater Elevation (ft NAVD88) UCU	G51D Groundwater Elevation (ft NAVD88) UA	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
3/3/2021	326.64	321.47	5.17	19.98	0.259	down
3/24/2021	330.47	326.10	4.37	17.43	0.251	down
4/14/2021	329.35	325.45	3.90	17.43	0.224	down
5/11/2021	329.35	323.14	6.21	17.43	0.356	down
6/1/2021	325.68	321.10	4.58	19.02	0.241	down
6/14/2021	326.03	320.84	5.19	19.37	0.268	down
7/6/2021	324.48	322.67	1.81	17.82	0.102	down
7/20/2021	324.77	319.59	5.18	18.11	0.286	down
			Middle of screen elevation G151			324.1
			Middle of screen elevation G51D			306.7

TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Date	G152B Groundwater Elevation (ft NAVD88) UCU	G52D Groundwater Elevation (ft NAVD88) UA	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
3/3/2021	338.25	327.46	10.79	35.26	0.306	down
3/24/2021-3/25/2021	338.38	323.36	15.02	35.26	0.426	down
4/14/2021	336.25	321.87	14.38	35.26	0.408	down
5/12/2021	338.96	309.79	29.17	35.26	0.827	down
6/1/2021	334.71	324.23	10.48	35.26	0.297	down
6/15/2021	335.06	323.91	11.15	35.26	0.316	down
7/6/2021	332.91	323.36	9.55	35.26	0.271	down
7/20/2021	332.91	322.91	10.00	35.26	0.284	down
			Middle of screen elevation G152B			306.4
			Middle of screen elevation G52D			271.2

Date	G153 Groundwater Elevation (ft NAVD88) UCU	G53D Groundwater Elevation (ft NAVD88) UA	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
3/3/2021	319.04	319.40	-0.36	18.97	-0.019	up
3/24/2021-3/25/2021	324.74	325.15	-0.41	16.79	-0.024	up
4/13/2021-4/14/2021	324.60	324.23	0.37	16.79	0.022	down
5/11/2021	320.59	320.99	-0.40	20.52	-0.019	up
6/1/2021	319.71	319.65	0.06	19.64	0.003	down
6/14/2021	320.19	320.17	0.02	20.12	0.001	flat
7/6/2021	318.17	318.02	0.15	18.10	0.008	down
7/20/2021	317.91	317.83	0.08	17.84	0.004	down
			Middle of screen elevation G153			316.9
			Middle of screen elevation G53D			300.1

TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Date	G54S Groundwater Elevation (ft NAVD88)	G54D Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	UCU	UA				
3/3/2021	310.25	317.69	-7.44	31.35	-0.237	up
3/24/2021	311.48	324.08	-12.60	32.58	-0.387	up
4/14/2021	312.84	322.45	-9.61	33.94	-0.283	up
5/12/2021	315.44	319.02	-3.58	36.54	-0.098	up
6/1/2021	312.65	314.79	-2.14	33.75	-0.063	up
6/14/201	314.30	314.93	-0.63	35.40	-0.018	up
7/6/2021	316.75	314.73	2.02	37.85	0.053	down
7/20/2021	318.87	314.77	4.10	39.97	0.103	down
			Middle of screen elevation G54S			313.9
			Middle of screen elevation G54D			278.9

[O: RAB 8/20/21, U: CJC 8/26/21, C: LDC 8/30/21, U: RAB 10/6/21, C: KLT 10/6/21]

Notes:
[1] Distance change was calculated using the midpoint of the piezometer screen and water table surface. If the water table surface was above the top of the monitoring well screen, then distance change was calculated using the midpoint of both screens.
[2] Vertical gradients between ±0.0015 are considered flat, and typically have less than 0.02 foot difference in groundwater elevation between wells.
dh = head change
dl = distance change
ft = foot/feet
LAU = lower aquifer unit
NAVD88 = North American Vertical Datum of 1988
UA = uppermost aquifer
UCU = upper confining unit

TABLE 3-3. FIELD HYDRAULIC CONDUCTIVITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Well ID	Gradient Position	Bottom of Screen Elevation (ft NAVD88)	Screen Length [1] (ft)	Field Identified Screened Material	Slug Type	Analysis Method	Falling Head (Slug In) K (cm/s)			Rising Head (Slug Out) K (cm/s)			Average Hydraulic Conductivity (cm/s)	Minimum Hydraulic Conductivity (cm/s)	Maximum Hydraulic Conductivity (cm/s)	Hydraulic Conductivity Geometric Mean (cm/s)
							1	2	3	1	2	3				
Uppermost Aquifer																
G06	D	267.60	10.0	Gravely Silty Clay	Solid	Bouwer-Rice	1.20E-03	1.02E-03	---	1.03E-03	8.14E-04	---	1.02E-03	4.84E-04	1.18E-02	3.10E-03
G07	D	290.34	10.0	Sand	Solid	Bouwer-Rice	6.96E-03	1.18E-02	8.98E-03	8.22E-03	1.05E-02	1.02E-02	9.45E-03			
G08	D	256.72	10.0	Sand	Solid	Bouwer-Rice	5.51E-03	5.82E-03	---	2.92E-03	3.69E-03	---	4.49E-03			
G09	D	279.19	10.0	Sandy Gravel	Solid	Bouwer-Rice	2.62E-03	---	---	1.55E-03	---	---	2.08E-03			
G10	D	280.45	10.0	Sand and Sandy Gravel	Solid	Bouwer-Rice	1.36E-03	8.69E-04	---	4.84E-04	5.25E-04	---	8.08E-04			
G11	U	297.68	10.0	Sand	Solid	Bouwer-Rice	7.15E-03	6.36E-03	---	6.72E-03	7.23E-03	---	6.86E-03			
Lower Aquifer Unit																
G09M	D	193.60	10.0	Bedrock	Solid	Bouwer-Rice	2.73E-04	5.82E-04	---	3.78E-04	4.16E-04	---	4.12E-04	2.73E-04	5.82E-04	3.97E-04
CCR Fill																
XPW-02	NA	343.53	5.0	Ash	Solid	Bouwer-Rice	9.82E-03	9.25E-03	---	4.46E-03	5.39E-03	---	7.23E-03	4.46E-03	1.65E-01	1.29E-02
XPW-03	NA	341.95	5.0	Ash	Solid	Springer-Gelhar	---	---	---	1.65E-01	---	---	1.65E-01			

Notes:
[O: XXX MM/DD/YY; U: CJC 08/24/21; C: LDC 08/30/21]
[1] All wells are constructed from 2 inch PVC with 0.01 inch slotted screens.
--- = Test not analyzed/performed
CCR = coal combustion residuals
cm/s = centimeters per second
D = downgradient
ft = foot/feet
NA = Not Applicable
NAVD88 = North American Vertical Datum of 1988
U = upgradient

RAMBOLL

R000749

TABLE 3-4. HORIZONTAL HYDRAULIC GRADIENTS AND GROUNDWATER FLOW VELOCITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

$V = K i / n_e$ V = Groundwater Velocity
K = Hydraulic Conductivity [1]
i = hydraulic gradient
n_e = Effective Porosity [2]

Northeast of CCR Unit (G02D to G53D): Uppermost Aquifer

Distance between Wells (ft): 2352
Hydraulic Conductivity (ft/day): 1.2
Effective Porosity (%): 27 Assumes: gravel and sand

Date	G02D Groundwater Elevation (ft NAVD88)	G53D Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity (ft/day)
3/3/2021	321.77	319.40	2.37	0.0010	0.004
3/24/2021	325.91	325.15	0.76	0.0003	0.001
4/14/2021	324.71	324.23	0.48	0.0002	0.001
5/11/2021-5/12/2021	323.72	320.99	2.73	0.0012	0.005
6/1/2021	321.23	319.65	1.58	0.0007	0.003
6/14/2021	321.86	320.17	1.69	0.0007	0.003
7/6/2021	319.74	318.02	1.72	0.0007	0.003
7/20/2021-7/21/2021	320.62	317.83	2.79	0.0012	0.005
			Average	0.0008	0.003

Center of CCR Unit (G02D to G08): Uppermost Aquifer

Distance between Wells (ft): 3768
Hydraulic Conductivity (ft/day): 6.8
Effective Porosity (%): 27 Assumes: gravel and sand

Date	G02D Groundwater Elevation (ft NAVD88)	G08 Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity (ft/day)
3/3/2021-3/4/2021	321.77	316.89	4.88	0.0013	0.032
3/24/2021	325.91	- - -	- - -	- - -	- - -
4/14/2021-4/14/2021	324.71	320.77	3.94	0.0010	0.026
5/11/2021-5/12/2021	323.72	315.82	7.90	0.0021	0.052
6/1/2021	321.23	313.42	7.81	0.0021	0.051
6/14/2021-6/15/2021	321.86	312.94	8.92	0.0024	0.059
7/6/2021	319.74	312.52	7.22	0.0019	0.047
7/20/2021-7/21/2021	320.62	312.49	8.13	0.0022	0.053
			Average	0.0019	0.046

TABLE 3-4. HORIZONTAL HYDRAULIC GRADIENTS AND GROUNDWATER FLOW VELOCITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Southwest of CCR Unit (G11 to G54D): Uppermost Aquifer

Distance between Wells (ft): 848
Hydraulic Conductivity (ft/day): 10.8
Effective Porosity (%): 25 Assumes: gravel, sand, and silt

Date	G11 Groundwater Elevation (ft NAVD88)	G54D Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity (ft/day)
3/3/3031-3/4/2021	319.77	317.69	2.08	0.0025	0.106
4/14/2021	325.15	322.45	2.70	0.0032	0.138
5/12/2021	322.77	319.02	3.75	0.0044	0.191
6/1/2021	323.49	314.79	8.70	0.0103	0.444
6/14/2021	320.25	314.93	5.32	0.0063	0.271
7/6/2021	319.25	314.73	4.52	0.0053	0.231
7/20/2021	319.20	314.77	4.43	0.0052	0.226
			Average	0.0053	0.230

South of CCR Unit (G11 to G10): Uppermost Aquifer

Distance between Wells (ft): 1150
Hydraulic Conductivity (ft/day): 10.9
Effective Porosity (%): 27 Assumes: gravel and sand

Date	G11 Groundwater Elevation (ft NAVD88)	G10 Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity (ft/day)
3/4/2021	319.77	319.43	0.34	0.0003	0.012
4/13/2021-4/14/2021	325.15	320.85	4.30	0.0037	0.149
5/11/2021-5/12/2021	322.77	- - -	- - -	- - -	- - -
6/1/2021	323.49	313.37	10.12	0.0088	0.350
6/14/2021-6/15/2021	320.25	313.34	6.91	0.0060	0.239
7/6/2021	319.25	313.38	5.87	0.0051	0.203
7/20/2021	319.20	313.54	5.66	0.0049	0.196
			Average	0.0048	0.191

[O: CJC 8/24/21, U: CJC 8/26/21, C: LDC 08/30/21, U: RAB 10/8/21, C: KLT 10/8/21]

Notes:

[1] Hydraulic conductivity values used above are average of the individual wells used in each velocity calculation as derived from slug tests reported in O'Brien and Gere Engineers, Inc. 2017 Hydrogeologic Monitoring Plan, Joppa East Ash Pond and March 2021 by Geosyntec Consultants, Inc.

[2] Effective porosity used in these calculations was derived from an average between estimated values of 0.20 for silt material, 0.267 for gravel, 0.07 for clay, and 0.28 for sand from Morris, D.A. and A.I. Johnson, 1967. Summary of hydrologic and physical properties of rock and soil materials as analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, U.S. Geological Survey Water-Supply Paper 1839-D, 42p. and Heath, R.C., 1983. Basic ground-water hydrology , U.S. Geological Survey Water-Supply Paper 2220, 86p.

Effective porosity may be as high as maximum total porosity (50%) calculated in Table 2-1.
% = percent
ft= foot/feet
ft/ft = feet per feet
ft/day = feet per day
NAVD88 = North American Vertical Datum of 1988

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G01D	12/03/2015	<0.001	0.0015	0.254	<0.001	<0.025	<0.001	37.9	13	0.0047	0.006	0.26	0.0018	0.0018	<0.0002	0.001	6.7	0.07	<0.001	20	<0.001	216
G01D	03/15/2016	<0.001	0.0026	0.283	<0.001	0.036	<0.001	45.5	20	0.0032	0.0136	0.29	0.0012	0.0017	<0.0002	0.0013	6.7	0.96	<0.001	126	<0.001	496
G01D	06/15/2016	<0.001	0.0018	0.204	<0.001	0.0296	<0.001	43.9	21	0.0016	0.0128	0.25	<0.001	0.0015	<0.0002	0.001	6.9	0.44	<0.001	157	<0.001	518
G01D	09/14/2016	<0.001	0.0021	0.19	<0.001	0.0416	<0.001	40.8	21	0.0031	0.0113	0.26	0.0013	0.0024	<0.0002	0.001	6.8	0.58	<0.001	129	<0.001	498
G01D	12/14/2016	<0.001	0.0012	0.163	<0.001	<0.025	<0.001	35.9	14	0.0036	0.0077	0.24	0.0012	0.0024	<0.0002	<0.001	6.8	0.4	<0.001	53	<0.001	294
G01D	03/07/2017	<0.001	<0.001	0.155	<0.001	<0.025	<0.001	34.9	16	0.0014	0.0061	0.22	<0.001	0.0013	<0.0002	<0.001	6.2	0.24	<0.001	72	<0.001	384
G01D	06/15/2017	<0.001	<0.001	0.14	<0.001	<0.025	<0.001	32.1	15	0.0032	0.0047	0.23	0.0013	0.0018	<0.0002	<0.001	6.7	0.93	<0.001	56	<0.001	372
G01D	07/20/2017	<0.001	0.001	0.14	<0.001	<0.025	<0.001	29.5	12	0.0042	0.0035	0.24	0.0014	0.0017	<0.0002	0.0018	6.8	0.41	<0.001	31	<0.001	368
G01D	11/30/2017	--	--	--	--	<0.025	--	37.2	18	--	--	0.22	--	--	--	--	6.8	--	--	117	--	450
G01D	06/19/2018	<0.001	0.0019	0.202	<0.001	<0.025	<0.001	29.5	13	0.0093	0.0057	0.24	0.0034	0.0038	<0.0002	<0.0015	6.8	1.41	<0.001	70	<0.002	394
G01D	09/05/2018	--	<0.001	0.147	--	<0.025	--	30.5	14	0.0026	0.0022	0.2	<0.001	0.0017	--	--	7.0	0.37	0.001	94	--	414
G01D	03/27/2019	<0.001	<0.001	0.129	<0.001	<0.025	<0.001	25.1	8	0.003	0.0014	0.23	<0.001	0.0015	<0.0002	<0.0015	6.7	0.78	0.0015	30	<0.002	310
G01D	09/09/2019	--	<0.001	0.123	--	<0.025	--	25.6	8	0.0044	0.0014	0.23	0.0012	<0.003	--	--	6.4	0.79	0.0011	37	--	336
G01D	03/30/2020	<0.001	0.0011	0.13	<0.001	<0.025	<0.001	22.7	8	0.0065	0.0018	0.21	0.0019	0.0034	<0.0002	<0.0015	6.8	1.44	0.0013	35	<0.002	296
G01D	09/23/2020	--	0.0014	0.123	--	<0.025	--	24.4	10	0.004	0.0016	0.21	0.0014	<0.003	--	--	6.7	2.27	0.0011	34	--	294
G01D	03/03/2021	<0.001	0.0017	0.137	0.0011	<0.025	0.001	25.8	10	0.0027	0.0015	0.2	0.0015	<0.003	<0.0002	0.0015	6.6	0.932	0.0024	18	<0.002	308
G01D	03/24/2021	<0.001	<0.001	0.136	<0.001	<0.025	<0.001	24.8	9	0.0022	<0.001	0.21	<0.001	<0.003	<0.0002	<0.0015	6.5	0	0.0016	21	<0.002	300
G01D	04/14/2021	<0.001	<0.001	0.112	<0.001	<0.025	<0.001	23.3	6	<0.0015	<0.001	0.23	<0.001	<0.003	<0.0002	<0.0015	6.7	0.831	0.001	39	<0.002	308
G01D	05/12/2021	<0.0066	<0.0033	0.133	<0.0033	0.0167	<0.0033	24.9	7	0.00204	<0.0033	0.21	<0.0033	<0.0165	<0.0002	<0.0033	6.5	0.176	0.00136	20	<0.0033	280
G01D	06/01/2021	<0.001	<0.001	0.134	<0.001	<0.025	<0.001	24.4	7	0.0033	<0.001	0.23	0.001	<0.003	<0.0002	<0.0015	6.3	0.525	0.0015	18	<0.002	260
G01D	06/14/2021	<0.001	<0.001	0.136	<0.001	<0.025	<0.001	24.4	9	0.0025	<0.001	0.23	<0.001	<0.003	<0.0002	<0.0015	6.5	0.706	0.0015	20	<0.002	268
G01D	07/06/2021	<0.001	<0.001	0.136	<0.001	<0.025	<0.001	23.3	10	0.0033	<0.001	0.22	0.001	<0.003	<0.0002	<0.0015	6.3	0.486	0.0015	20	0.002	262

RAMBOLL

R000752

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G01D	07/21/2021	<0.001	<0.001	0.125	<0.001	<0.025	<0.001	26	9	0.0023	<0.001	0.21	<0.001	<0.003	<0.0002	<0.0015	6.4	0.936	0.0016	18	<0.002	286
G02D	12/03/2015	<0.001	<0.001	0.232	<0.001	0.0536	<0.001	39.9	24	<0.001	0.0024	0.24	<0.001	0.0011	<0.0002	<0.001	6.7	1.1	0.0019	16	<0.001	244
G02D	03/15/2016	<0.001	<0.001	0.218	<0.001	0.0494	<0.001	39.8	24	<0.001	<0.001	0.22	<0.001	<0.001	<0.0002	<0.001	6.6	0.47	0.0022	17	<0.001	256
G02D	06/15/2016	<0.001	<0.001	0.203	<0.001	0.0508	<0.001	38.6	21	<0.001	<0.001	0.21	<0.001	0.0012	<0.0002	<0.001	6.8	0.63	0.0022	15	<0.001	248
G02D	09/14/2016	<0.001	<0.001	0.206	<0.001	0.0534	<0.001	34.7	24	<0.001	<0.001	0.2	<0.001	0.0013	<0.0002	<0.001	6.6	0.33	0.0033	22	<0.001	276
G02D	12/14/2016	<0.001	<0.001	0.224	<0.001	0.0552	<0.001	40.4	24	0.0057	0.0019	0.19	<0.001	0.0019	<0.0002	<0.001	6.3	0.4	0.0039	22	<0.001	266
G02D	03/08/2017	<0.001	<0.001	0.211	<0.001	0.0546	<0.001	40	24	<0.001	<0.001	0.19	<0.001	<0.001	<0.0002	<0.001	6.9	1.06	0.0024	18	<0.001	270
G02D	06/14/2017	<0.001	<0.001	0.192	<0.001	0.0467	<0.001	33.2	25	<0.001	<0.001	0.19	<0.001	0.0013	<0.0002	<0.001	6.3	0.63	0.0023	20	<0.001	198
G02D	07/20/2017	<0.001	<0.001	0.211	<0.001	0.044	<0.001	37.5	22	0.0016	<0.001	0.22	<0.001	<0.001	<0.0002	<0.001	6.7	1.33	0.0016	12	<0.001	264
G02D	11/30/2017	--	--	--	--	0.0496	--	40.1	23	--	--	0.21	--	--	--	--	6.9	--	--	17	--	246
G02D	06/19/2018	<0.001	<0.001	0.245	<0.001	0.0404	<0.001	33.9	23	<0.0015	<0.001	0.21	<0.001	<0.0015	<0.0002	<0.0015	6.7	0.92	0.0023	17	<0.002	232
G02D	09/05/2018	--	<0.001	0.209	--	0.0468	--	36.3	23	<0.0015	<0.001	0.18	<0.001	<0.0015	--	--	6.6	0.46	0.002	19	--	252
G02D	03/27/2019	<0.001	<0.001	0.235	<0.001	0.0473	<0.001	38.7	20	0.0026	<0.001	0.2	<0.001	<0.0015	<0.0002	<0.0015	6.6	0.12	0.003	20	<0.002	262
G02D	09/09/2019	--	<0.001	0.208	--	0.0429	--	40.3	18	<0.0015	<0.001	0.21	<0.001	<0.003	--	--	6.5	0.49	0.0021	20	--	264
G02D	03/30/2020	<0.001	<0.001	0.202	<0.001	0.0449	<0.001	33.5	20	<0.0015	<0.001	0.18	<0.001	<0.003	<0.0002	<0.0015	6.6	0.79	0.0035	22	<0.002	222
G02D	09/23/2020	--	<0.001	0.253	--	0.0442	--	45.8	19	<0.0015	<0.001	0.18	<0.001	<0.003	--	--	6.6	5.93	0.0052	22	--	234
G02D	03/03/2021	<0.001	<0.001	0.207	<0.001	0.0296	<0.001	34.5	21	<0.0015	<0.001	0.17	<0.001	<0.003	<0.0002	<0.0015	6.5	0.693	0.0024	21	<0.002	266
G02D	03/24/2021	<0.001	<0.001	0.206	<0.001	0.033	<0.001	34.4	22	<0.0015	<0.001	0.2	<0.001	<0.003	<0.0002	<0.0015	6.3	2.7	0.0024	18	<0.002	244
G02D	04/14/2021	<0.001	<0.001	0.187	<0.001	0.0318	<0.001	32.4	24	<0.0015	<0.001	0.21	<0.001	<0.003	<0.0002	<0.0015	6.3	0.464	0.0031	19	<0.002	242
G02D	05/12/2021	<0.0066	<0.0033	0.208	<0.0033	0.0356	<0.0033	34.6	18	<0.0033	<0.0033	0.18	<0.0033	<0.0165	<0.0002	<0.0033	6.3	0.152	0.00336	27	<0.0033	232
G02D	06/01/2021	<0.001	<0.001	0.191	<0.001	0.0433	<0.001	32.6	18	<0.0015	<0.001	0.19	<0.001	<0.003	<0.0002	<0.0015	6.2	1.33	0.0034	23	<0.002	246
G02D	06/14/2021	<0.001	<0.001	0.202	<0.001	0.0352	<0.001	34.6	20	<0.0015	<0.001	0.19	<0.001	<0.003	<0.0002	<0.0015	6.4	1.06	0.0027	23	<0.002	216

RAMBOLL

R000753

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G02D	07/06/2021	<0.001	<0.001	0.189	<0.001	0.0431	<0.001	32.3	21	<0.0015	<0.001	0.19	<0.001	<0.003	<0.0002	<0.0015	6.2	1.24	0.0026	22	<0.002	230
G02D	07/21/2021	<0.001	<0.001	0.181	<0.001	0.0329	<0.001	36.6	22	<0.0015	<0.001	0.2	<0.001	<0.003	<0.0002	<0.0015	6.2	0.774	0.0022	20	<0.002	246
G03	03/05/2021	<0.001	0.0043	0.112	<0.001	0.213	<0.001	46.1	20	0.0228	0.0063	0.2	0.0052	0.0049	<0.0002	0.0019	6.4	2.83	<0.001	66	<0.002	284
G03	03/24/2021	<0.001	0.0023	0.0821	<0.001	0.343	<0.001	53.5	24	0.0129	0.0037	0.21	0.0024	0.003	<0.0002	<0.0015	6.3	0.673	<0.001	104	<0.002	342
G03	04/14/2021	<0.001	0.003	0.0787	<0.001	0.603	<0.001	77.8	33	0.0114	0.0044	0.19	0.0032	0.004	<0.0002	0.0015	6.2	1.62	<0.001	168	<0.002	422
G03	05/12/2021	<0.0066	0.00133	0.0728	<0.0033	0.26	<0.0033	47.7	29	0.00606	0.00257	0.2	0.00229	<0.0165	<0.0002	<0.0033	6.4	0.739	<0.0033	112	<0.0033	304
G03	06/01/2021	<0.001	0.0019	0.0787	<0.001	0.232	<0.001	46	19	0.0094	0.002	0.22	0.0022	<0.003	<0.0002	<0.0015	6.3	0.211	<0.001	73	<0.002	294
G03	06/15/2021	<0.001	<0.001	0.0705	<0.001	0.225	<0.001	46.7	22	0.0025	<0.001	0.22	<0.001	<0.003	<0.0002	<0.0015	6.2	0.152	<0.001	79	<0.002	298
G03	07/06/2021	<0.001	<0.001	0.0564	<0.001	0.235	<0.001	42.1	22	<0.0015	<0.001	0.22	<0.001	<0.003	<0.0002	<0.0015	6.3	0.71	<0.001	77	<0.002	282
G03	07/21/2021	<0.001	<0.001	0.0555	<0.001	0.294	<0.001	50	24	0.0031	<0.001	0.2	0.0011	<0.003	<0.0002	<0.0015	6.4	0.503	<0.001	92	<0.002	310
G04	03/04/2021	<0.001	<0.001	0.339	<0.001	<0.025	<0.001	38.3	22	<0.0015	0.0017	0.22	<0.001	<0.003	<0.0002	0.0031	6.5	1.06	0.0023	21	<0.002	264
G04	03/24/2021	<0.001	<0.001	0.345	<0.001	<0.025	<0.001	42.7	31	<0.0015	0.0019	0.28	<0.001	<0.003	<0.0002	0.0042	6.5	2.79	0.0021	41	<0.002	308
G04	04/13/2021	<0.001	<0.001	0.291	<0.001	<0.025	<0.001	53.6	34	<0.0015	0.0016	0.27	<0.001	<0.003	<0.0002	0.0042	6.5	0.481	0.0033	63	<0.002	358
G04	05/11/2021	<0.0066	<0.0033	0.302	<0.0033	0.0157	<0.0033	51.5	35	<0.0033	0.00142	0.27	<0.0033	<0.0165	<0.0002	0.00485	6.3	1.93	0.00224	73	<0.0033	454
G04	07/20/2021	<0.001	<0.001	0.187	<0.001	<0.025	<0.001	57.4	36	<0.0015	0.0036	0.26	0.0012	<0.003	<0.0002	0.0037	6.3	1.33	0.0015	131	<0.002	436
G05	03/04/2021	<0.001	<0.001	0.13	<0.001	0.181	<0.001	55.3	13	0.0031	0.0101	0.28	<0.001	0.0032	<0.0002	0.0049	6.5	0.355	0.0029	94	<0.002	370
G05	03/24/2021	<0.001	<0.001	0.129	<0.001	0.195	<0.001	59.4	15	0.0028	0.0096	0.32	<0.001	<0.003	<0.0002	0.0058	6.4	1.85	0.0021	92	<0.002	370
G05	04/13/2021	<0.001	<0.001	0.126	<0.001	0.19	<0.001	68.5	21	<0.0015	0.0095	0.33	<0.001	<0.003	<0.0002	0.0055	6.5	0.381	0.002	95	<0.002	368
G05	05/11/2021	<0.0066	<0.0033	0.132	<0.0033	0.158	<0.0033	60.3	19	<0.0033	0.0087	0.34	<0.0033	<0.0165	<0.0002	0.00505	6.4	0.237	0.00142	109	<0.0033	348
G05	06/01/2021	<0.001	<0.001	0.144	<0.001	0.157	<0.001	57.1	21	<0.0015	0.0078	0.34	<0.001	<0.003	<0.0002	0.0051	6.5	0.572	0.0016	83	<0.002	366
G05	06/15/2021	<0.001	<0.001	0.132	<0.001	0.14	<0.001	58.6	18	<0.0015	0.0057	0.33	<0.001	<0.003	<0.0002	0.0049	6.3	1.65	0.0022	91	<0.002	366
G05	07/06/2021	<0.001	<0.001	0.139	<0.001	0.148	<0.001	51.8	22	<0.0015	0.0091	0.34	<0.001	0.0031	<0.0002	0.0058	6.4	0.94	0.0012	90	0.0033	334

RAMBOLL

R000754

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G05	07/20/2021	<0.001	<0.001	0.133	<0.001	0.131	<0.001	55.9	20	<0.0015	0.0059	0.32	<0.001	<0.003	<0.0002	0.0039	6.3	0.434	0.0011	87	<0.002	378
G06	03/04/2021	<0.001	0.0011	0.0484	<0.001	2.9	<0.001	90.2	22	0.0034	0.0026	0.3	<0.001	0.0039	<0.0002	<0.0015	6.7	1.26	<0.001	250	<0.002	546
G06	03/24/2021	<0.001	0.0019	0.049	<0.001	3.4	<0.001	90.1	23	0.0075	0.0034	0.27	0.0016	0.0045	<0.0002	<0.0015	6.6	0.4	<0.001	215	<0.002	536
G06	04/13/2021	<0.001	0.001	0.0382	<0.001	3.27	<0.001	124	22	0.0033	0.0021	0.28	<0.001	0.0042	<0.0002	<0.0015	6.6	0.253	<0.001	229	<0.002	534
G06	05/11/2021	<0.0066	<0.0033	0.0311	<0.0033	3.37	<0.0033	93.4	22	<0.0033	<0.0033	0.26	<0.0033	<0.0165	<0.0002	<0.0033	6.4	0.393	<0.0033	219	<0.0033	500
G06	06/01/2021	<0.001	<0.001	0.0323	<0.001	3.56	<0.001	92.6	22	0.0016	<0.001	0.28	<0.001	0.0037	<0.0002	<0.0015	6.6	0.89	<0.001	216	<0.002	546
G06	06/15/2021	<0.001	<0.001	0.028	<0.001	2.97	<0.001	91.5	21	<0.0015	<0.001	0.28	<0.001	<0.003	<0.0002	<0.0015	6.5	1.03	<0.001	230	<0.002	542
G06	07/06/2021	<0.001	<0.001	0.0272	<0.001	3.93	<0.001	86.7	22	<0.0015	<0.001	0.27	<0.001	0.005	<0.0002	<0.0015	6.3	0.493	<0.001	223	<0.002	500
G06	07/20/2021	<0.001	<0.001	0.0244	<0.001	3.41	<0.001	90.6	21	<0.0015	<0.001	0.26	<0.001	0.0035	<0.0002	<0.0015	6.4	1.12	<0.001	213	<0.002	548
G06S	03/04/2021	<0.001	<0.001	0.0886	<0.001	0.229	<0.001	27.7	<4	<0.0015	0.0045	0.28	<0.001	<0.003	<0.0002	<0.0015	6.2	0.542	<0.001	35	<0.002	198
G06S	03/24/2021	<0.001	<0.001	0.084	<0.001	0.253	<0.001	21.7	1	<0.0015	0.0144	0.37	<0.001	0.0055	<0.0002	<0.0015	5.8	0.95	<0.001	31	<0.002	166
G06S	04/13/2021	<0.001	<0.001	0.0823	<0.001	0.265	<0.001	29.4	1	<0.0015	0.0189	0.41	<0.001	0.0057	<0.0002	<0.0015	5.8	0.108	<0.001	30	<0.002	176
G06S	05/11/2021	<0.0066	<0.0033	0.0869	<0.0033	0.245	<0.0033	23.5	1	<0.0033	0.0141	0.4	<0.0033	0.00501	<0.0002	<0.0033	5.6	0.237	<0.0033	31	<0.0033	146
G06S	07/20/2021	<0.001	<0.001	0.0798	<0.001	0.248	<0.001	26.5	1	<0.0015	0.0021	0.3	<0.001	0.003	<0.0002	<0.0015	5.7	1.25	<0.001	30	<0.002	198
G07	03/04/2021	<0.001	0.0025	0.0958	<0.001	4.37	<0.001	93.9	21	0.0116	0.0062	0.2	0.002	0.0048	<0.0002	<0.0015	6.5	0.706	<0.001	285	<0.002	636
G07	03/24/2021	<0.001	<0.001	0.0643	<0.001	4.67	<0.001	92.8	21	0.0047	0.0035	0.42	<0.001	<0.003	<0.0002	<0.0015	6.4	0.226	<0.001	258	<0.002	600
G07	04/13/2021	<0.001	<0.001	0.0497	<0.001	5.04	<0.001	126	20	0.0024	0.0024	0.42	<0.001	<0.003	<0.0002	<0.0015	6.3	0.229	<0.001	274	<0.002	624
G07	05/11/2021	<0.0066	<0.0033	0.0448	<0.0033	4.55	<0.0033	90.4	19	<0.0033	0.00185	0.41	<0.0033	<0.0165	<0.0002	<0.0033	6.3	0.161	<0.0033	248	<0.0033	570
G07	06/01/2021	<0.001	<0.001	0.054	<0.001	5.23	<0.001	96.6	22	0.0038	0.0023	0.43	<0.001	0.0032	<0.0002	<0.0015	6.2	0.208	<0.001	257	<0.002	594
G07	06/15/2021	<0.001	<0.001	0.0429	<0.001	3.91	<0.001	89.3	20	<0.0015	0.0013	0.41	<0.001	<0.003	<0.0002	<0.0015	6.2	0.681	<0.001	246	<0.002	562
G07	07/06/2021	<0.001	<0.001	0.0373	<0.001	4.95	<0.001	84.8	21	<0.0015	0.0012	0.4	<0.001	<0.003	<0.0002	<0.0015	6.0	0.598	<0.001	258	<0.002	562
G07	07/20/2021	<0.001	<0.001	0.047	<0.001	4.48	<0.001	96.5	21	<0.0015	0.0014	0.4	<0.001	<0.003	<0.0002	<0.0015	6.1	1.36	<0.001	252	<0.002	598

RAMBOLL

R000755

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G08	03/04/2021	<0.001	0.0096	0.166	<0.001	4.53	<0.001	111	14	0.006	0.0103	0.41	0.0018	0.0038	<0.0002	0.0028	7.0	0.576	<0.001	241	<0.002	604
G08	03/24/2021	<0.001	0.0063	0.0946	<0.001	4.39	<0.001	115	16	0.0018	0.0064	0.36	<0.001	<0.003	<0.0002	0.0021	6.9	0.0774	<0.001	225	<0.002	592
G08	04/13/2021	<0.001	0.0073	0.0772	<0.001	5.25	<0.001	142	15	0.0016	0.0041	0.34	<0.001	<0.003	<0.0002	0.0024	7.0	0.635	<0.001	286	<0.002	620
G08	05/11/2021	<0.0066	0.00946	0.0685	<0.0033	3.77	<0.0033	101	12	<0.0033	0.0022	0.36	<0.0033	<0.0165	<0.0002	0.00227	6.9	0.699	<0.0033	203	<0.0033	508
G08	06/01/2021	<0.001	0.0061	0.0588	<0.001	4.63	<0.001	114	15	0.0023	0.0041	0.34	<0.001	<0.003	<0.0002	0.0022	7.0	0.256	<0.001	204	<0.002	568
G08	06/15/2021	<0.001	0.0066	0.0608	<0.001	3.97	<0.001	111	15	0.002	0.0029	0.32	<0.001	<0.003	<0.0002	0.0017	6.9	1.35	<0.001	226	<0.002	540
G08	07/06/2021	<0.001	0.0091	0.0575	<0.001	4.56	<0.001	109	16	0.0028	0.004	0.32	<0.001	<0.003	<0.0002	0.0015	6.8	1.49	<0.001	227	<0.002	548
G08	07/20/2021	<0.001	0.0091	0.0635	<0.001	3.98	<0.001	116	16	0.0039	0.0045	0.32	0.001	<0.003	<0.0002	0.0031	6.8	0.894	<0.001	227	<0.002	556
G09	03/04/2021	<0.001	0.0012	0.0675	<0.001	3.19	<0.001	103	24	<0.0015	0.0108	0.25	<0.001	0.0046	<0.0002	<0.0015	6.2	0.213	<0.001	351	<0.002	728
G09	03/25/2021	<0.001	0.0057	0.0984	0.0012	3.15	<0.001	95.2	29	0.0135	0.0159	0.31	0.0028	0.0058	<0.0002	<0.0015	6.3	1.65	<0.001	286	<0.002	688
G09	04/14/2021	<0.001	0.0044	0.0673	<0.001	3.48	<0.001	110	25	0.008	0.0131	0.35	0.0019	0.0047	<0.0002	<0.0015	6.3	0.206	<0.001	297	<0.002	712
G09	05/12/2021	<0.0066	0.00326	0.0586	<0.0033	3.26	<0.0033	87.7	22	0.00254	0.0103	0.37	<0.0033	<0.0165	<0.0002	<0.0033	6.4	0.215	<0.0033	272	<0.0033	656
G09	06/01/2021	<0.001	0.0028	0.0548	<0.001	3.65	<0.001	91.3	23	0.0024	0.0096	0.33	<0.001	0.0038	<0.0002	<0.0015	6.2	0.587	<0.001	284	<0.002	672
G09	06/15/2021	<0.001	<0.001	0.0136	<0.001	0.282	<0.001	137	21	<0.0015	0.0011	0.32	<0.001	0.0034	<0.0002	<0.0015	6.0	0.53	0.0053	294	<0.002	632
G09	07/06/2021	<0.001	0.0037	0.0444	<0.001	4.05	<0.001	79	22	<0.0015	0.0089	0.36	<0.001	0.0042	<0.0002	<0.0015	6.3	0.729	<0.001	289	<0.002	614
G09	07/21/2021	<0.001	0.0026	0.0454	<0.001	3.75	<0.001	92.1	21	0.0018	0.0085	0.31	<0.001	0.0034	<0.0002	<0.0015	6.0	0.321	<0.001	286	<0.002	652
G09M	03/04/2021	<0.001	0.0091	0.442	<0.001	0.0507	<0.001	114	7	0.0108	0.0097	0.31	0.0039	0.0103	<0.0002	0.0046	6.9	0.971	0.0011	20	<0.002	444
G09M	03/25/2021	<0.001	0.0062	0.437	<0.001	0.0299	<0.001	98.6	7	0.004	0.0066	0.34	0.0013	0.008	<0.0002	0.0044	6.8	2.06	<0.001	<10	<0.002	432
G09M	04/14/2021	<0.001	0.0038	0.407	<0.001	0.0544	<0.001	134	7	0.002	0.0041	0.36	<0.001	0.0089	<0.0002	0.0051	6.9	2.34	<0.001	<10	<0.002	506
G09M	05/12/2021	<0.0066	0.00719	0.34	<0.0033	0.0191	<0.0033	73.7	5	<0.0033	0.00162	0.27	<0.0033	<0.0165	<0.0002	0.00385	7.0	1.24	<0.0033	<10	<0.0033	282
G09M	07/21/2021	<0.001	0.0098	0.316	<0.001	0.0376	0.0018	99.9	7	0.0183	0.0105	0.34	0.0066	0.0096	<0.0002	0.0056	6.9	3.9	<0.001	<10	0.002	316
G10	03/04/2021	<0.001	0.0011	0.0608	<0.001	4.98	<0.001	107	35	0.0032	0.0109	0.29	<0.001	0.0035	<0.0002	0.0018	6.7	0.503	<0.001	391	<0.002	798

RAMBOLL

R000756

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G10	03/24/2021	<0.001	0.0019	0.0553	<0.001	4.31	<0.001	115	31	0.0053	0.0122	0.3	<0.001	0.0031	<0.0002	0.0018	6.7	0.709	<0.001	369	<0.002	752
G10	04/13/2021	<0.001	0.0017	0.0496	<0.001	4.26	<0.001	142	29	0.0063	0.01	0.31	<0.001	0.0033	<0.0002	0.0015	6.6	0.245	<0.001	382	<0.002	754
G10	05/11/2021	<0.0066	0.00118	0.0453	<0.0033	3.95	<0.0033	120	25	0.00109	0.00754	0.28	<0.0033	<0.0165	<0.0002	0.00107	6.3	0.954	<0.0033	364	<0.0033	746
G10	06/01/2021	<0.001	0.0014	0.0444	<0.001	4.73	<0.001	124	29	0.0037	0.0071	0.29	<0.001	0.0032	<0.0002	<0.0015	6.5	1.13	<0.001	401	<0.002	810
G10	06/15/2021	<0.001	<0.001	0.0439	<0.001	3.74	<0.001	128	26	<0.0015	0.005	0.28	<0.001	<0.003	<0.0002	<0.0015	6.5	1.33	<0.001	407	<0.002	760
G10	07/06/2021	<0.001	<0.001	0.0356	<0.001	4.81	<0.001	119	26	<0.0015	0.0049	0.27	<0.001	<0.003	<0.0002	<0.0015	6.5	1.31	<0.001	415	<0.002	750
G10	07/20/2021	<0.001	<0.001	0.0368	<0.001	4.2	<0.001	132	26	<0.0015	0.0045	0.26	<0.001	<0.003	<0.0002	<0.0015	6.5	0.693	<0.001	410	<0.002	806
G11	03/04/2021	<0.001	<0.001	0.0287	<0.001	0.247	<0.001	125	44	0.0017	0.0039	0.16	<0.001	0.0041	<0.0002	<0.0015	5.9	0.357	0.0038	400	<0.002	804
G11	03/24/2021	<0.001	<0.001	0.0244	<0.001	0.42	<0.001	178	35	<0.0015	0.0079	0.21	<0.001	0.0052	<0.0002	<0.0015	5.9	0.43	0.0128	658	<0.002	1110
G11	04/14/2021	<0.001	<0.001	0.0195	<0.001	0.411	<0.001	177	33	<0.0015	0.0031	0.22	<0.001	0.0058	<0.0002	0.0019	5.8	0.659	0.0118	761	<0.002	1200
G11	05/12/2021	<0.0066	<0.0033	0.0167	<0.0033	0.321	<0.0033	166	30	<0.0033	0.00393	0.2	<0.0033	<0.0165	<0.0002	<0.0033	5.9	0.0533	0.0092	730	<0.0033	1130
G11	06/01/2021	<0.001	<0.001	0.0166	<0.001	0.309	<0.001	165	33	<0.0015	0.0029	0.21	<0.001	0.0067	<0.0002	<0.0015	5.8	0.909	0.0077	671	<0.002	1120
G11	06/14/2021	<0.001	<0.001	0.0139	<0.001	0.266	<0.001	136	39	<0.0015	<0.001	0.19	<0.001	0.0034	<0.0002	<0.0015	5.9	1.18	0.0056	505	<0.002	850
G11	07/06/2021	<0.001	<0.001	0.0109	<0.001	0.358	<0.001	135	42	<0.0015	<0.001	0.18	<0.001	0.005	<0.0002	<0.0015	5.8	0.563	0.0041	474	<0.002	862
G11	07/20/2021	<0.001	<0.001	0.0119	<0.001	0.302	<0.001	149	39	<0.0015	<0.001	0.19	<0.001	0.0042	<0.0002	<0.0015	5.8	0.249	0.0062	487	0.0023	874
G51D	12/03/2015	<0.001	<0.001	0.129	<0.001	0.117	<0.001	39.2	9	<0.001	0.0141	0.13	<0.001	0.0035	<0.0002	<0.001	6.2	0.02	0.0024	117	<0.001	304
G51D	03/15/2016	<0.001	<0.001	0.0702	<0.001	0.184	<0.001	39.7	9	0.0014	0.0249	0.1	<0.001	0.0048	<0.0002	<0.001	5.9	0.69	0.0019	145	<0.001	342
G51D	06/15/2016	<0.001	<0.001	0.0628	<0.001	0.213	<0.001	42.3	7	<0.001	0.0198	<0.1	<0.001	0.0059	<0.0002	<0.001	5.8	0.43	0.0028	139	<0.001	330
G51D	09/14/2016	<0.001	<0.001	0.0536	<0.001	0.263	<0.001	29.6	9	<0.001	0.011	<0.1	<0.001	0.0052	<0.0002	<0.001	5.6	0.8	0.0031	136	<0.001	360
G51D	12/14/2016	<0.001	<0.001	0.0459	<0.001	0.171	<0.001	30	11	<0.001	0.0119	<0.1	<0.001	0.005	<0.0002	<0.001	5.9	0.29	0.0031	101	<0.001	270
G51D	03/08/2017	<0.001	<0.001	0.0493	<0.001	0.309	<0.001	32.6	8	<0.001	0.0082	<0.1	<0.001	0.0045	<0.0002	<0.001	6.2	0.52	0.0033	146	<0.001	340
G51D	06/15/2017	<0.001	<0.001	0.0442	<0.001	0.58	<0.001	34	9	<0.001	0.0052	<0.1	<0.001	0.0058	<0.0002	<0.001	5.6	0.56	0.0039	149	<0.001	340

RAMBOLL

R000757

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G51D	07/20/2017	<0.001	<0.001	0.0462	<0.001	0.332	<0.001	31.8	8	<0.001	0.0055	<0.1	<0.001	0.0047	<0.0002	<0.001	5.9	1.68	0.0035	140	<0.001	344
G51D	11/30/2017	--	--	--	--	0.302	--	34.4	8	--	--	<0.1	--	--	--	--	5.6	--	--	138	--	356
G51D	06/19/2018	<0.001	<0.001	0.0756	<0.001	0.337	<0.001	31.1	7	<0.0015	0.0038	<0.1	<0.001	0.007	<0.0002	<0.0015	5.7	1.22	0.0035	124	<0.002	324
G51D	09/05/2018	--	<0.001	0.0395	--	0.263	--	29.1	7	<0.0015	0.0043	<0.1	<0.001	0.0054	--	--	6.0	0.42	0.0036	134	--	342
G51D	03/27/2019	<0.001	<0.001	0.0495	<0.001	0.778	<0.001	34.7	6	0.0016	0.0026	<0.1	<0.001	0.0059	<0.0002	<0.0015	5.7	0.23	0.005	125	<0.002	350
G51D	09/09/2019	--	<0.001	0.0377	--	0.501	--	31.3	6	<0.0015	0.0017	<0.1	<0.001	0.0057	--	--	5.3	0.36	0.0042	109	--	320
G51D	03/30/2020	<0.001	<0.001	0.0445	<0.001	0.697	<0.001	31.2	6	0.0019	0.0024	<0.1	<0.001	0.0065	<0.0002	<0.0015	5.6	0.9	0.0048	130	<0.002	304
G51D	09/23/2020	--	<0.001	0.0445	--	0.863	--	42.1	6	<0.0015	0.002	<0.1	<0.001	0.0071	--	--	5.7	1.4	0.0063	121	--	314
G51D	03/24/2021	<0.001	<0.001	0.04	<0.001	0.786	<0.001	31.7	5	<0.0015	0.0022	<0.1	<0.001	0.0061	<0.0002	<0.0015	5.6	1.74	0.0055	122	<0.002	322
G52D	12/03/2015	<0.001	0.0032	0.318	<0.001	<0.025	<0.001	46.6	22	<0.001	0.0056	0.25	<0.001	0.0026	<0.0002	0.0017	6.5	0.31	<0.001	65	<0.001	332
G52D	03/15/2016	<0.001	0.0051	0.345	<0.001	<0.025	<0.001	49.1	22	<0.001	0.0064	0.26	<0.001	0.0023	<0.0002	<0.001	6.3	1.16	<0.001	99	<0.001	310
G52D	06/15/2016	<0.001	0.0072	0.506	<0.001	<0.025	<0.001	69.2	21	<0.001	0.0093	0.25	<0.001	0.004	<0.0002	<0.001	6.6	2.18	<0.001	88	<0.001	360
G52D	09/14/2016	<0.001	0.0043	0.362	<0.001	<0.025	<0.001	47.6	20	<0.001	0.0063	0.26	<0.001	0.0027	<0.0002	0.0017	6.4	1.81	<0.001	84	<0.001	376
G52D	12/14/2016	<0.001	0.003	0.356	<0.001	<0.025	<0.001	53.4	20	<0.001	0.003	0.25	<0.001	0.0036	<0.0002	0.0024	6.7	1.24	<0.001	82	<0.001	356
G52D	03/07/2017	<0.001	0.0066	0.358	<0.001	<0.025	<0.001	55	18	<0.001	0.0072	0.24	<0.001	0.0024	<0.0002	<0.001	5.9	0.8	<0.001	115	<0.001	410
G52D	06/14/2017	<0.001	0.0054	0.289	<0.001	<0.025	<0.001	51	17	<0.001	0.0062	0.24	<0.001	0.003	<0.0002	<0.001	6.2	1.28	<0.001	112	<0.001	372
G52D	07/19/2017	<0.001	0.0016	0.293	<0.001	<0.025	<0.001	50.7	15	<0.001	0.0013	0.27	<0.001	0.0028	<0.0002	0.0011	6.4	0.8	<0.001	108	<0.001	412
G52D	11/30/2017	--	--	--	--	<0.025	--	54.7	15	--	--	0.26	--	--	--	--	6.0	--	--	97	--	392
G52D	06/19/2018	<0.001	0.0025	0.34	<0.001	<0.025	<0.001	50.1	15	<0.0015	0.0045	0.26	<0.001	0.0035	<0.0002	<0.0015	6.4	1.64	<0.001	97	<0.002	388
G52D	09/05/2018	--	0.0014	0.275	--	<0.025	--	49.8	14	<0.0015	0.0019	0.24	<0.001	0.0032	--	--	6.3	0.68	<0.001	101	--	384
G52D	03/27/2019	<0.001	0.0064	0.271	<0.001	<0.025	<0.001	59.8	13	<0.0015	0.0069	0.28	<0.001	0.0028	<0.0002	<0.0015	6.4	0.58	<0.001	81	<0.002	376
G52D	09/09/2019	--	0.0021	0.254	--	<0.025	--	52.2	14	<0.0015	0.0022	0.27	<0.001	<0.003	--	--	6.0	1.54	<0.001	78	--	370

RAMBOLL

R000758

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G52D	03/30/2020	<0.001	0.0017	0.254	<0.001	<0.025	<0.001	48.8	14	<0.0015	0.0033	0.27	<0.001	<0.003	<0.0002	<0.0015	6.4	1.3	<0.001	84	<0.002	362
G52D	09/23/2020	--	0.0014	0.278	--	<0.025	--	59	15	<0.0015	0.0015	0.26	<0.001	<0.003	--	--	6.5	0.61	<0.001	84	--	336
G52D	03/25/2021	<0.001	0.0015	0.254	<0.001	<0.025	<0.001	48.6	14	<0.0015	0.0016	0.27	<0.001	<0.003	<0.0002	<0.0015	6.2	0.966	<0.001	75	<0.002	332
G53D	12/03/2015	<0.001	<0.001	0.353	<0.001	0.332	<0.001	62.6	22	0.0017	0.0087	0.79	<0.001	0.002	<0.0002	0.0013	6.8	0.28	<0.001	103	<0.001	368
G53D	03/15/2016	<0.001	<0.001	0.279	<0.001	0.334	<0.001	50.5	20	<0.001	0.0087	0.72	<0.001	0.0015	<0.0002	0.0012	6.7	1.24	<0.001	107	<0.001	406
G53D	06/15/2016	<0.001	<0.001	0.207	<0.001	0.342	<0.001	47.2	17	<0.001	0.0059	0.68	<0.001	0.0017	<0.0002	<0.001	6.6	1.11	<0.001	107	<0.001	392
G53D	09/14/2016	<0.001	<0.001	0.191	<0.001	0.368	<0.001	44.4	20	<0.001	0.002	0.7	<0.001	0.0016	<0.0002	<0.001	6.5	0.1	<0.001	104	<0.001	424
G53D	12/14/2016	<0.001	<0.001	0.169	<0.001	0.364	<0.001	44.5	20	<0.001	0.0029	0.69	<0.001	0.0018	<0.0002	<0.001	6.8	0.39	<0.001	106	<0.001	418
G53D	03/08/2017	<0.001	<0.001	0.109	<0.001	0.138	<0.001	23.6	6	0.0018	0.0027	0.49	<0.001	0.0021	<0.0002	<0.001	7.2	0.08	<0.001	35	<0.001	216
G53D	06/15/2017	<0.001	<0.001	0.172	<0.001	0.309	<0.001	38.9	18	<0.001	<0.001	0.59	<0.001	0.0022	<0.0002	<0.001	6.6	0.16	<0.001	79	<0.001	348
G53D	07/20/2017	<0.001	<0.001	0.165	<0.001	0.366	<0.001	40.8	18	<0.001	0.0011	0.69	<0.001	0.0015	<0.0002	<0.001	6.8	1.25	<0.001	94	<0.001	396
G53D	11/30/2017	--	--	--	--	0.427	--	44.6	20	--	--	0.74	--	--	--	--	6.6	--	--	98	--	348
G53D	06/19/2018	<0.001	<0.001	0.176	<0.001	0.361	<0.001	37.8	18	<0.0015	<0.001	0.66	<0.001	0.0019	<0.0002	<0.0015	6.6	0.77	<0.001	84	<0.002	360
G53D	09/05/2018	--	<0.001	0.133	--	0.392	--	40.3	20	<0.0015	0.0016	0.61	<0.001	0.0018	--	--	6.8	0.55	<0.001	81	--	390
G53D	03/27/2019	<0.001	<0.001	0.101	<0.001	0.269	<0.001	30.5	12	<0.0015	<0.001	0.59	<0.001	<0.0015	<0.0002	<0.0015	6.6	0.17	<0.001	54	<0.002	272
G53D	09/09/2019	--	<0.001	0.128	--	0.385	--	42.2	18	<0.0015	0.002	0.67	<0.001	<0.003	--	--	6.2	0.03	<0.001	80	--	364
G53D	03/30/2020	<0.001	<0.001	0.109	<0.001	0.334	<0.001	34.8	17	<0.0015	<0.001	0.63	<0.001	<0.003	<0.0002	<0.0015	6.7	1.32	<0.001	66	<0.002	296
G53D	09/23/2020	--	<0.001	0.122	--	0.411	--	44.4	20	<0.0015	0.0024	0.74	<0.001	<0.003	--	--	6.7	1.16	<0.001	79	--	342
G53D	03/25/2021	<0.001	<0.001	0.112	<0.001	0.355	<0.001	38.6	19	<0.0015	0.0026	0.71	<0.001	<0.003	<0.0002	<0.0015	6.5	0.321	<0.001	71	<0.002	334
G54S	03/03/2021	<0.001	<0.001	0.0456	<0.001	0.0966	<0.001	88.5	28	<0.0015	0.001	0.31	<0.001	0.0051	<0.0002	0.0035	6.3	0.648	0.0181	363	<0.002	788
G54S	03/24/2021	<0.001	<0.001	0.0573	<0.001	0.0563	<0.001	56.6	43	<0.0015	<0.001	0.36	<0.001	<0.003	<0.0002	0.0034	6.4	0.659	0.0324	150	<0.002	528
G54S	04/14/2021	<0.001	<0.001	0.0701	<0.001	0.0382	<0.001	59.6	39	<0.0015	<0.001	0.4	0.0013	<0.003	<0.0002	0.0039	6.2	0.231	0.0332	145	<0.002	468

RAMBOLL

R000759

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G54S	05/12/2021	<0.0066	<0.0033	0.0623	<0.0033	0.0528	<0.0033	56	36	<0.0033	<0.0033	0.34	<0.0033	<0.0165	<0.0002	0.00243	6.3	0.162	0.0298	144	<0.0033	440
G54S	07/20/2021	<0.001	<0.001	0.0917	<0.001	0.0353	<0.001	42.7	40	<0.0015	<0.001	0.52	<0.001	<0.003	<0.0002	0.0039	6.4	1.41	0.0286	71	<0.002	394
G54D	12/03/2015	<0.001	0.002	0.115	<0.001	0.663	<0.001	103	33	0.0016	0.0268	0.38	<0.001	0.0069	<0.0002	<0.001	7.0	0.2	<0.001	191	<0.001	556
G54D	03/15/2016	<0.001	0.0025	0.106	<0.001	0.513	<0.001	75.2	32	0.003	0.0183	0.38	<0.001	0.0078	<0.0002	0.001	6.8	0.354	<0.001	176	<0.001	554
G54D	06/15/2016	<0.001	0.002	0.114	<0.001	0.508	<0.001	72.8	28	<0.001	0.0158	0.34	<0.001	0.0068	<0.0002	<0.001	6.6	1.02	<0.001	160	<0.001	476
G54D	09/14/2016	<0.001	0.0026	0.134	<0.001	0.557	<0.001	70.4	28	<0.001	0.0167	0.34	<0.001	0.0062	<0.0002	<0.001	6.6	0.39	<0.001	149	<0.001	502
G54D	12/14/2016	<0.001	0.0033	0.138	<0.001	0.564	<0.001	74.3	26	<0.001	0.0178	0.32	<0.001	0.0061	<0.0002	<0.001	6.7	1.05	<0.001	144	<0.001	456
G54D	03/08/2017	<0.001	0.0025	0.132	<0.001	0.499	<0.001	74.1	26	<0.001	0.017	0.3	<0.001	0.0048	<0.0002	<0.001	7.1	0.68	<0.001	131	<0.001	482
G54D	06/15/2017	<0.001	<0.001	0.105	<0.001	0.685	<0.001	80.5	24	0.0018	0.016	0.32	<0.001	0.0047	<0.0002	<0.001	6.8	1.67	<0.001	170	<0.001	506
G54D	07/20/2017	<0.001	0.0012	0.127	<0.001	0.58	<0.001	75.7	24	0.0017	0.0139	0.32	<0.001	0.0044	<0.0002	<0.001	6.8	0.32	<0.001	151	<0.001	512
G54D	11/30/2017	--	--	--	--	0.646	--	76.2	26	--	--	0.33	--	--	--	--	6.7	--	--	136	--	472
G54D	06/19/2018	<0.001	0.0019	0.196	<0.001	0.631	<0.001	72.7	26	0.0019	0.0134	0.34	<0.001	0.006	<0.0002	<0.0015	6.7	1	<0.001	146	<0.002	486
G54D	09/05/2018	--	0.001	0.131	--	0.66	--	73.6	25	0.002	0.0109	0.3	<0.001	0.0046	--	--	6.5	1.32	<0.001	152	--	480
G54D	03/27/2019	<0.001	0.0011	0.12	<0.001	1.03	<0.001	115	22	<0.0015	0.0138	0.35	<0.001	0.0037	<0.0002	<0.0015	6.8	0.42	<0.001	142	<0.002	510
G54D	09/09/2019	--	<0.001	0.128	--	0.614	--	79.9	<25	<0.0015	0.0117	0.32	<0.001	0.0037	--	--	6.4	0.84	<0.001	136	--	482
G54D	03/30/2020	<0.001	<0.001	0.105	<0.001	0.766	<0.001	84.9	22	<0.0015	0.013	0.33	<0.001	0.0036	<0.0002	<0.0015	6.8	0.89	<0.001	184	<0.002	508
G54D	09/23/2020	--	<0.001	0.16	--	0.819	--	122	25	<0.0015	0.0163	0.33	<0.001	0.0047	--	--	6.7	1.18	<0.001	173	--	508
G54D	03/24/2021	<0.001	<0.001	0.0941	<0.001	0.404	<0.001	78.1	23	<0.0015	0.0045	0.32	<0.001	0.0036	<0.0002	<0.0015	6.6	0.576	<0.001	186	<0.002	532
G151	03/03/2021	<0.001	<0.001	0.0459	<0.001	0.103	<0.001	23.4	10	<0.0015	<0.001	<0.1	<0.001	0.007	<0.0002	<0.0015	5.8	0.173	0.0024	111	<0.002	310
G151	03/24/2021	<0.001	<0.001	0.0477	<0.001	0.137	<0.001	23.9	11	<0.0015	<0.001	<0.1	<0.001	0.0057	<0.0002	<0.0015	5.8	0.368	0.0029	113	<0.002	282
G151	04/14/2021	<0.001	<0.001	0.0454	<0.001	0.0992	<0.001	27.2	11	<0.0015	<0.001	<0.1	<0.001	0.006	<0.0002	<0.0015	5.7	0.17	0.0027	119	<0.002	272
G151	05/11/2021	<0.0066	<0.0033	0.0471	<0.0033	0.134	<0.0033	25.4	10	<0.0033	<0.0033	<0.1	<0.0033	<0.0165	<0.0002	<0.0033	5.5	1.05	0.00252	129	<0.0033	264

RAMBOLL

R000760

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
G151	07/20/2021	<0.001	<0.001	0.0767	<0.001	0.114	<0.001	24	11	0.0028	0.0025	<0.1	<0.001	0.0064	<0.0002	<0.0015	5.5	1.58	0.0033	101	<0.002	288
G152B	03/03/2021	<0.001	<0.001	0.575	<0.001	<0.025	<0.001	53.1	45	0.0025	<0.001	0.46	<0.001	0.0057	<0.0002	<0.0015	6.6	0.631	0.0045	16	<0.002	444
G152B	03/25/2021	<0.001	<0.001	0.579	<0.001	<0.025	<0.001	56.1	44	0.0023	<0.001	0.48	<0.001	0.0047	<0.0002	<0.0015	6.5	1.4	0.0047	14	<0.002	406
G152B	04/14/2021	<0.001	<0.001	0.548	<0.001	<0.025	<0.001	53.4	42	0.0022	<0.001	0.49	<0.001	0.0046	<0.0002	<0.0015	6.7	0.69	0.0047	17	<0.002	440
G152B	05/12/2021	<0.0066	<0.0033	0.558	<0.0033	<0.033	<0.0033	55.6	43	0.00228	<0.0033	0.5	<0.0033	<0.0165	<0.0002	<0.0033	6.5	0.761	0.00476	22	<0.0033	424
G152B	07/20/2021	<0.001	<0.001	0.588	<0.001	<0.025	<0.001	55.9	43	0.0025	<0.001	0.49	<0.001	0.0049	<0.0002	<0.0015	6.5	2.36	0.0054	17	<0.002	430
G153	03/03/2021	<0.001	<0.001	0.192	<0.001	<0.025	<0.001	29.6	23	0.0016	<0.001	0.98	<0.001	<0.003	<0.0002	0.0031	6.9	1.49	<0.001	72	<0.002	362
G153	03/25/2021	<0.001	<0.001	0.186	<0.001	<0.025	<0.001	30.9	24	<0.0015	<0.001	0.88	<0.001	<0.003	<0.0002	0.0035	6.8	0.736	<0.001	69	<0.002	322
G153	04/13/2021	<0.001	<0.001	0.183	<0.001	<0.025	<0.001	29.9	23	<0.0015	<0.001	0.92	<0.001	<0.003	<0.0002	0.0038	6.9	0.334	<0.001	70	<0.002	344
G153	05/11/2021	<0.0066	<0.0033	0.208	<0.0033	<0.033	<0.0033	32	22	<0.0033	<0.0033	0.91	<0.0033	<0.0165	<0.0002	0.00305	6.6	0.289	<0.0033	77	<0.0033	330
G153	07/20/2021	<0.001	<0.001	0.164	<0.001	<0.025	<0.001	30.4	24	<0.0015	<0.001	0.9	<0.001	<0.003	<0.0002	0.0019	6.8	2.07	<0.001	69	<0.002	356

Notes:
Detected at concentration greater than the GWPS
-- = data not available
GWPS = groundwater protection standard
mg/L = milligrams per liter
pCi/L = picocuries per liter
SU = standard units
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method. Estimated concentrations below the reporting limit and associated qualifiers are not provided since they are not utilized in statistics to determine exceedances above Part 845 standards.
35 I.A.C. 845.600 = Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845

RAMBOLL

R000761

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
G01D	12/03/2015	<1	60	6.7	372	16.1	51.6
G01D	03/15/2016	<1	-103	6.7	667	18.3	<1
G01D	06/15/2016	1.36	-110	6.9	662	16.9	6.5
G01D	09/14/2016	2.71	-26	6.8	555	18.4	4.1
G01D	12/14/2016	1.47	113	6.8	593	15.5	57
G01D	03/07/2017	<1	80	6.2	434	14.1	16.8
G01D	06/15/2017	2.08	123	6.7	518	17.5	36
G01D	07/20/2017	<1	102	6.8	464	17.6	95.1
G01D	11/30/2017	<1	21	6.8	679	15.0	2.5
G01D	06/19/2018	2.88	29	6.8	512	17.6	3.6
G01D	09/05/2018	<1	131	7.0	614	17.8	<1
G01D	03/27/2019	2.57	118	6.7	522	15.4	56.4
G01D	09/09/2019	<1	193	6.4	664	17.6	7.6
G01D	03/30/2020	<1	138	6.8	548	15.8	5
G01D	09/23/2020	2.13	202	6.7	534	16.3	8.9
G01D	03/03/2021	4.18	145	6.6	495	15.7	26
G01D	03/24/2021	4.37	160	6.5	352	16.2	22
G01D	04/14/2021	2.28	134	6.7	562	16.3	2.1
G01D	05/12/2021	4.81	180	6.5	682	15.9	31
G01D	06/01/2021	4.98	164	6.3	556	15.8	47
G01D	06/14/2021	4.28	160	6.5	507	17.3	42
G01D	07/06/2021	5.57	139	6.3	550	16.9	52
G01D	07/21/2021	4.58	122	6.4	531	16.6	37
G02D	12/03/2015	<1	146	6.7	317	14.8	<1
G02D	03/15/2016	<1	28	6.6	344	17.4	<1
G02D	06/15/2016	<1	82	6.8	351	16.2	<1
G02D	09/14/2016	1.52	69	6.6	271	23.0	<1
G02D	12/14/2016	1.36	218	6.3	439	15.4	2.8
G02D	03/08/2017	1.97	254	6.9	318	13.8	<1
G02D	06/14/2017	9.12	95	6.3	298	17.7	3.8
G02D	07/20/2017	<1	132	6.7	372	16.8	15.8
G02D	11/30/2017	2.49	70	6.9	424	14.8	<1
G02D	06/19/2018	4.73	187	6.7	287	16.7	<1
G02D	09/05/2018	2.19	169	6.6	392	15.8	<1
G02D	03/27/2019	3.26	130	6.6	441	14.5	<1
G02D	09/09/2019	6.12	186	6.5	456	16.0	<1
G02D	03/30/2020	3.12	179	6.6	379	14.8	1.3
G02D	09/23/2020	2.49	246	6.6	400	15.2	1.9
G02D	03/03/2021	2.02	151	6.5	434	14.6	<1
G02D	03/24/2021	3.10	175	6.3	307	14.9	<1
G02D	04/14/2021	3.76	151	6.3	438	14.7	<1
G02D	05/12/2021	2.99	183	6.3	600	14.9	9.8
G02D	06/01/2021	2.57	140	6.2	437	14.9	<1
G02D	06/14/2021	3.01	169	6.4	441	15.6	<1

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
G02D	07/06/2021	3.87	128	6.2	477	15.8	<1
G02D	07/21/2021	3.72	100	6.2	464	15.4	1
G03	03/05/2021	3.70	117	6.4	409	15.2	200
G03	03/24/2021	2.95	150	6.3	454	15.7	85
G03	04/14/2021	2.23	137	6.2	805	15.6	78
G03	05/12/2021	3.45	180	6.4	734	15.7	250
G03	06/01/2021	3.82	149	6.3	569	15.6	140
G03	06/15/2021	3.78	128	6.2	472	15.9	30
G03	07/06/2021	4.15	116	6.3	557	15.9	20
G03	07/21/2021	3.81	52	6.4	584	16.2	44
G04	03/04/2021	3.02	120	6.5	401	18.5	16
G04	03/24/2021	0.60	257	6.5	623	16.8	8.2
G04	04/13/2021	1.13	104	6.5	605	16.8	1.3
G04	05/11/2021	1.21	101	6.3	631	16.6	1.3
G04	07/20/2021	1.30	17	6.3	769	17.9	7.1
G05	03/04/2021	1.79	56	6.5	519	15.7	9.9
G05	03/24/2021	1.06	35	6.4	599	16.6	60
G05	04/13/2021	0.74	18	6.5	630	16.3	33
G05	05/11/2021	0.71	42	6.4	650	16.1	10
G05	06/01/2021	2.49	452	6.5	687	16.4	9.9
G05	06/15/2021	1.44	59	6.3	553	16.1	<1
G05	07/06/2021	1.52	102	6.4	663	17.3	7.1
G05	07/20/2021	1.22	134	6.3	591	17.5	3.6
G06	03/04/2021	0.21	92	6.7	734	14.9	66
G06	03/24/2021	1.29	313	6.6	804	16.0	110
G06	04/13/2021	0.36	130	6.6	829	15.1	77
G06	05/11/2021	0.40	140	6.4	823	15.0	28
G06	06/01/2021	1.07	122	6.6	926	15.0	27
G06	06/15/2021	0.48	94	6.5	754	15.1	12
G06	07/06/2021	0.42	101	6.3	903	15.4	14
G06	07/20/2021	0.51	122	6.4	817	15.4	13
G06S	03/04/2021	4.10	116	6.2	251	15.2	5.3
G06S	03/24/2021	0.50	259	5.8	259	15.5	6.6
G06S	04/13/2021	0.57	167	5.8	265	15.3	<1
G06S	05/11/2021	0.45	123	5.6	271	14.9	<1
G06S	07/20/2021	1.26	102	5.7	267	16.1	1.3
G07	03/04/2021	0.18	80	6.5	826	15.3	110
G07	03/24/2021	0.43	192	6.4	892	15.5	35
G07	04/13/2021	0.36	163	6.3	921	15.2	33
G07	05/11/2021	0.30	120	6.3	889	15.1	17
G07	06/01/2021	0.26	37	6.2	1030	15.1	40
G07	06/15/2021	0.42	76	6.2	804	15.2	2.6
G07	07/06/2021	0.46	141	6.0	975	15.5	3
G07	07/20/2021	0.40	145	6.1	903	15.3	9.9

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
G08	03/04/2021	0.23	-63	7.0	757	15.6	220
G08	03/24/2021	0.40	-36	6.9	846	16.6	71
G08	04/13/2021	0.34	-40	7.0	898	16.3	36
G08	05/11/2021	0.73	-188	6.9	812	16.4	15
G08	06/01/2021	0.42	95	7.0	938	16.0	44
G08	06/15/2021	0.36	-164	6.9	766	16.1	62
G08	07/06/2021	0.41	-72	6.8	920	16.6	97
G08	07/20/2021	0.45	-29	6.8	834	16.3	110
G09	03/04/2021	0.23	9	6.2	917	16.6	18
G09	03/25/2021	0.26	42	6.3	994	16.1	22000
G09	04/14/2021	0.45	-22	6.3	999	16.2	140
G09	05/12/2021	0.35	-78	6.4	1300	16.3	71
G09	06/01/2021	0.30	-24	6.2	1080	16.5	44
G09	06/15/2021	0.80	-46	6.0	873	16.6	7.1
G09	07/06/2021	0.86	-40	6.3	1030	17.3	23
G09	07/21/2021	0.41	-6	6.0	998	16.8	27
G09M	03/04/2021	0.29	-130	6.9	670	16.8	240
G09M	03/25/2021	0.99	-126	6.8	763	17.3	100
G09M	04/14/2021	0.22	-151	6.9	833	15.9	26
G09M	05/12/2021	2.31	-158	7.0	1070	16.3	26.8
G09M	07/21/2021	0.36	-153	6.9	610	17.4	360
G10	03/04/2021	0.19	16	6.7	946	16.0	35
G10	03/24/2021	0.43	33	6.7	1040	17.1	9.4
G10	04/13/2021	0.28	42	6.6	1070	16.6	53
G10	05/11/2021	0.58	30	6.3	1040	16.6	20
G10	06/01/2021	0.28	5	6.5	1210	16.5	38
G10	06/15/2021	0.42	-22	6.5	995	16.8	10
G10	07/06/2021	0.63	35	6.5	1220	18.0	5.8
G10	07/20/2021	0.81	52	6.5	1110	17.6	4.1
G11	03/04/2021	0.37	69	5.9	1020	16.3	8.6
G11	03/24/2021	0.46	154	5.9	1150	16.5	2.7
G11	04/14/2021	1.08	100	5.8	1650	16.1	2.3
G11	05/12/2021	0.77	194	5.9	2260	16.5	<1
G11	06/01/2021	0.72	159	5.8	1760	16.4	<1
G11	06/14/2021	0.60	149	5.9	1360	16.6	4.2
G11	07/06/2021	0.73	78	5.8	1400	16.7	2
G11	07/20/2021	0.88	135	5.8	1320	16.9	<1
G151	03/03/2021	4.87	156	5.8	413	16.5	3.2
G151	03/24/2021	8.64	189	5.8	298	17.3	8.8
G151	04/14/2021	7.65	124	5.7	432	17.2	1.6
G151	05/11/2021	8.48	205	5.5	423	17.2	9.7
G151	07/20/2021	5.08	159	5.5	386	21.8	24
G152B	03/03/2021	2.19	146	6.6	759	15.2	1.7
G152B	03/25/2021	2.59	107	6.5	583	14.5	2.6

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
G152B	04/14/2021	4.74	151	6.7	765	15.1	<1
G152B	05/12/2021	5.17	190	6.5	1070	14.7	<1
G152B	07/20/2021	3.76	176	6.5	771	18.4	7.5
G153	03/03/2021	7.28	110	6.9	533	16.4	6.4
G153	03/25/2021	7.16	323	6.8	549	13.1	9.8
G153	04/13/2021	8.88	136	6.9	560	17.4	<1
G153	05/11/2021	8.12	136	6.5	564	16.0	2.5
G153	07/20/2021	6.64	91	6.8	559	20.0	1
G51D	12/03/2015	<1	133	6.2	327	16.7	5.5
G51D	03/15/2016	<1	122	5.9	397	17.6	12.2
G51D	06/15/2016	<1	213	5.8	375	17.8	13.9
G51D	09/14/2016	<1	231	5.6	315	20.8	1.2
G51D	12/14/2016	<1	134	5.9	421	16.2	2.7
G51D	03/08/2017	<1	282	6.2	328	15.1	<1
G51D	06/15/2017	<1	168	5.6	397	18.5	4.4
G51D	07/20/2017	<1	180	5.9	381	18.9	3.5
G51D	11/30/2017	<1	168	5.6	464	16.2	<1
G51D	06/19/2018	<1	247	5.7	319	19.1	<1
G51D	09/05/2018	<1	217	6.0	412	17.7	<1
G51D	03/27/2019	<1	130	5.7	478	16.2	9.3
G51D	09/09/2019	<1	157	5.3	468	17.3	10
G51D	03/30/2020	1.12	261	5.6	398	16.4	4.2
G51D	09/23/2020	1.48	292	5.7	415	16.9	4.2
G51D	03/24/2021	<1	136	5.6	317	17.0	7.1
G52D	12/03/2015	<1	-5	6.5	370	15.4	1.26
G52D	03/15/2016	<1	-81	6.3	454	17.9	<1
G52D	06/15/2016	<1	-131	6.6	433	19.6	<1
G52D	09/14/2016	<1	-76	6.4	391	19.0	<1
G52D	12/14/2016	8.94	104	6.7	531	16.1	1.8
G52D	03/07/2017	<1	26	5.9	389	14.1	<1
G52D	06/14/2017	3.25	61	6.2	351	24.1	<1
G52D	07/19/2017	<1	-48	6.4	414	23.8	<1
G52D	11/30/2017	<1	-59	6.0	509	14.8	<1
G52D	06/19/2018	2.63	-136	6.4	361	17.0	<1
G52D	09/05/2018	<1	-49	6.3	475	17.1	<1
G52D	03/27/2019	<1	-31	6.4	525	14.8	<1
G52D	09/09/2019	<1	164	6.0	535	17.3	1.6
G52D	03/30/2020	1.00	-12	6.4	438	15.2	1.3
G52D	09/23/2020	<1	-19	6.5	459	15.7	2
G52D	03/25/2021	<1	4	6.2	357	15.3	<1
G53D	12/03/2015	<1	45	6.8	465	16.3	<1
G53D	03/15/2016	<1	64	6.7	512	18.2	<1
G53D	06/15/2016	<1	112	6.6	515	16.8	<1
G53D	09/14/2016	<1	189	6.5	448	18.8	3.4

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
G53D	12/14/2016	<1	70	6.8	607	17.0	1.8
G53D	03/08/2017	4.63	251	7.2	180	14.2	9
G53D	06/15/2017	<1	200	6.6	465	16.5	9.2
G53D	07/20/2017	<1	100	6.8	497	18.1	3.3
G53D	11/30/2017	<1	85	6.6	580	15.9	<1
G53D	06/19/2018	<1	151	6.6	371	17.4	2.2
G53D	09/05/2018	<1	37	6.8	544	17.3	<1
G53D	03/27/2019	<1	172	6.6	385	15.9	9.7
G53D	09/09/2019	<1	171	6.2	603	17.6	4.9
G53D	03/30/2020	1.00	141	6.7	337	15.9	6.2
G53D	09/23/2020	<1	101	6.7	516	16.4	6.2
G53D	03/25/2021	<1	138	6.5	550	15.6	6
G54D	12/03/2015	<1	3	7.0	580	15.8	7.5
G54D	03/15/2016	<1	-73	6.8	641	17.8	9.8
G54D	06/15/2016	<1	-118	6.6	599	17.1	4.8
G54D	09/14/2016	<1	7	6.6	517	18.3	4.4
G54D	12/14/2016	<1	142	6.7	668	16.3	5.3
G54D	03/08/2017	1.31	92	7.1	519	14.3	4.3
G54D	06/15/2017	3.72	100	6.8	603	17.2	30.6
G54D	07/20/2017	5.07	37	6.8	567	17.6	25.4
G54D	11/30/2017	6.71	39	6.7	676	15.5	12.3
G54D	06/19/2018	<1	25	6.7	513	17.3	4.9
G54D	09/05/2018	<1	-13	6.5	699	16.8	<1
G54D	03/27/2019	1.49	43	6.8	770	15.3	21.1
G54D	09/09/2019	<1	121	6.4	788	17.4	86
G54D	03/30/2020	1.00	-1	6.8	706	15.6	2.5
G54D	09/23/2020	<1	62	6.7	677	15.8	8.7
G54D	03/24/2021	<1	92	6.6	586	16.0	2.6
G54S	03/03/2021	7.35	190	6.3	1080	15.8	9.9
G54S	03/24/2021	7.26	152	6.4	621	17.2	<1
G54S	04/14/2021	7.83	63	6.2	773	14.3	<1
G54S	05/12/2021	7.89	168	6.3	949	15.7	9.7
G54S	07/20/2021	8.00	116	6.4	665	19.3	1.1

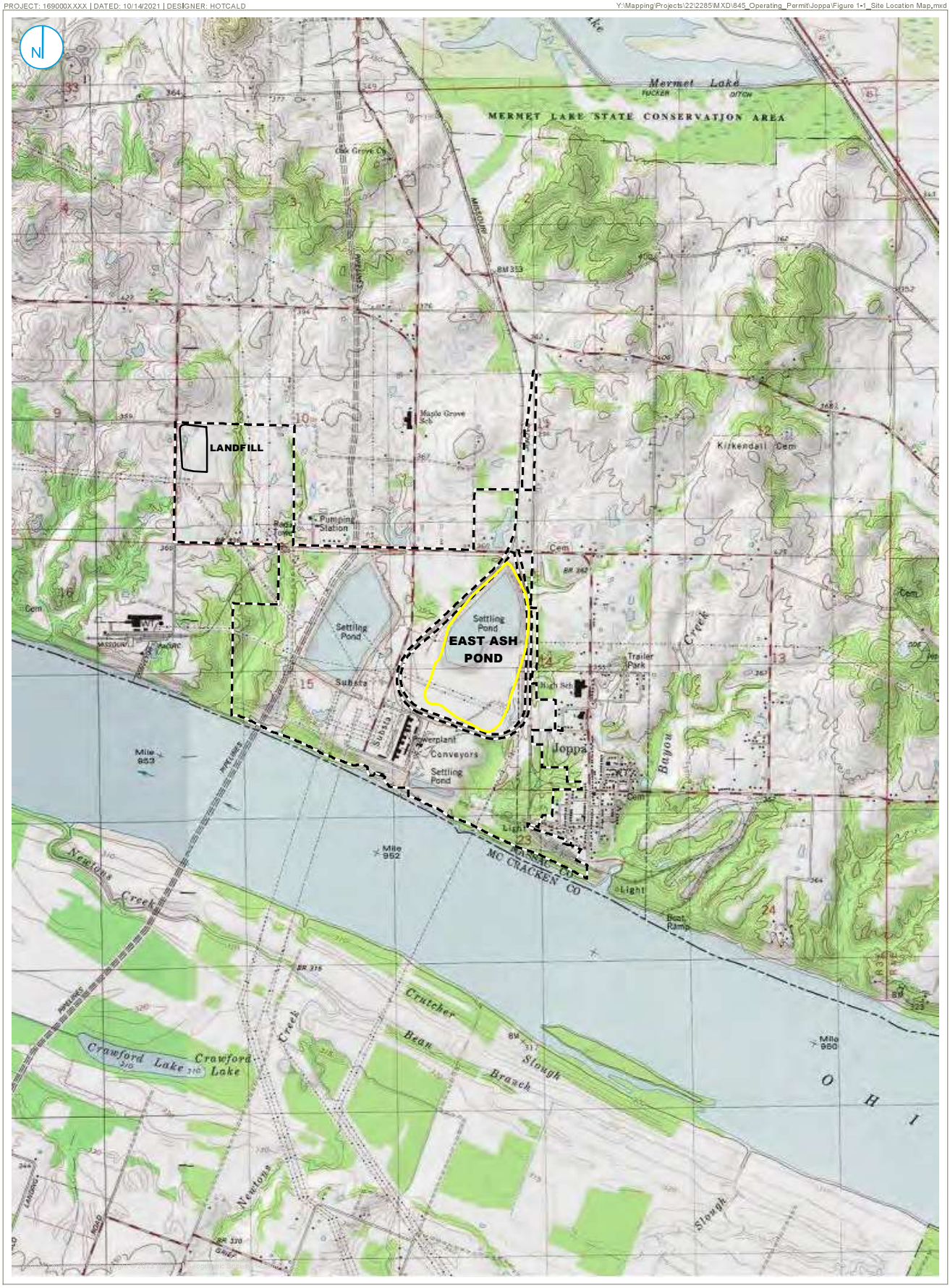
Notes:
Field readings are reported with as many significant figures as provided by analytical laboratory.
cm = centimeter
deg. C = degrees Celsius
mg/L = milligrams per liter
mV = millivolts
NTU = nephelometric turbidity units
SU = standard units

generated 10/05/2021, 3:58:13 PM CDT

FIGURES

PROJECT: 169000X.XXX | DATED: 10/14/2021 | DESIGNER: HOTCALD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 1-1_Site Location Map.mxd



PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
PROPERTY BOUNDARY

0 1,000 2,000 Feet

SITE LOCATION MAP

FIGURE 1-1

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Joppa\GMP\Figure 1-2_Site Map.mxd

PROJECT: 169000XXX | DATED: 10/15/2021 | DESIGNER: HOTCALD

PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
CENTRAL DIKE
PROPERTY BOUNDARY

0 375 750 Feet

SITE MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 1-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

R000769

PROJECT: 169000XXXX | DATED: 8/30/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 2-1_Site Topographic Map.mxd

10FT TOPOGRAPHIC CONTOUR
2FT TOPOGRAPHIC CONTOUR
PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
PROPERTY BOUNDARY

Note:
Elevation contours shown in feet, North American Vertical Datum of 1988 (NAVD88)

0 250 500 Feet

SOURCE:
INGENAE SURVEY, 2021

SITE TOPOGRAPHIC MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

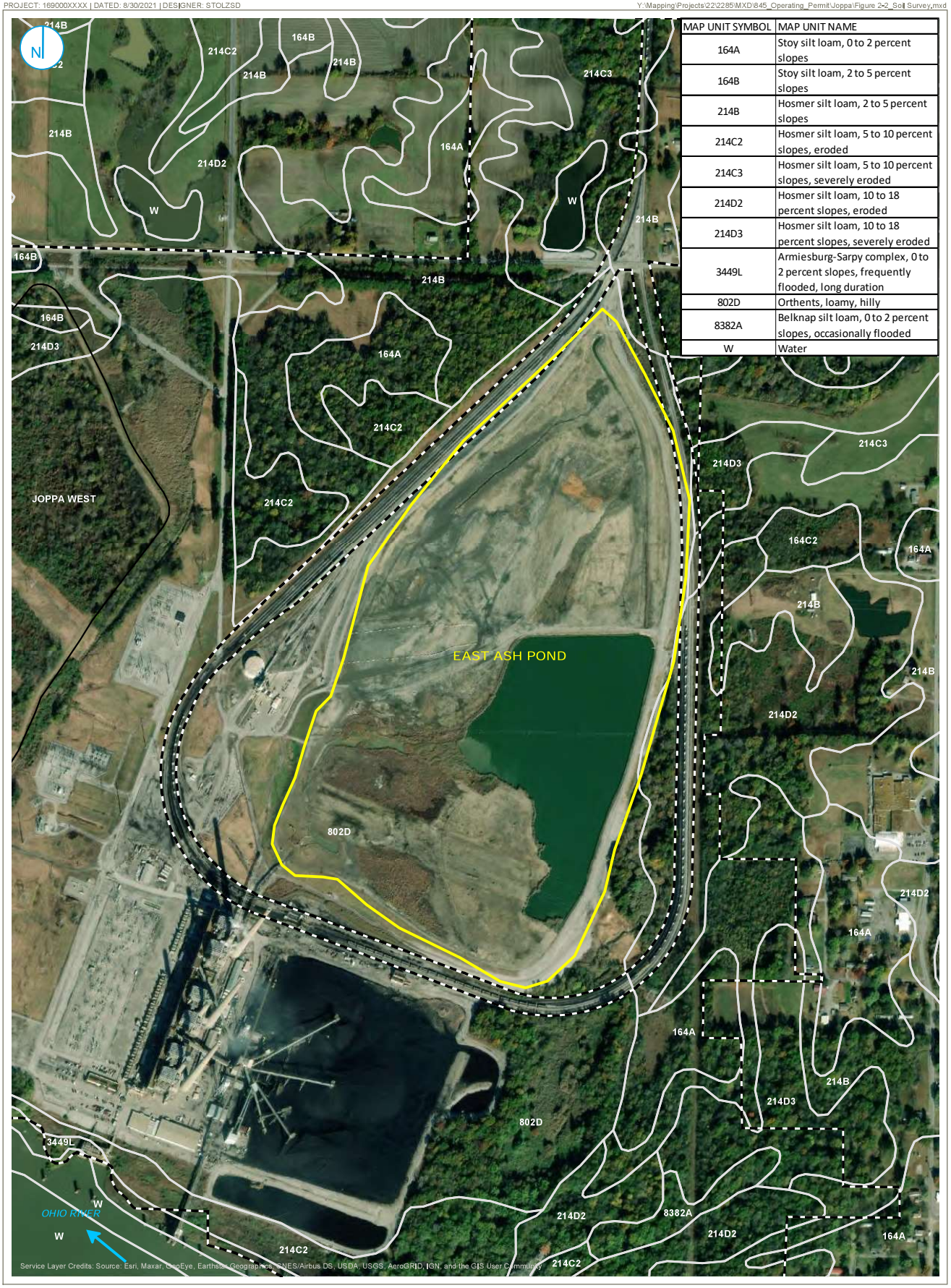
FIGURE 2-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 8/30/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 2-2_Soil Survey.mxd



MAP UNIT SYMBOL	MAP UNIT NAME
164A	Stoy silt loam, 0 to 2 percent slopes
164B	Stoy silt loam, 2 to 5 percent slopes
214B	Hosmer silt loam, 2 to 5 percent slopes
214C2	Hosmer silt loam, 5 to 10 percent slopes, eroded
214C3	Hosmer silt loam, 5 to 10 percent slopes, severely eroded
214D2	Hosmer silt loam, 10 to 18 percent slopes, eroded
214D3	Hosmer silt loam, 10 to 18 percent slopes, severely eroded
3449L	Armiesburg-Sarpy complex, 0 to 2 percent slopes, frequently flooded, long duration
802D	Orthents, loamy, hilly
8382A	Belknap silt loam, 0 to 2 percent slopes, occasionally flooded
W	Water

PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
PROPERTY BOUNDARY
NRCS SOIL SURVEY MAP UNIT BOUNDARY

SOURCE:
NATURAL RESOURCES CONSERVATION SERVICE (NRCS)

0 250 500 Feet

SOIL SURVEY MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 2-2

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 8/30/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 2-3_Surficial Geologic Deposits.mxd

- PART 845 REGULATED UNIT (SUBJECT UNIT)
- OTHER UNIT
- PROPERTY BOUNDARY
- CAHOKIA ALLUVIUM (INCLUDES ALLUVIAL FAN FACIES)
- EQUALITY FORMATION
- HENRY FORMATION
- MOUNDS GRAVEL
- MCNAIRY FORMATION

0 1,000 2,000 Feet

SOURCE:
ILLINOIS STATE GEOLOGICAL SURVEY (ISGS)

SURFICIAL GEOLOGIC DEPOSITS

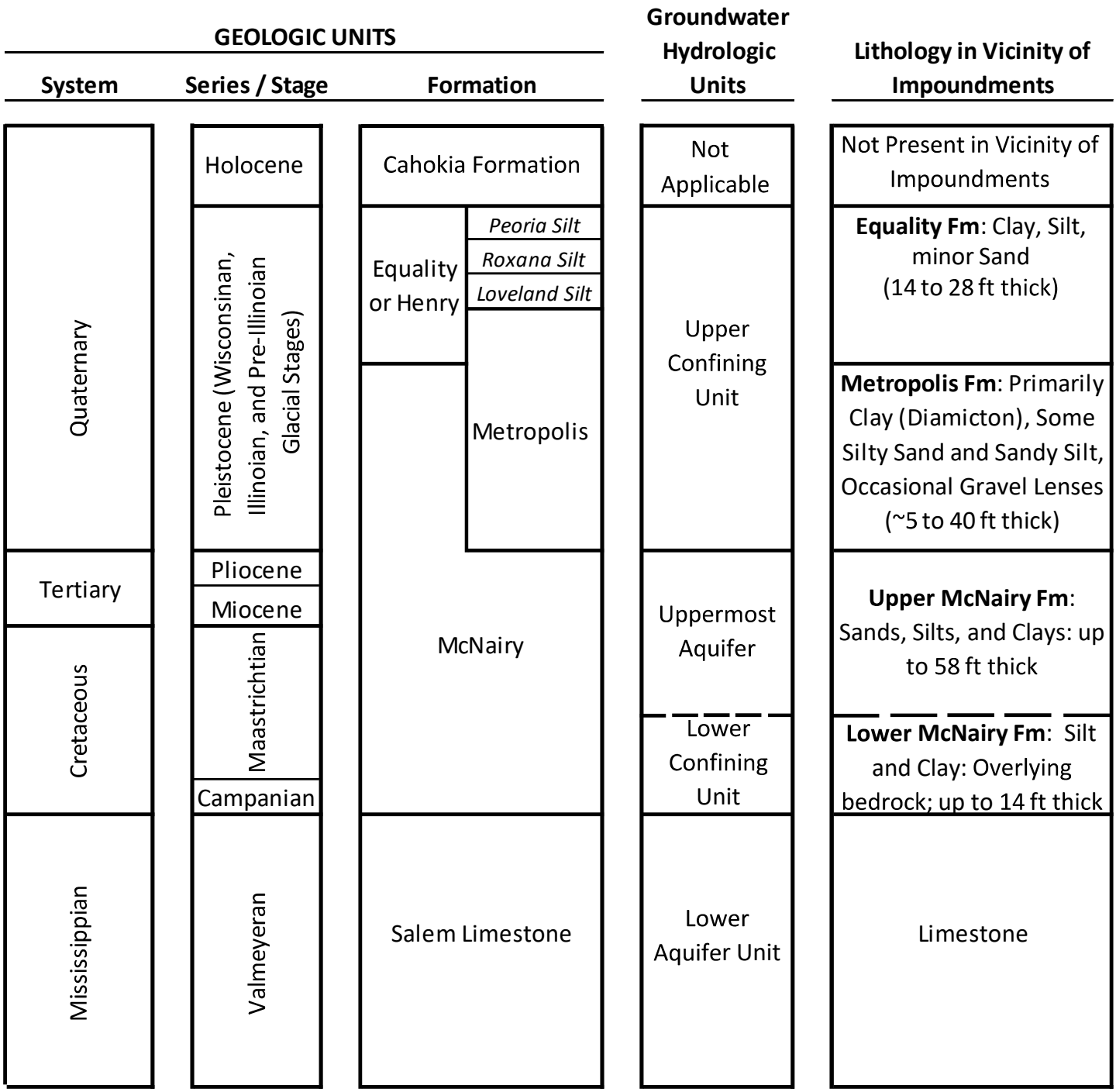
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 2-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2\2285\MXD\845_Operating_Permit\Joppa\Figure 2-4_Generalized Stratigraphic Column.mxd
PROJECT: 169000XXXX | DATED: 8/30/2021 | DESIGNER: STOLZSD



GENERALIZED STRATIGRAPHIC COLUMN FOR THE JOPPA AREA

FIGURE 2-4

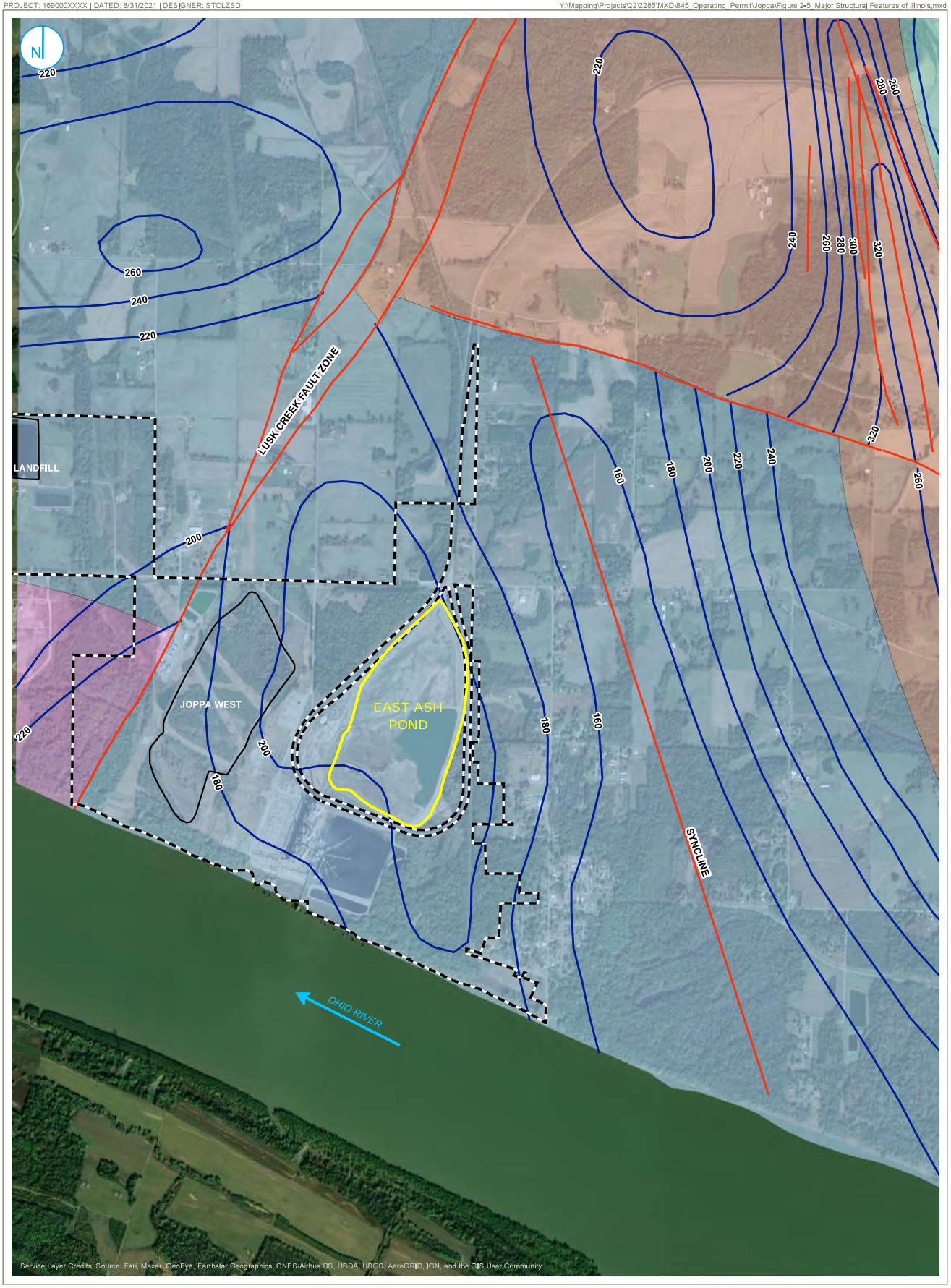
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 8/31/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 2-5_Major Structural Features of Illinois.mxd



- GEOLOGIC STRUCTURE
- BEDROCK ELEVATION CONTOURS, (20-FT CONTOUR INTERVAL, NAD 83)
- SALEM LIMESTONE
- ST LOUIS LIMESTONE
- STE GENEVIEVE LIMESTONE AND POPE GROUP
- ULLIN LIMESTONE
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- OTHER UNIT
- PROPERTY BOUNDARY

0 750 1,500 Feet

MAJOR STRUCTURAL FEATURES OF JOPPA QUADRANGLE

FIGURE 2-5

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 9/3/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 2-6_Field Investigation Locations.mxd

MONITORING WELL
STAFF GAGE
PART 845 REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

0 200 400 Feet

FIELD INVESTIGATION LOCATIONS

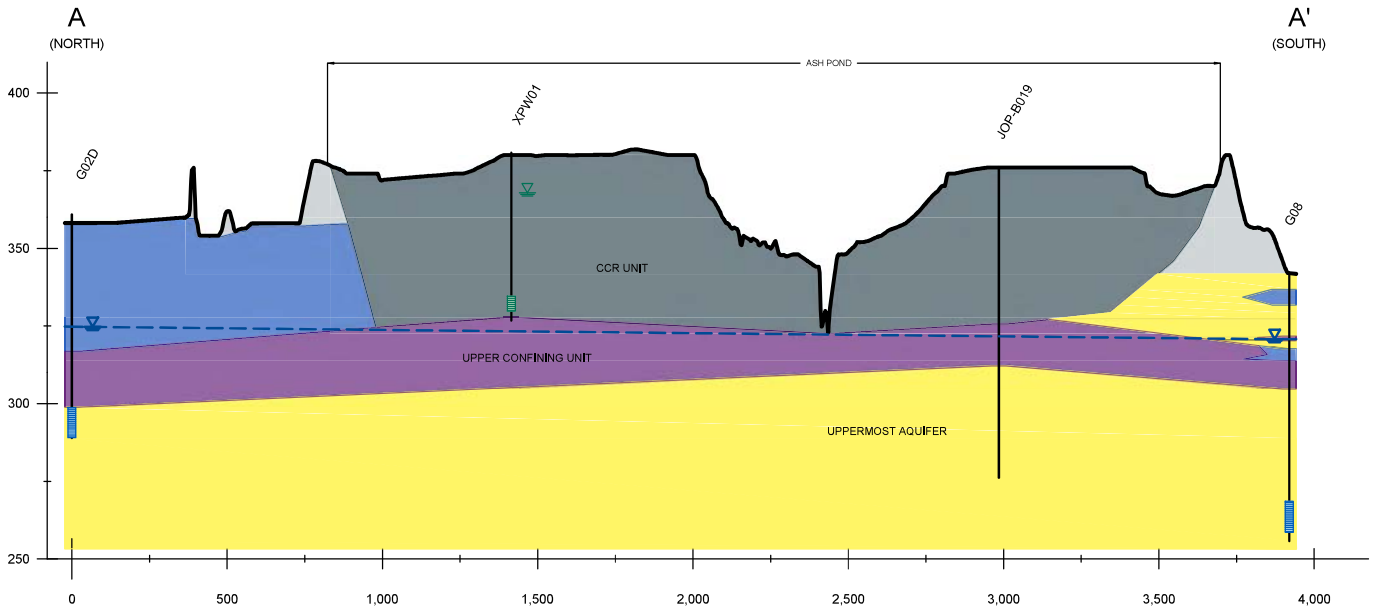
FIGURE 2-6

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

NOTES
1. This profile was developed by interpolation between widely spaced boreholes. Only at the borehole location should it be considered as an approximately accurate representation and then only to the degree implied by the notes on the borehole logs.
2. Scale is approximate.
3. Vertical scale is exaggerated 10X.
4. Groundwater elevations measured on April 13-14, 2021.



LEGEND
- COAL COMBUSTION RESIDUALS (CCR)
- FILL
- CLAY (CL/CH)
- SILT (ML)
- SAND (SP/SM/SW)
- WELL SCREEN INTERVAL
- UPPERMOST AQUIFER POTENTIOMETRIC SURFACE
- UPPERMOST AQUIFER GROUNDWATER ELEVATION
- POREWATER ELEVATION

40'
0
400'

GEOLOGIC CROSS SECTIONS
A-A'

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 2-7

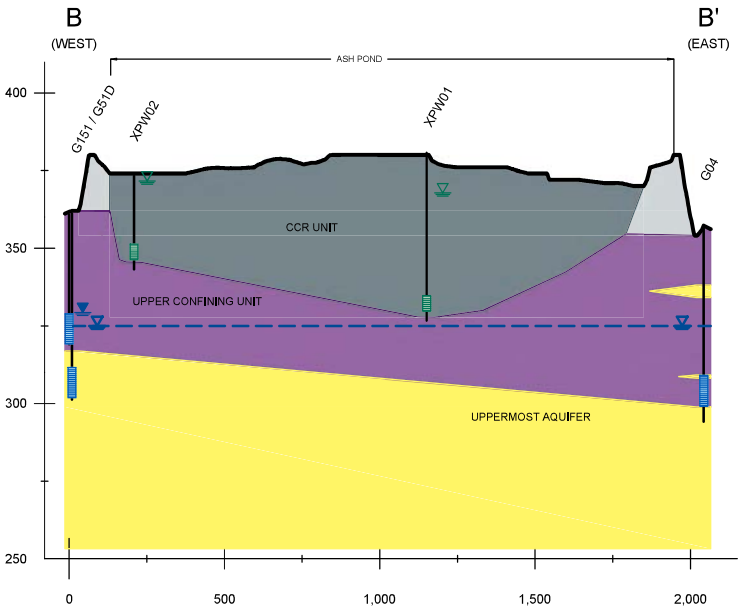
RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

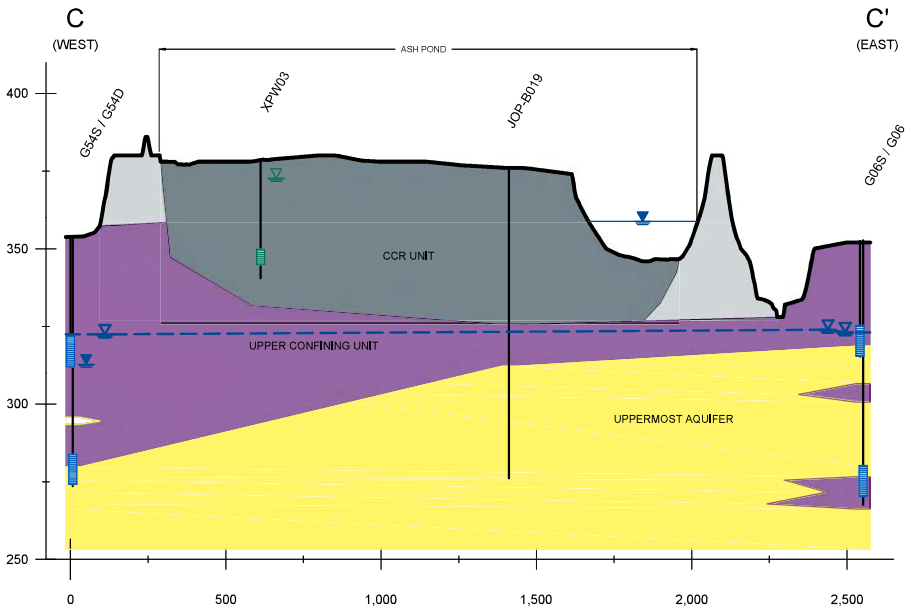
RAMBOLL

R000776

PROJECT: 1940100806 DATED: 10/5/2021 DESIGNER: ENGELHAM

NOTES
1. This profile was developed by interpolation between widely spaced boreholes. Only at the borehole location should it be considered as an approximately accurate representation and then only to the degree implied by the notes on the borehole logs.
2. Scale is approximate.
3. Vertical scale is exaggerated 10X.
4. Groundwater elevations measured on April 13-14, 2021.





LEGEND

- COAL COMBUSTION RESIDUALS (CCR)
- FILL
- CLAY (CL/CH)
- SAND (SP/SM/SW)
- WELL SCREEN INTERVAL
- UPPERMOST AQUIFER POTENTIOMETRIC SURFACE
- UPPERMOST AQUIFER GROUNDWATER ELEVATION
- POREWATER ELEVATION
- BEDROCK GROUNDWATER / OTHER GROUNDWATER / SURFACE WATER ELEVATION(S)

40' 0 400'

GEOLOGIC CROSS SECTIONS
B-B' & C-C'

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 2-8

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

R000777

PROJECT 1940100806 DATED 10/5/2021 Vertical exaggeration @ 8.5in Dev\WAA\Root sites\vistra\Shared Documents\CCR GW\Deliverables\Part 845 Operating Permits\Sites\Joppa\HCR\Figures\CAD working files\Joppa East Cross Sections.dwg

PROJECT: 169000XXXX | DATED: 10/14/2021 | DESIGNER: HOTCALD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 3-1_Monitoring Well Location Map.mxd

- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 200 400 Feet

MONITORING WELL LOCATION MAP

FIGURE 3-1

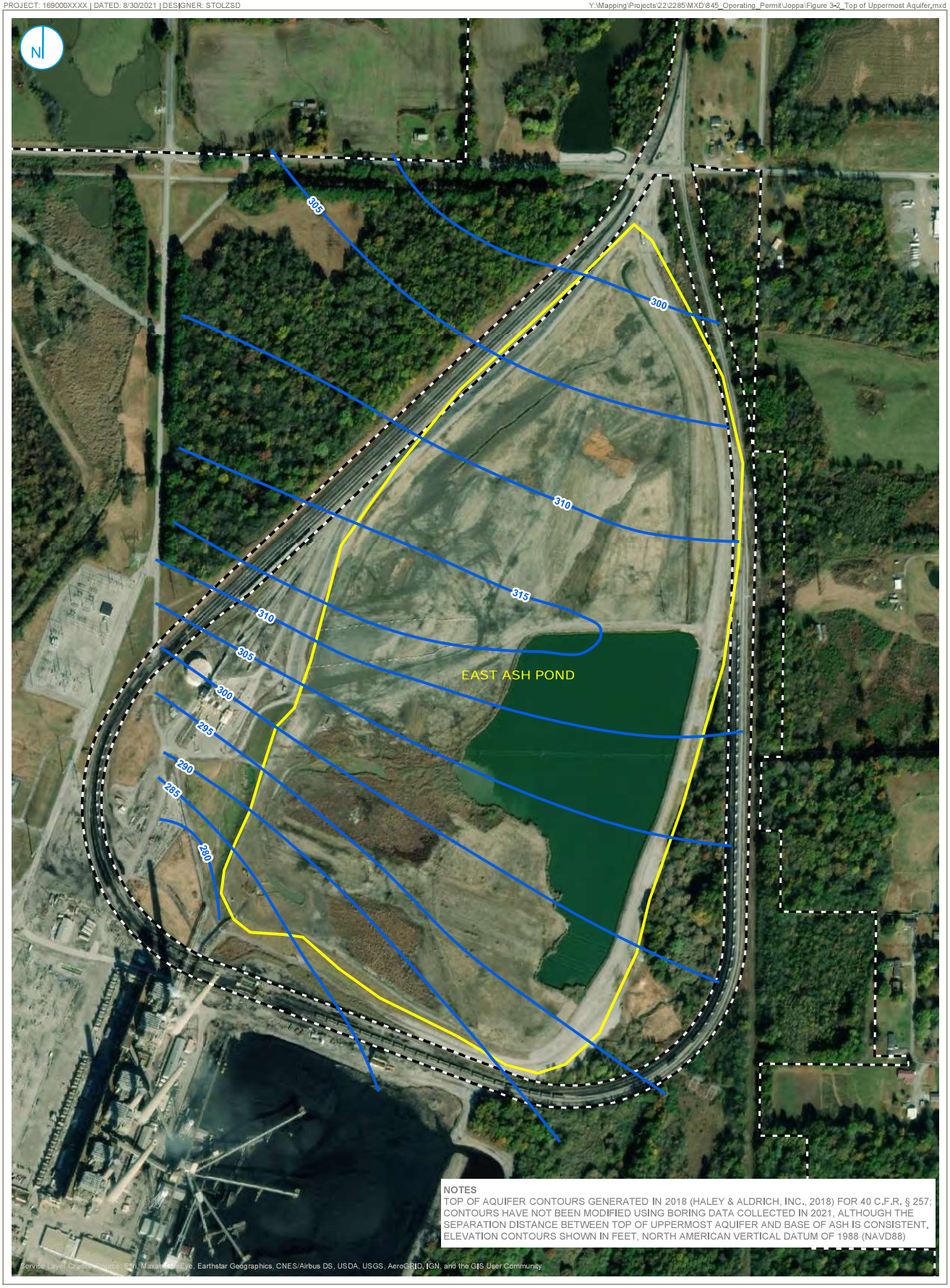
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 8/30/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 3-2_Top of Uppermost Aquifer.mxd



INTERPRETED TOP OF UPPERMOST AQUIFER (95TH PERCENTILE GROUNDWATER ELEVATION CONTOURS, 2017)

PART 845 REGULATED UNIT (SUBJECT UNIT)

PROPERTY BOUNDARY

0 200 400 Feet

TOP OF UPPERMOST AQUIFER

FIGURE 3-2

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 9/28/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 3-3_GWE_Contours_20210304.mxd

- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (1-FT CONTOUR INTERVAL, NAVD88)
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 200 400 Feet

NOTES:
1. ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.
2. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS MARCH 3 AND 4, 2021

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

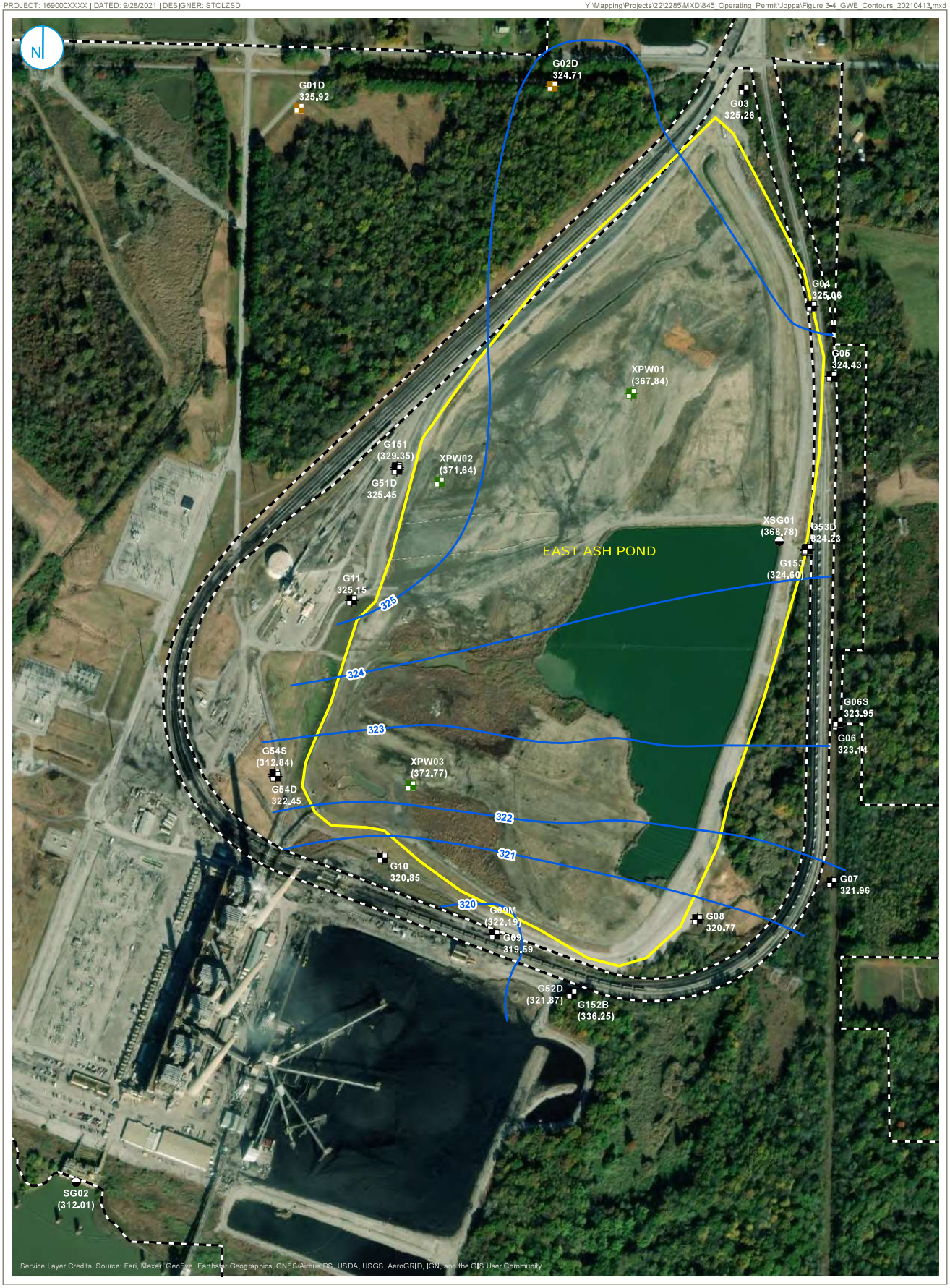
FIGURE 3-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 9/28/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 3-4_GWE_Contours_20210413.mxd



BACKGROUND WELL
MONITORING WELL
SOURCE SAMPLE LOCATION
STAFF GAGE
GROUNDWATER ELEVATION CONTOUR (1-FT CONTOUR INTERVAL, NAVD88)
PART 845 REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

0 200 400 Feet

NOTES:
1.ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.
2. ELEVATIONS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS APRIL 13 AND 14, 2021

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 3-4

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 9/28/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Figure 3-5_GWE_Contours_20210511_12.mxd

- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (1-FT CONTOUR INTERVAL, NAVD88)
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 200 400 Feet

NOTES:
1. ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.
2. ELEVATIONS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS MAY 11 AND 12, 2021

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 3-5

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

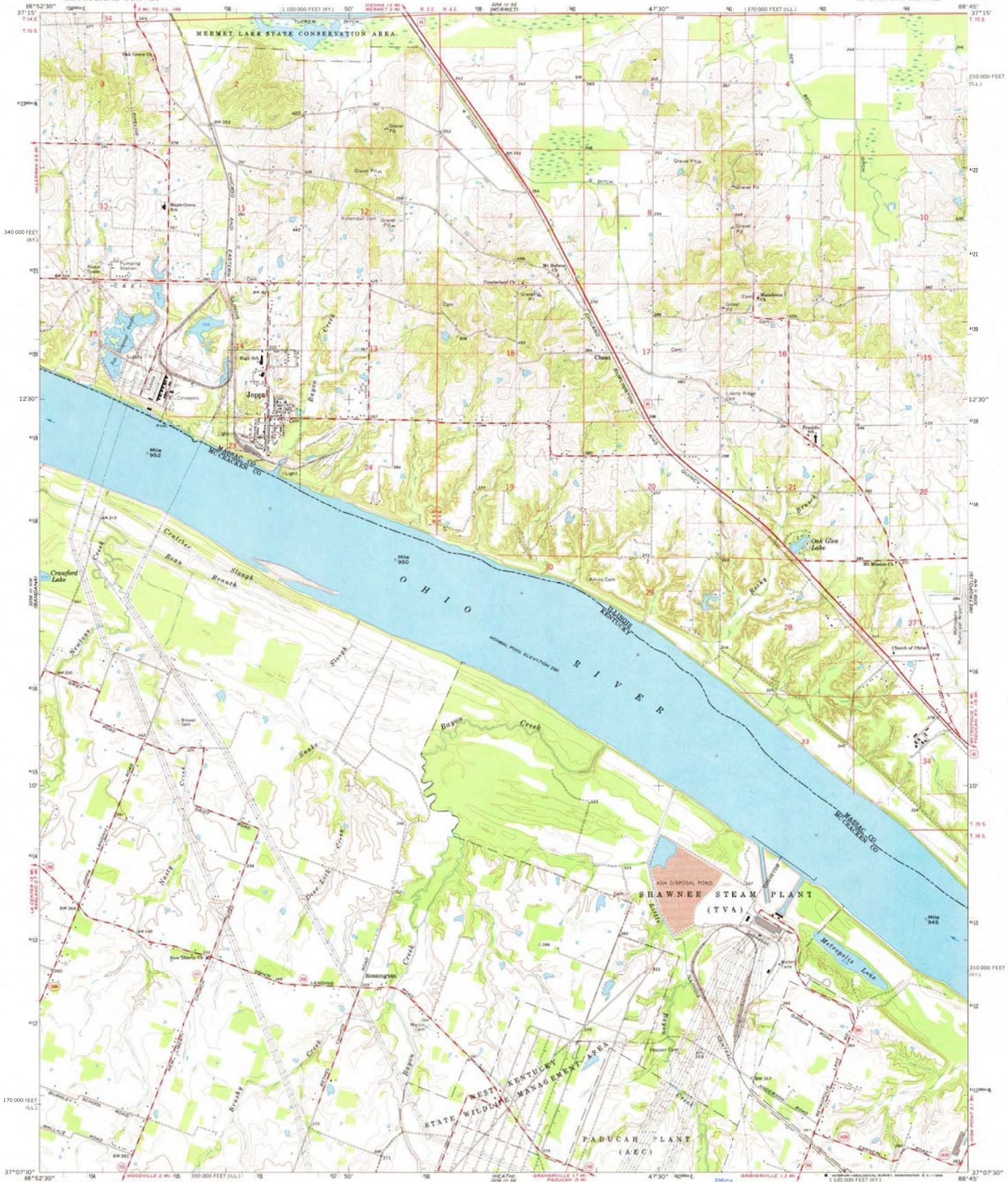
APPENDICES

APPENDIX A
HISTORICAL TOPOGRAPHIC MAP (1967)

R000785

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JOPPA QUADRANGLE
ILLINOIS–KENTUCKY
7.5 MINUTE SERIES (TOPOGRAPHIC)
NE/4 LA CENTER 15' QUADRANGLE



Mapped, edited, and published by the Geological Survey. Kentucky area mapped in cooperation with Kentucky Geological Survey

Control by USGS, USC&GS, and Tennessee Valley Authority

Topography of Illinois area by photogrammetric methods from aerial photographs taken 1965. Field checked 1967. Plasimetry of Kentucky area by photogrammetric methods from aerial photographs taken 1952. Topography by planetable surveys 1954. Revised 1967

Polyconic projection. 1927 North American datum
10,000 foot grids based on Illinois coordinate system, east zone, and Kentucky coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 16, shown in blue

The state boundary as shown represents the approximate position of the low waterline as determined from U. S. Corps of Engineers, Ohio River Charts, surveyed 1912, and supplementary information
Fine red dashed lines indicate selected fence and field lines where generally visible on aerial photographs. This information is unchecked

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242,
STATE GEOLOGICAL SURVEY, URBANA, ILLINOIS 61801,
KENTUCKY GEOLOGICAL SURVEY, LEXINGTON, KENTUCKY 40506,
AND KENTUCKY DEPARTMENT OF COMMERCE, FRANKFORT, KENTUCKY 40601
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

UTM GRID AND 1967 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

USGS
Historical File
Topographic Division

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

QUADRANGLE LOCATION

U.S.G.S.
FILE COPY
TOPOGRAPHIC DIVISION

JOPPA, ILL.–KY.
NE/4 LA CENTER 15' QUADRANGLE
N3707.5—W8845/7.5
1967
AMS 3258 III NE–SERIES V853

2855
SEP 9 1968

APPENDIX B
BORING LOGS AND WELL CONSTRUCTION LOGS

BORING AND WELL LOCATION MAPS

GEOSYNTEC BORING LOGS AND WELL CONSTRUCTION LOGS

BORING LOGS

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 1 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	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)
0				SS	14/24	2 2 3 6	5	(0') CLAY (CL); some silt, high organics/roots, brown (10YR 4/3). (0.25') CLAYEY SILT (ML); brownish yellow (10YR 6/6), soft, dry, some light gray mottling.		
				SS	20/24	2 3 4 5	7	(2') As above: higher plasticity. (MH)		
5				SS	23/24	2 3 5 6	8	(4') As above: few sand, lower plasticity. (ML)		
				SS	24/24	2 3 4 6	7	(6') SILT (ML); few sand and clay, yellowish brown (10YR 5/6), medium dense, dry, some light gray mottling.		
				SS	23/24	1 4 6 7	10	(8') As above.		
10				SS	23/24	2 6 6 8	12	(11') As above: trace fine gravel from 11 to 11.5' bgs.		
				SS	24/24	2 6 7 10	13	(12') As above: brownish yellow (10YR 6/6).		
				SS	24/24	2 3 5 5	8	(14') As above: more light gray (10YR 7/2) mottling.		
15				SS	24/24	2 3 5 6	8	(16') As above: trace sand.		
				SS	24/24	3 4 5 9	9	(18') As above: light gray (10YR 7/2) becomes dominant.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 2 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	1 4 8 10	12	(20') SILT (ML); few clay, brownish yellow (10YR 6/6), very stiff, dry.		
				SS	24/24	4 6 7 4	13	(22') SANDY SILT (ML); yellowish brown (10YR 5/6), soft, dry.		
				SS	24/24	2 5 5 8	10	(24') As above: becomes moist, few red (2.5YR 4/6) silt.		
25				SS	24/24	1 5 5 6	10	(26') As above: red silt disappears.		
				SS	24/24	1 3 4 6	7	(28') As above: becomes grayish brown (10YR 5/2).		
30				SS	24/24	1 4 4 5	8	(30') As above.	30-32 Chem	
				SH	24/24				32-34 Geotech	
				SS	24/24	3 4 5 6	9	(34') POORLY GRADED SAND (SP-SM); fine grained, few silt, brownish yellow (10YR 6/6), loose, moist to wet.		
35				SS	24/24	2 2 3 5	5	(36') SANDY SILT (ML); light yellowish brown (10YR 6/4), soft, moist, medium plasticity.		
		▼		SS	24/24	2 2 3 5	5	(38') As above: becomes evenly mottled with light gray (10YR 7/2).		
40										

NOTES: SBG03- (32-34)-20210202: 15.5% moisture content, 730 U mg/kg total organic carbon, 112.7 pcf dry unit weight, 2.659 specific gravity, 4.7x 10^{-7}, 27 LL, 16 PL, 11 PI, 0.6% gravel, 53.8% sand, 45.6% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 3 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	1 4 4 4	8	(40') SILT (ML); little sand, brownish yellow (10YR 6/6), soft, moist, medium plasticity.		
				SS	24/24	1 3 4 5	7	(42') As above.		
				SS	24/24	2 4 6 6	10	(44') As above: becomes dry, stiff.		
45				SS	24/24	2 4 13 13	17	(46') SILTY SAND (SP-SM); very pale brown (10YR 7/3), loose, moist.		
				SS	23/24	8 10 10 9	20	(48') As above: becomes brownish yellow (10YR 6/8).		
50				SS	20/24	1 6 10 13	16	(50.5') Wet at 50.5 to 50.8' bgs. (51') SAND (SP); fine grained, light gray (10YR 7/2), loose, moist.		
				SS	24/24	1 1 1 5	2	(52') As above: brownish yellow (10YR 6/6).		
				SS	12/24	1 1 1 3	2	(54') GRAVELLY SAND (SW); very pale brown (10YR 7/4), loose, wet.		
55				SS	24/24	1 1 1 3	2	(56') As above: moist, very loose.		
				SS	11/24	1 1 1 7	2	(58') WELL-GRADED SAND (SW); medium to coarse grained, few gravel, very pale brown (10YR 7/4), very loose, moist.	58-60 Chem and Geotech (not tested)	
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 4 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	20/24	2 6 10 11	16	(60') WELL-GRADED SAND (SW); medium to coarse grained, few gravel, very pale brown (10YR 7/4), wet, loose.	60-62 Geotech	
				SS	24/24	1 3 13 12	16	(62') As above: reddish yellow (7.5YR 6/6).		
65				SS	24/24	1 15 14 13	29	(64') GRAVELLY SAND (SW); reddish yellow (7.5YR 6/8), wet, loose.		
				SS	8/12	1 4		(66') As above: brownish yellow (10YR 6/6).		
70								(67') End of Boring.		

NOTES: SBG03- (60-62)-20210202: 20.0% moisture content, 740 U mg/kg total organic carbon, 2.671 specific gravity, 1.5% gravel, 94.4% sand, 4.1% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G04
Page: 1 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	02/02/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	359.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	356.15	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21902, -88.8494	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)
0				SS	12/24	2 3 3 2	6	(0') TOPSOIL. (0.25') CLAY (CL); low plasticity, brown (7.5YR 5/6), dry, very stiff.		
				SS	12/24	2 3 3 3	6	(3') As above.		
5				SS	18/24	2 2 2 3	4	(4') CLAY (CH); high plasticity, dry, moist, soft, brown (7.5YR 5/6) mottled with light gray (8/1).		
				SS	12/24	1 2 2 3	4	(6') As above: some organics (black).		
				SS	18/24	2 2 2 1	4	(8') As above: light gray dominant (brown mottled), moist.		
10				SS	24/24	3 3 3 5	6	(11') As above: now stiff, low plasticity. (CL)		
				SS	24/24	3 4 6 7	12	(12') As above: dry, some silt and fine to very fine sand.		
15				SS	24/24	3 6 7 9	13	(14') As above.		
				SS	24/24	3 5 7 9	12	(16-17') As above: medium stiff. (17-18') As above: stiff.		
20				SS	24/24	5 9 2 4	11	(18') SILTY SAND (SM); light gray (8/1), tight, moist (18-19'), dry (19-20'), poorly graded, mostly very fine to fine grained sand and silt, some clay.		

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G04
Page: 2 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	02/02/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	359.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	356.15	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21902, -88.8494	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	4 6 8 4	14	(20') SILTY SAND AND CLAY (CL/SM); light gray (8/1), interbedded, stiff/tight, mostly clay.		
				SS	24/24	8 7 8 8	15	(22') SANDY CLAY (CL); low plasticity, dry, medium stiff, mostly clay with some silt and very fine sand.		
				SS	24/24	3 6 7 9	15	(24') As above: trace fine gravel.		
25				SS	24/24	3 4 7 15	11	(26') As above: soft to medium stiff.		
				SS	24/24	8 7 8 9	15	(28') As above: less sand, very stiff, moist to dry, less brown mottling.		
				SS	24/24	5 7 9 11	16	(30') As above: moist/wet.		
30				SH	24/24	4 5 8 8	13	(32') As above: dry, brown mottling back.		
				SS	24/24	3 6 7 9	13	(34') As above: little sand/silt, moist, stiff.		
				SS	24/24	4 7 10 10	17	(36') As above: dry.		
35				SS	24/24	4 5 7 9	12	(38') As above: very stiff to hard.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G04
Page: 3 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	02/02/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	359.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	356.15	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21902, -88.8494	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	5 7 9 12	16	(40') As above: all clay, moderate plasticity, gray dominant (8/1).		
				SS	24/24	3 5 7 8	12	(42') As above: brown dominant (5YR 5/8).		
45				SS	24/24	5 5 7 11	12	(44') As above: sandy clay, some black splotches.		
				SS	24/24	19 33 15 11	48	(46') As above: wet.		
								(47') SILTY SAND (SM); mostly silt, very fine to fine grained sand, poorly graded, dry, very tight, light gray (8/1).		
				SS	24/24	5 7 5 6	9	(48') SANDY CLAY (CL); stiff, low plasticity, gray/brown mottled, dry, mostly clay, some sand.		
50				SS	24/24	9 5 8 11	14	(50') CLAY (CL); little sand, very stiff to hard, low plasticity, moist to dry, brown/gray mottled.		
				SS	24/24	3 4 6 8	14	(52') As above: moist, stiff to medium stiff.		
				SS	24/24	4 5 8 8	13	(54-55') As above: soft. (55-56') As above: trace coarse gravel, stiff.		
55				SS	24/24	4 7 21 32	28	(56') SANDY CLAY (CH); soft, high plasticity, gray/brown mottled, moist. (57.25') SILTY SAND (SM); tight, poorly graded, moist, very fine to fine grained sand and silt, gray/brown mottled.		
				SS	24/24	17 21 22 19	43	(58') SILTY SAND (SM); pinkish white (7.5YR 8/2), poorly graded, tight, saturated for middle 4", rest is moist.		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G04
Page: 4 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	02/02/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	359.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	356.15	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21902, -88.8494	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)
60				SS	24/24	8 9 12 20	21	(60') As above.		
								(62') End of Boring.		
65										

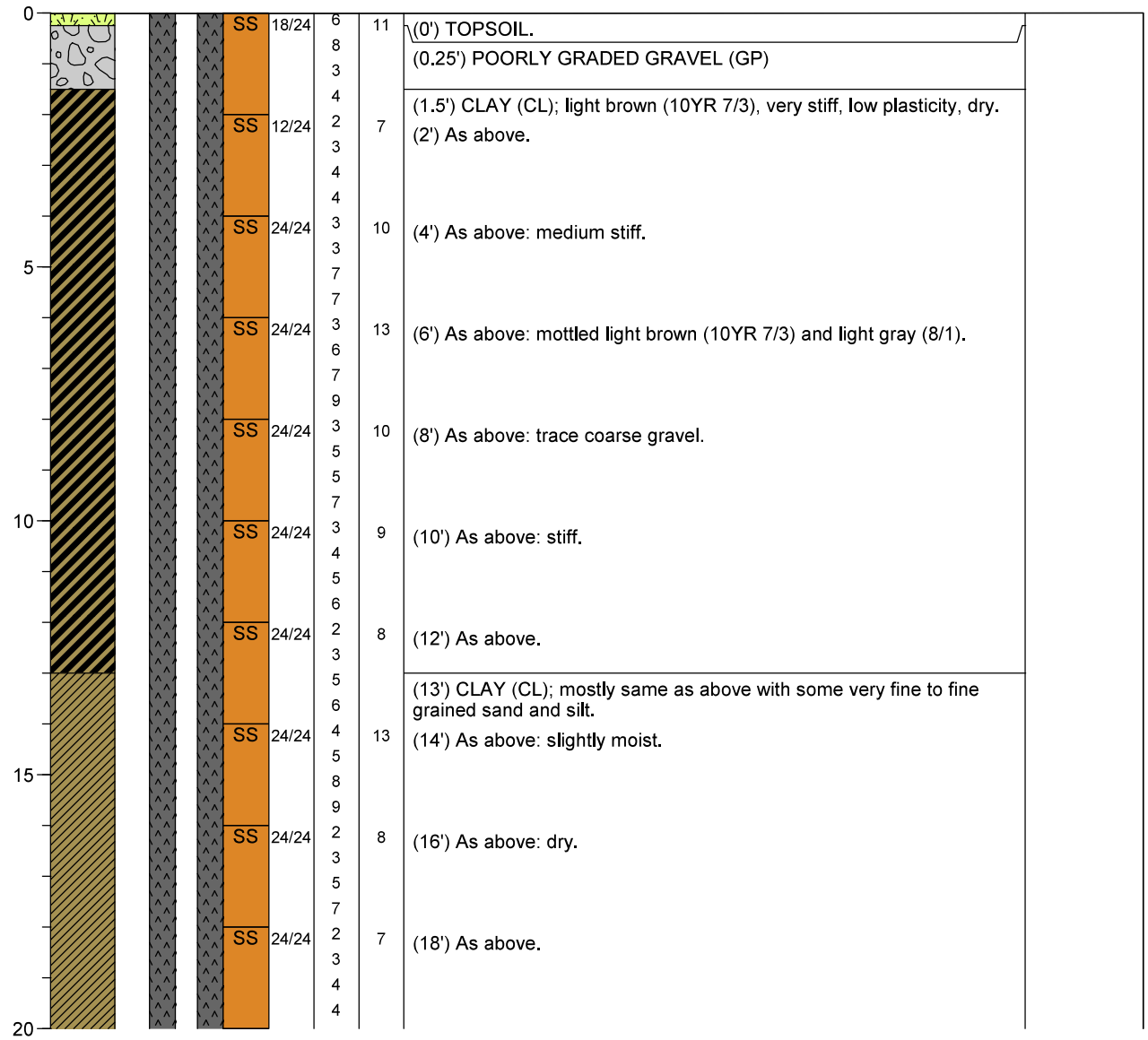
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 1 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	Filter Pack:	Sand



NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 2 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	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				SS	24/24	4 6 6 9	12	(20') As above.		
				SS	24/24	3 5 6 7	11	(22') As above: medium stiff.		
				SS	24/24	4 7 7 4	14	(24') As above.		
25				SS	24/24	3 4 7 9	11	(26') As above: stiff.		
				SS	24/24	4 5 8 10	13	(28') As above.		
30				SS	24/24	2 4 6 7	10	(30') As above.		
				SH	24/24	3 8 11 12	19	(32') As above.		
				SS	24/24	8 10 11 12	21	(34') As above.		
35				SS	24/24	3 5 7 9	12	(36') As above.		
				SS	24/24	3 8 11 14	19	(38') SILTY CLAY (CL); same as above with more silt.		
40										

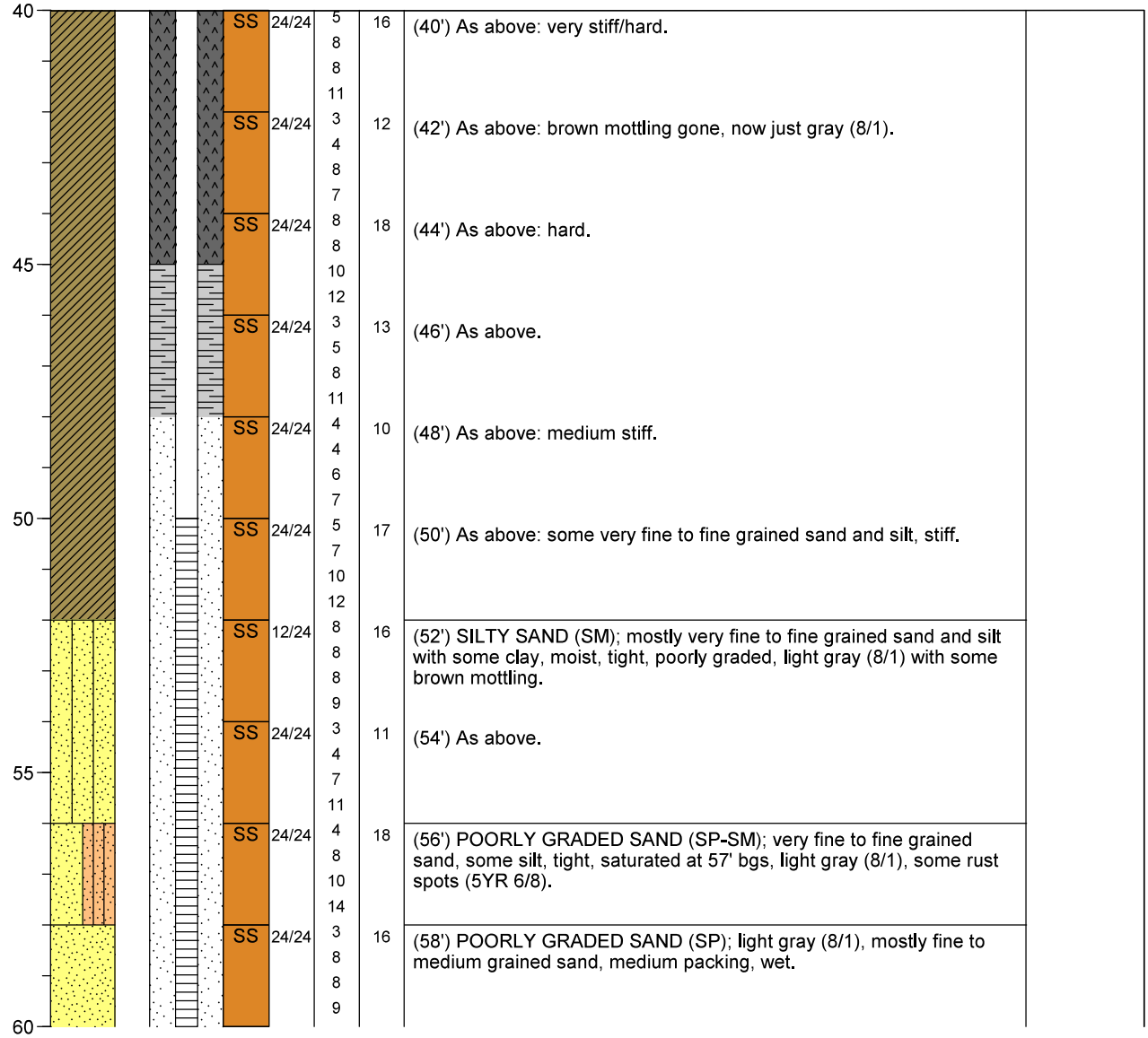
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 3 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
40	SS	24/24	5 8 8 11	16	(40') As above: very stiff/hard.		
	SS	24/24	3 4 8 7	12	(42') As above: brown mottling gone, now just gray (8/1).		
	SS	24/24	8 8 10 12	18	(44') As above: hard.		
45	SS	24/24	3 5 8 11	13	(46') As above.		
	SS	24/24	4 4 6 7	10	(48') As above: medium stiff.		
	SS	24/24	5 7 10 12	17	(50') As above: some very fine to fine grained sand and silt, stiff.		
50	SS	12/24	8 8 8 9	16	(52') SILTY SAND (SM); mostly very fine to fine grained sand and silt with some clay, moist, tight, poorly graded, light gray (8/1) with some brown mottling.		
	SS	24/24	3 4 7 11	11	(54') As above.		
55	SS	24/24	4 8 10 14	18	(56') POORLY GRADED SAND (SP-SM); very fine to fine grained sand, some silt, tight, saturated at 57' bgs, light gray (8/1), some rust spots (5YR 6/8).		
	SS	24/24	3 8 8 9	16	(58') POORLY GRADED SAND (SP); light gray (8/1), mostly fine to medium grained sand, medium packing, wet.		
60							

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 4 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	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)
60				SS	24/24	2 4 5 8	9	(60') As above: wet.		
								(61') As above: moist, some red color lamination.		
				SS	24/24	2 2 3 4	5	(62') As above: some silt, saturated, poorly graded, medium packing/toughness. (SP-SM)		
								(63') As above: moist, some red lamination.		
				SS	24/24	1 2 3 5	5	(64') As above: saturated, medium to loose toughness.		
65								(65.5') SAND (SW); some gravel, color change to (5YR 7/6)		
								(66') End of Boring.		
70										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06
Page: 1 of 5

Drilling Start Date:	01/29/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.65	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.46	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21294, -88.84915	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	12/24	2 3 3 3	6	(0') TOPSOIL. (0.25') FAT CLAY (CH); brown (5YR 6/8), soft, dry.		
				SS	12/24	2 3 3 4	6	(2') As above: trace coarse gravel.		
5				SS	6/24	2 2 3 3	5	(4') CLAY (CH); brown (5YR 6/8), high plasticity, dry, soft. ~2" coal seam.		
				SS	12/24	2 1 2 2	3	(6') As above: moist.		
				SS	12/24	1 1 3 2	4	(8') CLAY (CH); dark gray, trace coarse gravel, friable, dry.		
10				SS	12/24	2 2 3 4	5	(9') CLAY (CH); brown (5YR 6/8), high plasticity, moist, soft. (10') As above: trace fine gravel.		
				SS	12/24	1 1 2 3	3	(12') As above: dry.		
15				SS	24/24	3 3 4 4	7	(14') CLAY (CH); mottle (brown and light gray), high plasticity, soft, dry.		
				SS	12/24	3 3 4 4	7	(16') As above: wet.		
				SS	18/24	1 2 1 2	3	(18') As above: dry.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06
Page: 2 of 5

Drilling Start Date:	01/29/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.65	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.46	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21294, -88.84915	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	18/24	1 2 4 7	6	(20') CLAY (CH); soft, dry, light brown (7.5YR 8/2), moderate plasticity.		
				SS	24/24	5 7 7 8	14	(22') CLAY (CL); stiff, low plasticity, light brown (7.5YR 8/2) with dark brown mottling, dry.		
				SS	24/24	3 2 3 3	5	(24') As above.		
25				SS	24/24	2 3 3 7	6	(26') CLAY (CL); low plasticity, very stiff, dry, light brown (7.5YR 8/2) mottled with dark brown.		
				SS	24/24	3 4 4 4	8	(28') CLAY (CH); dry, high plasticity, medium stiffness, light brown (7.5YR 8/2) mottled with dark brown.		
30				SS	24/24	8 17 15 12	32	(30') SILTY SAND (SM); mostly silt and fine sand, poorly graded, dry, light gray (7.5YR 8/1), tight.		
				SH	12/24	8 7 7 9	14	(32') As above: with dark brown (7.5YR 5/8) mottling.		
				SS	18/24	3 14 12 12	26	(34') POORLY GRADED (SP); light gray (7.5YR 8/1), tight, dry, some silt, mostly very fine to fine grained sand, some rust marks.		
35				SS	18/24	4 4 9 12	13	(36') As above: moist.		
				SS	18/24	6 7 12 14	19	(38') As above: dry.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06
Page: 3 of 5

Drilling Start Date:	01/29/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.65	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.46	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21294, -88.84915	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	18/24	9 12 18 18	30	(40') As above: mottled with orange (5YR 6/8) color, medium packing, poorly graded, dry.		
				SS	12/24	8 15 16 21	31	(42') POORLY GRADED SAND (SP); red (5YR 7/8), loose, dry, mostly fine grained sand.		
				SS	18/24	7 11 12 12	23	(44') As above. (45') As above: wet.		
45				SS	24/24	8 7 14 8	21	(46') CLAY (CL); low plasticity, moist to wet, stiff, gray to reddish orange (5YR 7/8).		
				SS	24/24	5 8 10 11	18	(48') SILTY SAND (SM); mostly silt, very fine to fine grained sand, some clay, poorly sorted, tight, moist, gray (8/1).		
50				SS	24/24	10 11 9 3	20	(50') As above: saturated, mottled with (5YR 7/8) and (8/1).		
				SS	24/24	3 6 7 14	13	(52') POORLY GRADED SAND (SP); red (5YR 7/8), loose, wet, coarse gravel at bottom 1".		
				SS	24/24	4 18 18 15	36	(54') As above: sand with 1-2" gravel at bottom.		
55				SS	24/24	3 7 8 14	15	(56') POORLY GRADED SAND (SP); mostly fine to medium grained sand, wet, medium packing, reddish yellow (5YR 7/6).		
				SS	24/24	8 12 26 27	38	(58') As above: some fine to coarse gravel. (59') DIAMICTON - mostly fine-coarse grained WELL-GRADED GRAVEL and SAND (GW-SW); wet, medium packing, reddish yellow		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06
Page: 4 of 5

Drilling Start Date:	01/29/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.65	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.46	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21294, -88.84915	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	18/24	8 11	47	(5YR 7/6).		
						36 23		(60') POORLY GRADED SAND (SP); reddish yellow (5YR 7/6), tight, wet.		
				SS	18/24	7 18	47	(61') WELL-GRADED SAND (SW); lots of coarse gravel (orange chert), loose.		
						29 31		(62') DIAMICTON - mostly fine-coarse grained GRAVEL AND SAND (GW-SW); (orange chert), wet, very loose, reddish yellow (5YR 7/6).		
				SS	12/24	11 12	40	(64') As above: saturated.		
65						28 26				
				SS	18/24	21 33	85	(66') 6" tan (5YR 7/6), same as above (SP)		
						52		(66.5') DIAMICTON same as above (GW-SW)		
				SS	18/24	5 3	13	(68') POORLY GRADED SAND same as above (SP)		
						10 16		(69') DIAMICTON same as above (GW-SW)		
70				SS	18/24	7 12	27	(70') GRAVELLY SILT DIAMICTON (GW/SM); mostly fine to coarse gravel, fine to coarse sand, silt and some clay, wet, stiff, well-graded, orangish tan (5YR 7/6).		
						15 17				
				SS	24/24	9 9	23	(72') As above: saturated.		
						14 9				
				SS	12/24	6 7	17	(74') As above: very stiff/tight.		
75						10 11				
				SS	18/24	6 6	16	(76') As above: more clay than sand (medium to high plasticity). (CH/MH/GW)		
						10 11				
				SS	12/24	7 9	16	(78') As above: less clay. (GW/SW)		
						7 5		(79') Moist, 1cm dark brown layer diamicton gravel up to 1.5" diameter.		
80										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06
Page: 5 of 5

Drilling Start Date:	01/29/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.65	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.46	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21294, -88.84915	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)
80				SS	24/24	4 4 5 5	9	(80') SILTY CLAY (CH/MH); light gray (8/1) with red splotches, soft, low plasticity, moist.		
				SS	12/24	2 3 4 50/5	7	(82') As above: trace coarse gravel, rust red mottled.		
85				SS	6/24	50/20	15	(84') As above.		
								(85') SILTY SAND (SM); dark b brown, poorly graded, loose, moist.		
90								(86') End of Boring. Bedrock likely encountered at 86' bgs. very high resistance material.		

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06S
Page: 1 of 3

Drilling Start Date:	02/01/2021	Boring Depth (ft):	44	Well Depth (ft):	40
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.92	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.22187, -88.84904	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)
0								(0') Blind drill.		
5										
10										
15										
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06S
Page: 2 of 3

Drilling Start Date:	02/01/2021	Boring Depth (ft):	44	Well Depth (ft):	40
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.92	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.22187, -88.84904	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								(20') Blind drill.		
25				SS	24/24	4 7 8 9	15	(26') CLAY (CH); light gray (7.5YR 8/1) mottled with brown, dry, very stiff, low plasticity.		
				SS	24/24	5 5 9 8	14	(28') As above.		
30				SS	24/24	3 7 14 24	21	(30') As above.		
				SH	24/24	4 1 8 11	9	(31') SILTY SAND (SM); very tight, mostly silt and fine to very fine grained sand, poorly graded, dry, (8/1) with (5YR 7/8), some clay. (32') As above.		
35				SS	12/24	9 22 10 10	32	(34') SAND AND SILTY SAND (SP-SM); mostly very fine to fine grained sand with some silt, poorly graded, tight, dry, light gray/organic.		
				SS	24/24	3 6 8 16	14	(36') As above. (SM)		
				SS	18/24	7 10 12 17	22	(38') As above. (SP-SM)		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G06S
Page: 3 of 3

Drilling Start Date:	02/01/2021	Boring Depth (ft):	44	Well Depth (ft):	40
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	355.92	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.22187, -88.84904	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)
40				SS	24/24	8		(40') POORLY GRADED SAND (SP); (5YR 7/8), mostly fine grained sand, medium density, dry.		
				SS	24/24			(42') As above.		
45								(44') End of Boring.		

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 1 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	4 8 6 6	14	(0') TOPSOIL. (0.25') FAT CLAY (CH); light brown (5YR 6/8), stiff, dry.		
				SS	12/24	4 5 5 6	10	(2') As above.		
5				SS	24/24	4 4 7 5	11	(4') As above.		
				SS	24/24	4 6 7 8	13	(6') As above.		
				SS	24/24	4 3 3 5	6	(8') As above: medium stiffness.		
10				SS	24/24	4 4 7 8	11	(10') LEAN CLAY (CL); light brown (5YR 7/4) to gray (mottled), stiff, dry.		
				SS	24/24	4 5 5 6	10	(12') As above: top 6" soft with plant material.		
				SS	24/24	3 3 4 4	7	(14') As above.		
15				SS	24/24			(16') As above.		
				SS	24/24	3 4 5 7	9	(18') As above: silt and clay, some fine sand, stiff, dry. (ML-CL)		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 2 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	3 4 6 7	10	(20') As above: rust spots.		
				SS	24/24	3 3 4 6	7	(22') As above: moist.		
				SS	24/24	3 3 4 5	7	(24') As above: mottled (10R 8/1).		
25				SS	24/24	3 4 7 7	11	(26') SILTY SAND (SP-SM); mostly silt, fine grained sand, some mottling as previous, poorly graded, tight, moist.		
				SS	24/24	3 6 7 7	13	(28') POORLY GRADED SAND (SP); very fine to fine grained sand, light gray (10R 8/1), tight, moist.		
30				SS	24/24	9 20 21 26	41	(30') As above. (31') POORLY GRADED SAND (SP); medium to coarse grained, loose, moist, (10R 8/1).		
				SH	18/24	10 6 9 9	15	(32') As above: color change to orange (5YR 6/8), clay at bottom.		
				SS	24/24	4 5 6 7	11	(34') FAT CLAY (CH); stiff, moist, light gray/orange mottled (10R 8/1 to 5YR 6/8).		
35				SS	24/24	3 3 5 5	8	(36') As above: medium stiffness.		
				SS	24/24	2 2 2 3	4	(38') As above.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 3 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	3 3 5 8	8	(40') As above.		
				SS	24/24	6 12 23 24	35	(42') SILTY SAND (SP-SM); very fine grained sand and silt, tight, moist, poorly graded, light gray (10R 8/1).		
				SS	18/24	7 18 27 33	45	(44') As above.		
45								(45') POORLY GRADED SAND (SP); very fine to fine grained sand, tight, moist, (10R 8/1).		
				SS	24/24	7 18 43 47	61	(46') POORLY GRADED SAND (SP); fine to medium grained sand, loose, wet, interbedded gray to reddish orange (5YR 6/8) - seams 2cm.		
				SS	18/24	14 17 18 7	35	(48') DIAMICTON (GW); mostly fine to coarse gravel and medium to coarse sand, saturated, very loose, well graded, (5YR 7/8).		
50				SS	24/24	12 22 36 39	58	(50') WELL-GRADED SAND (SW); medium to coarse grained with fine gravel, saturated, loose.		
				SS	24/24	9 11 14 18	25	(52') As above: (5YR 7/6).		
								(53') DIAMICTON (GW-SW); same as above, (5YR 6/8).		
				SS	24/24	19 31 53	84	(54') Same as above (SW).		
55				SS	24/24	7 21 14 8	35	(55') WELL-GRADED GRAVEL and SAND (GW-SW); mostly fine to coarse grained gravel and fine to medium sand, loose, wet, light gray (10R 8/1), orangish tan chert nodules. (57') As above: top 1' tan (5YR 6/8) bottom gray (10R 8/1), wet.		
				SS	24/24	6 9 11 16	20	(58') POORLY GRADED SAND (SP); mostly very fine to fine grained sand, wet, loose, tan (7.5YR 8/4).		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 4 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	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)
60				SS	24/24	32 48 38 8	86	(60') As above. (62') DIAMICTON (GW-SW); same as above.		
								(62') End of Boring.		
65										

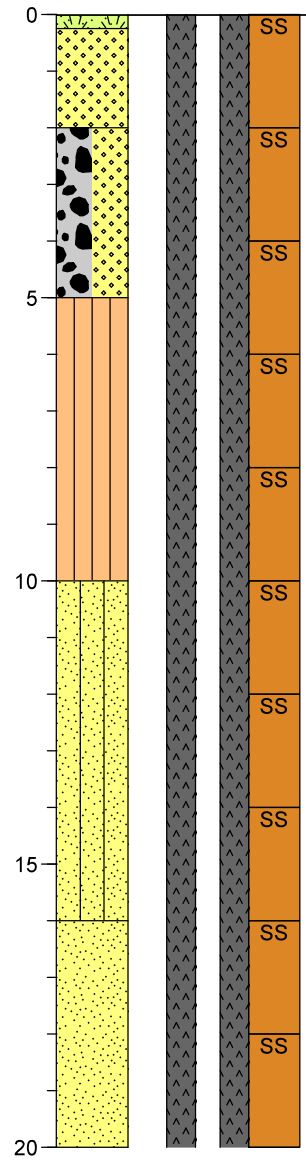
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 1 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
0	SS		7 3 4	7	(0') TOPSOIL. (0.25') WELL-GRADED SAND (SW); light brown/gray, loose, dry.		
	SS		6 14 11	18	(2') GRAVELLY SAND (GW-SW); loose, dry, mostly fine to coarse grained gravel and sand.		
	SS		7 6 4	7			
5	SS		3 4 4		(5') SILT (ML); low plasticity, dark gray, dry, trace coarse gravel.		
	SS		3 2 2	4	(6') As above.		
	SS		4 2 2	4	(8') As above: trace fine gravel.		
10	SS		2 2 2				
	SS		3 4 4	8	(10') SILTY SAND (SM); dark gray, loose, dry, well-graded.		
	SS		4 2 2	5	(12') As above.		
	SS		3 3 2	5	(14') As above: clay seam at 15' (1-2").		
15	SS		3 2 4				
	SS		2 2 2	4	(16') POORLY GRADED SAND and CLAY (SP/CL); dark gray interbedded with dark gray, medium stiff, clay - 2" beds alternating.		
	SS		2 2 1	3			
20			2 1 1				

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 2 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	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				SS		1 1 1	2	(20') CLAY (CH); high plasticity, soft, moist, gray to green.		
				SS		2 1 1 1 1	2	(21.5') SILTY SAND (SM); wet, loose, gray to green. (22') As above.		
25				SS		3 2 2 2 2	4	(24') SILT (ML); loose, dark gray, black clay seam - 2".		
				SS		2 2 1 2	3	(26') CLAY (CH); gray to green, saturated, high plasticity.		
								(27') SILT (ML); soft, moist, gray to green.		
				SS		1 1 1 2	2	(28') SILTY SAND (SM-SP); light gray, firm, saturated, mostly poorly graded fine to medium grained sand and silt.		
30				SS		2 3 2 3	5	(30') As above.		
				SS		4 3 3 4	7	(31') SILTY SAND (SM); tight, light gray, poorly graded, fine to medium grained sand. (32') As above.		
				SS		4 4 4 4	7	(33') CLAY (CL); light gray, hard, low plasticity, dry.		
35				SS		3 3 3 4	8	(35') As above: some fine grained sand. (36') As above: gradually grades to fine to medium sand.		
				SS		4 5 3 3	6	(37') POORLY GRADED SAND (SP); fine to medium grained sand, tight, trace gravel, mottled with rusty red color. (38') As above.		
40						3 3				

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 3 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS		5 10 12 12	22	(40') POORLY GRADED SAND (SP); fine to medium grained, tight, light gray, mottled with rust color. (41') As above: saturated.		
				SS		3 5 8 8	13	(42') As above: some fine to coarse gravel. (43.5') As above: nodule (red chert), saturated.		
45				SS		3 6 7 7	13	(44') As above: lots of fine to coarse gravel, yellow/orange/red, gravel/nodules.		
				SS		5 7 7 11	14	(46') GRAVELLY SAND (GW-SW); mostly fine grained sand and fine to coarse gravel, light gray, gravel bits are red/yellow, saturated.		
				SS		1 5 5 5	10	(48') As above: very loose.		
50				SS		9 9 5 14	14	(50') As above. (51.5') As above: some silt.		
				SS		3 11 11 10	22	(52') WELL-GRADED SAND (SW); fine to coarse grained, trace fine gravel, tan, very loose.		
				SS		9 14 12 10	26	(54') WELL-GRADED GRAVELLY SAND (GW-SW); tan, moist, coarse grained gravel, fine to coarse sand, very loose, wet. (55') As above: light gray.		
55				SS		17 19 17 17	36	(56') POORLY GRADED SAND (SP); fine to medium grained, wet, loose, dark tan. (57.5') WELL-GRADED GRAVELLY SAND (GW); dark tan, loose.		
				SS		6 8 11 12	19	(58') As above. (59') WELL-GRADED SAND (SW); dark tan, wet, loose, trace fine gravel.		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 4 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	24/24	14 10	24	(60') As above.		
						14 11		(61') GRAVELLY SAND (GW-SW); dark tan, well-graded, coarse chert nodules, wet, loose.		
				SS	18/24	5 3	7	(62') As above.		
						4 5				
				SS	12/24	4 8	13	(64') As above.		
65						5 8				
				SS	18/24	5 8	16	(66') As above.		
						8 7				
				SS	18/24	5 7	14	(68') As above: saturated.		
						7 8				
70				SS	12/24	5 6	13	(70') As above.		
						7 7				
				SS	18/24	7 9	18	(72') As above.		
						9 11				
				SS	24/24	7 7	15	(74') As above: mostly silt and gravel, (5YR 6/8).		
75						8 9				
				SS	18/24	10 16	33	(76') WELL-GRADED SAND (SW); mostly medium to coarse grained sand, wet, loose, (5YR 6/8).		
						17 25				
				SS	24/24	8 15	54	(78') DIAMICTON (SW-SM); mostly coarse grained gravel, fine sand, silt, wet, medium density, (5YR 6/8).		
						39 42		(79') Same fine to coarse gravel, more coarse gravel, (5YR 6/8). (GW-SW)		
80										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 5 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	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)
80				SS	18/24	6 11 12	23	(80') As above. (SW)		
						14		(81.5') 1/2" seam - orangish sand, medium packing, moist, (7.5YR 8/6). (SP)		
				SS	24/24	7 14 19 21	33	(82') Same as above. (SW) (83') Same as above, top 3" (10R 6/6), tight, moist. (SP)		
85				SS	12/24	19 27 15 5	42	(84') As above. (85') 2cm seam of reddish/oxidized fine grained sand, dry.		
90								(86') End of Boring.		

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09
Page: 1 of 4

Drilling Start Date:	01/31/2021	Boring Depth (ft):	72	Well Depth (ft):	70
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	36.31	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.99	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.69	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21039, -88.54247	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)
0								(0') Blind drilled.		
5										
10										
15										
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09
Page: 2 of 4

Drilling Start Date:	01/31/2021	Boring Depth (ft):	72	Well Depth (ft):	70
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	36.31	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.99	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.69	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21039, -88.54247	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								(20') Blind drilled.		
25										
30										
35		▼								
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09
Page: 3 of 4

Drilling Start Date:	01/31/2021	Boring Depth (ft):	72	Well Depth (ft):	70
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	36.31	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.99	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.69	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21039, -88.54247	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)
40								(40') Blind drilled.		
45										
50										
55				SS	13/24	1 1 5 15	6	(54') POORLY GRADED SAND (SP); fine to medium grained sand, light gray (2.5Y 7/1), medium dense, dry, few coarse gravel.		
				SS	23/24	8 13 15 20	28	(56') As above.		
60				SS	15/24	4 9 17 16	26	(58') WELL-GRADED SAND (SW); coarse grained with gravel, reddish yellow (7.5YR 6/6), loose, moist. (59') Becomes wetter.		

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09
Page: 4 of 4

Drilling Start Date:	01/31/2021	Boring Depth (ft):	72	Well Depth (ft):	70
Drilling End Date:	01/31/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	36.31	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.99	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.69	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21039, -88.54247	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)
60				SS	19/24	13 24 48 25	72			
								(61') SANDY GRAVEL (GW); yellow (10YR 7/8), loose, wet.		
				SS	11/24	9 17 17 22	34	(62') Becomes sandier.		
				SS	13/24	4 18 19 16	37			
65								(65') As above: brownish yellow (10YR 6/8).		
				SS	13/24	4 17 23 50	40			
								(67') As above.		
				SS	2/24	50/5				
								(69') As above.		
70				SS	14/24	6 18 18 13	36	(70') POORLY GRADED SAND (SP); fine to medium grained, yellow (10YR 7/6), loose, moist.		
								(71') SANDY GRAVEL (GW); yellowish brown (10YR 5/6), loose, wet, well-graded.		
								(72') End of Boring.		
75										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 1 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	6/24	6 4 5 6	9	(0') LEAN CLAY (CL); brown (7.5YR 5/3), stiff, dry, some reddish brown mottling, trace sand.		
				SS	22/24	4 5 6 4	11			
				SS	24/24	2 3 3 4	6	(4') FAT CLAY (CH); light brown (7.5YR 6/4), medium dense, moist.		
5				SS	24/24	0 3 3 4	6	(6') As above: lean clay, moist. (CL)		
				SS	24/24	2 3 5 5	8	(8') As above: brown (7.5YR 5/4), some reddish brown mottling.		
10				SS	20/24	2 3 4 5	7	(10') As above.	10-12 Chem	
				SS	22/24	2 4 5 5	9	(12') CLAY (CL); gray to light brown (7.5YR 6/1) mottled, medium dense, dry, few sand.		
				SS	21/24	2 3 5 5	8	(14') As above: brown (7.5YR 5/4).		
15				SH	24/24			(16') As above: light brown (7.5YR 6/3).	16-18 Geotech	
				SS	23/24	2 5 6 7	11	(18') CLAY (CL); gray to light brown (7.5YR 6/1) mottled, very stiff, moist, few sand.		
20										

NOTES: SBG09M- (16-18)-20210127: 20.6% moisture content, 950 mg/kg total organic carbon, 105.4 pcf dry unit weight, 2.666 specific gravity, 8.3x 10^{-8} cm/s vertical hydraulic conductivity, 39 LL, 16PL, 23PI, 0.0% gravel, 5.0% sand, 95.0% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 2 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	2 4 7 8	11	(20') CLAY (CL); light gray with brown (10YR 7/1) mottling, very stiff, moist, trace sand and silt.	20-22 Chem	
				SS	24/24	4 6 7 8	13	(22') As above: (10YR 7/2).		
				SS	24/24	2 5 7 8	12	(24') As above: fewer brown mottling.		
25				SS	24/24	3 3 6 7	9	(27-28') As above: increased reddish brown mottling.		
				SS	24/24	4 8 8 7	16	(28') SILT (ML); with few sand and clay, light gray (10YR 7/2) with some brown mottling, dry, stiff.		
30				SS	24/24	4 8 6 8	14	(30') As above: moist.		
				SS	24/24	4 5 6 7	11	(32') As above.		
				SS	24/24	2 4 4 6	8	(34') SANDY CLAY (SC); light gray (10YR 7/2) with some brown mottling, moist.		
35								(34.5') SILT (ML); with some sand, few clay, stiff.		
				SS	24/24	3 4 5 8	9	(36') As above: trace black organics.		
				SS	24/24	5 20 18 17	38	(38') SANDY CLAY (SC); fine grained sand, few silt, gray (7.5YR 5/1), moist.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 3 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	3 6 8 7	14	(40') SILT WITH SAND (ML); few clay, gray (7.5YR 6/1), moist.		
				SS	24/24	5 3 4 5	7	(42') As above: some reddish brown mottling.		
				SS	24/24	2 3 5 6	8	(44') As above: fewer clay, more sand.		
45				SH	24/24				46-48 Geotech	
				SS	24/24	5 8 18 12	26	(48') SILT WITH CLAY (ML); gradationally sandier, becomes moist, stiff to medium dense, gray (7.5YR 6/1).	48-50 Chem	
50		▼		SS	20/24	18 8 15 23	23	(50') POORLY GRADED SAND (SP); light gray (7.5YR 7/1), moist, loose.		
				SS	16/24	16 22 28 32	50	(52') POORLY GRADED SAND (SP); fine grained, with gravel up to cobble size, light gray (10YR 7/1), medium dense to loose, moist.		
				SS	20/24	25 45 49 49	94	(54') POORLY GRADED SAND (SP); fine to medium grained, light gray (7.5YR 7/1), moist, loose. (55') As above: few coarse gravel, reddish yellow (7.5YR 7/6).		
55				SS	23/24	27 33 20 20	53	(56') POORLY GRADED SAND (SP); fine to coarse grained, with coarse gravel, moist, gray (7.5YR 7/1) to reddish yellow (7.5YR 7/8).		
				SS	18/24	8 33 47 34	80	(58') As above: fine gray sand contains trace silt.		
60										

NOTES: SBG09M- (46-48)-20210127: 19.8% moisture content,105.4 pcf dry unit weight, 2.715 specific gravity, 3.5x 10^{-7} cm/s vertical hydraulic conductivity, 35 LL, 15 PL, 20 PI, 0.0% gravel, 17.2% sand, 82.8% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 4 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	16/24	32 35 47 21	82	(60') POORLY GRADED SAND (SP); coarse grained, reddish yellow (7.5YR 6/8), moist, loose.		
				SS	16/24	22 50/5 14	64	(62') POORLY GRADED SAND (SP); coarse grained, reddish yellow (7.5YR 6/8), medium dense, some coarse gravel pebble size.		
65				SS	13/24	17 11 12 12	23	(64') As above: increasing fine to coarse gravel.		
				SS	12/24	15 16 15 11	31	(66') As above.		
				SS	11/24	38 50	50	(68') POORLY GRADED GRAVEL WITH SAND (GP); strong brown (7.5YR 5/6), loose, moist.		
70				SS	12/24	14 17 30 32	47	(70') As above.		
				SS	12/24	25 24 15 16	39	(72') As above: reddish yellow (7.5YR 6/8).		
				SS	8/24	6 25 20 12	45	(74') As above: sand disappears, wet.		
75				SS	14/24	7 7 8 7	15	(76') As above: strong brown (7.5YR 5/8).		
				SS	16/24	11 22 14 8	36	(78') As above: with some sand.		
80										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 5 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
80				SS	12/24	2 17 19 12	36	(80') POORLY GRADED GRAVEL (GP); little sand, reddish yellow (7.5YR 6/8), very loose, wet.	80-82 Chem	
				SS	10/24	5 18 13 14	31		82-84 Geotech	
				SS	14/24		19	(83.7') POORLY GRADED SAND (SP); medium grained, trace gravel, reddish brown (7.5YR 6/8), loose, moist.		
85				SS	14/24	12 9 10 10	22	(86') WELL-GRADED GRAVEL (GW); few sand, trace clay, reddish brown (7.5YR 6/8), loose, wet.		
				SS	14/24	25 14 8 6	14	(88') As above: clay disappears.		
90				SS		4 6 8 7		(91') GRAVELLY LEAN CLAY (CL); very pale brown (10YR 8/2), moist, soft.		
				SS		2 3 3 4	6	(92') CLAY (CL); trace gravel, gray (7.5YR 6/1), medium dense.		
				SS		2 1 3 3	4	(94') As above: gray (10YR 5/1).		
95				SS		1 6 23 23	29	(96') POORLY GRADED SAND (SP); fine grained, strong brown (7.5YR 5/8), loose.		
				SS		5 14 25 23	39	(98') As above.		
100										

NOTES: SBG09M- (82-84)-20210127: 7.6% moisture content, 740 U mg/kg total organic carbon, 100.0 pcf dry unit weight, 2.686 specific gravity, 22.7% gravel, 75.4% sand, 1.9% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 6 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
100				SS	14/24	14 14	27	(100') CLAY (CL); (10YR 6/1), very soft, trace gravel.		
						13 15		(101') CLAYEY GRAVEL (GC); (7.5YR 5/8), moist, loose.		
				SS	15/24	14 12	20	(102') As above: some sand, brown (7.5YR 4/4).		
						8 15				
				SS	9/24	12 12	21	(104') GRAVELLY CLAY (CL); light gray (2.5Y 7/2), stiff, moist.		
105						9 14				
				SS	15/24	12 12	24	(106') CLAYEY GRAVEL (GC); pinkish gray (7.5YR 7/2), medium dense, moist.		
						12 20				
				SS	14/24	9 28	39	(108') POORLY GRADED SAND (SP); fine grained, yellow (10YR 7/6) to white (10YR 8/1) at 109.8' bgs, moist, loose.		
						11 11				
110				SS	15/24	8 12	20	(110') As above: light gray (10YR 7/1).	110-112 Chem	
						8 12				
				SH	8/24				112-114 Geotech	
				SS	13/24	10 11	20	(114') As above: yellow (10YR 7/6), trace gravel.		
115						9 10				
				SS	12/24	7 9	18	(116') As above: light gray (10YR 7/2), no gravel.	116-118 Geotech (not tested)	
						9 12				
				SS	22/24	7 1	3	(118') SILT WITH SAND (ML); gray (10YR 6/1) with some light brown mottling, soft, moist.		
						2 3				
120								(119.5') CLAY (CL); little silt, gray (10YR 6/1), stiff, moist.		

NOTES: SBG09M- (110-112)-20210127: 25.5% moisture content, 760 U mg/kg total organic carbon, 87.0 pcf dry unit weight, 2.675 specific gravity, 0.7% gravel, 84.1% sand, 15.2% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 7 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
120				SS	21/24	2 3 4	7	(120') SAND WITH SILT (SM); light gray (10YR 7/1), medium dense, moist.		
						14		(121') As above: less silty. (SP-SM)		
				SS	16/24	7 7 22	29			
						31		(123.5') As above: yellow (2.5Y 7/6). (SP)		
				SS	11/24	13 14 16	30	(124') POORLY GRADED SAND (SP); fine to medium grained, red (2.5YR 5/6), loose, dry.		
125						14				
				SS	16/24	3 5 8 10	13	(126') CLAY (CL); few silt and sand, light brownish gray (10YR 6/2), very stiff, dry.		
				SS	15/24	3 8 9 13	17	(128') As above.	128-130 Chem	
130				SS	15/24	8 13 17	30			
						6		(130') Crushed SAPROLITE, dark yellowish brown (10YR 3/4) to black (10YR 2/1).		
				SS	16/24	6 4 6 6	10	(132') CLAY (CL); few gravel, few sand, yellowish brown (10YR 5/4), moist, stiff.	132-134 Chem	
				SS	22/24	1 2 6 7	8	(134') As above: light brownish gray (10YR 6/2), no sand.		
135				SS	20/24	2 5 5 6	10	(136') As above: very pale brown (10YR 7/3).		
				SS	13/24	4 8 7 21	15	(138') As above: light yellowish brown (5YR 6/4).		
140										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 8 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	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)
140				SS	6/24	70/1		(140') CALCARENITE, very pale brown (10YR 7/3), dry.	140-142 Chem	
145										
150										
155								(155') End of Boring.		
								(158') Redrilled to 158' due to well installation difficulties.		
160										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G10
Page: 1 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	72	Well Depth (ft):	72
Drilling End Date:	02/01/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	33.35	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.83	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21125, -88.85573	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	12/24	2 5 3 5	8	(0') GRAVEL FILL. (0.25') SANDY CLAY (CL); dark brown (7.5YR 3/2), with organics, soft, dry.		
				SS	12/24	2 3 3 4	6	(2') CLAY (CL); little silt, trace gravel, reddish yellow (7.5YR 6/6), moist, medium dense.		
5				SS	21/24	2 3 3 5	6	(4') As above: strong brown (7.5YR 5/6), little light gray mottling.		
				SS	15/24	2 3 5 6	8	(6') As above: gravel disappears.		
				SS	23/24	2 3 4 5	7	(8') As above.		
10				SS	0/24			(10') No Recovery.		
				SS	21/24	1 4 5 6	9	(12') As above: becomes light brown (7.5YR 6/4), siltier, dry. (CL)		
				SS	24/24	2 4 4 6	8	(14') As above: becomes very stiff, trace sand.		
15				SS	24/24	3 3 4 6	7	(16') SILTY CLAY (CL); light brownish gray (10YR 6/2) with some reddish brown mottling, dry, stiff.		
				SS	23/24	4 5 6 10	11	(18') CLAYEY SILT (ML); light brownish gray (10YR 6/2), little reddish brown mottling, very stiff, dry.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G10
Page: 2 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	72	Well Depth (ft):	72
Drilling End Date:	02/01/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	33.35	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.83	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21125, -88.85573	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value	RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	20/24	4 6 6 9	12		(20') SILT (ML); some sand and little clay, very pale brown (10YR 7/3), very stiff, dry.		
				SS	24/24	3 4 7 8	11		(22') As above: becomes more clayey.		
25				SS	24/24	3 5 6 7	11		(24') SILTY CLAY (CL); light yellowish brown (10YR 6/4), very stiff, dry.		
				SS	24/24	2 4 5 7	9		(26') As above: becomes gray (10YR 6/1) with little reddish brown mottling.		
				SS	24/24	2 4 1 8	5		(28') As above.		
30				SS	24/24	3 5 8 7	13		(30') As above: becomes light brownish gray (10YR 6/2).		
		▼		SS	24/24	3 4 4 6	8		(32') SILT (MH); little clay, pale brown (10YR 6/3), stiff, dry, high plasticity.		
				SS	24/24	3 4 5 6	9		(34') As above: moist.		
35				SS	24/24	3 7 6 7	13		(36') As above: clay disappears, lower plasticity. (ML)		
				SS	21/24	3 8 27 32	35		(38') SANDY SILT (ML); pale brown (10YR 6/3), very stiff, wet.		
40											

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G10
Page: 3 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	72	Well Depth (ft):	72
Drilling End Date:	02/01/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	33.35	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.83	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21125, -88.85573	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	19/24	8 28 26 30	54	(40') POORLY GRADED SAND (SP-SM); fine grained, light gray (10YR 7/2), dense, little silt, moist to wet.		
				SS	20/24	8 13 15 21	28	(42') As above: few silt. (SP)		
45				SS	19/24	10 14 14 11	28	(44') As above: light brownish gray (10YR 6/2), moist to dry, medium dense.		
				SS	22/24	4 8 9 10	17	(46') As above: gray (10YR 6/1).		
				SS	24/24	5 5 7 6	12	(48') SILT (ML); few sand and clay, little gray (10YR 7/2), medium dense, moist to wet.		
50				SS	24/24	1 3 3 4	6	(50') SILT (MH); light gray (10YR 7/2), soft, moist, high plasticity.		
				SS	23/24	1 5 8 18	13	(53') 8" GRAVELLY SAND lens (SW); loose, wet, yellowish red (5YR 5/6).		
				SS	22/24	1 3 4 8	7	(53'8") Returns to SILT as above. (MH)		
55				SS	18/24	8 10 7 4	17	(55') CLAYEY SILT (ML); brownish yellow (10YR 6/6), moist, medium dense. (56') WELL-GRADED GRAVELLY SAND (SW); reddish yellow (7YR 6/8), loose, wet.		
				SS	24/24	2 28 3 7	31	(57') POORLY GRADED SAND (SP-SM); fine grained, little silt, light gray (10YR 7/1), medium dense, moist. (59') 4" GRAVELLY SAND layer (SW); wet.		
60										

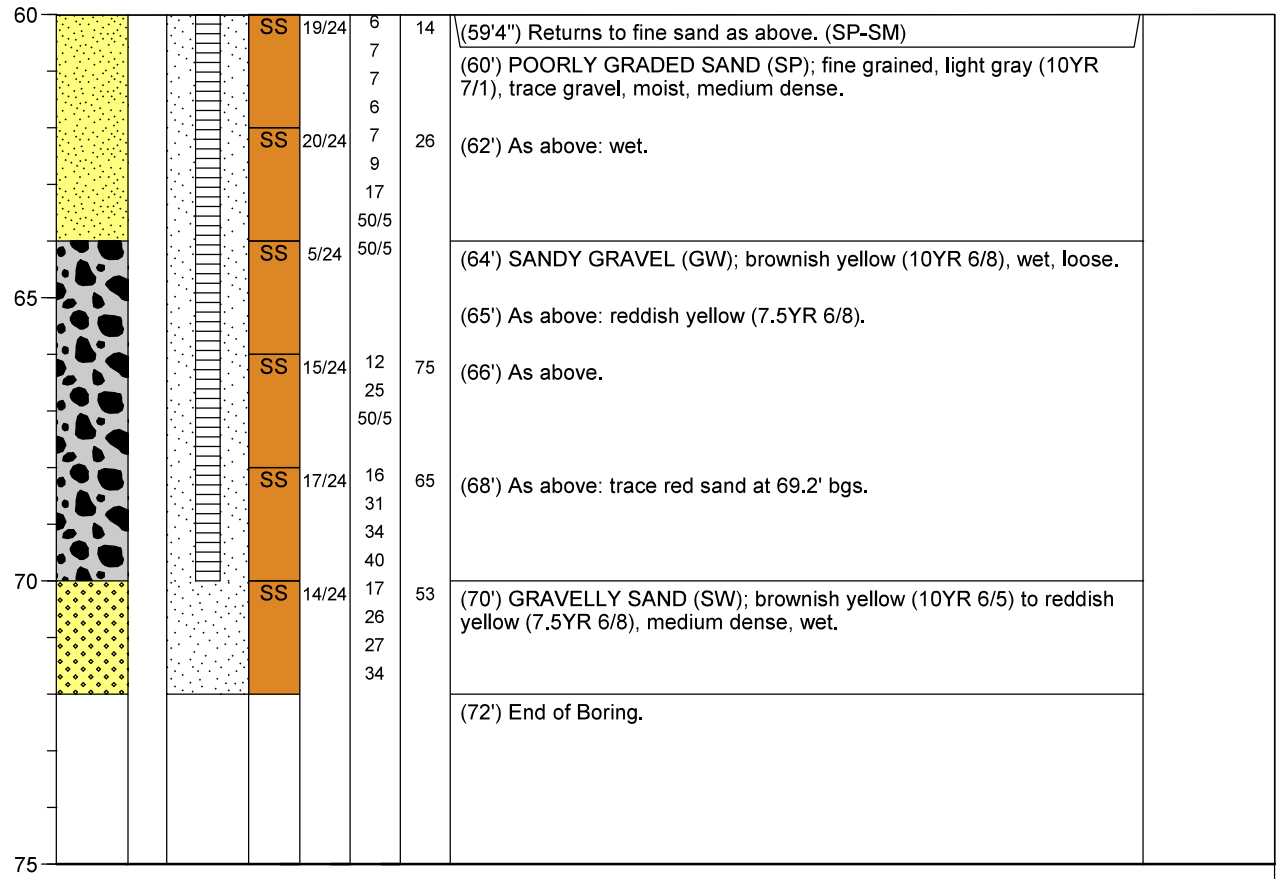
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G10
Page: 4 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	72	Well Depth (ft):	72
Drilling End Date:	02/01/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	33.35	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.83	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.21125, -88.85573	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
60	SS	19/24	6 7 7 6	14	(59'4") Returns to fine sand as above. (SP-SM)		
					(60') POORLY GRADED SAND (SP); fine grained, light gray (10YR 7/1), trace gravel, moist, medium dense.		
	SS	20/24	7 9 17 50/5	26	(62') As above: wet.		
	SS	5/24	50/5		(64') SANDY GRAVEL (GW); brownish yellow (10YR 6/8), wet, loose.		
65					(65') As above: reddish yellow (7.5YR 6/8).		
	SS	15/24	12 25 50/5	75	(66') As above.		
	SS	17/24	16 31 34 40	65	(68') As above: trace red sand at 69.2' bgs.		
70	SS	14/24	17 26 27 34	53	(70') GRAVELLY SAND (SW); brownish yellow (10YR 6/5) to reddish yellow (7.5YR 6/8), medium dense, wet.		
					(72') End of Boring.		
75							

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 1 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	6 4 9 7	13	(0') TOPSOIL. (0.2') ASH (ML) (0.8') LEAN SILT (ML); trace fine sand, stiff, moist, tan (2.5Y 7/4).		
				SS	17/24	1 1 2 4	3	(2.7') LEAN CLAY (CL); some orange fine sand, soft, wet, brown (2.5Y 3/3).		
				SS	16/24	5 21 50/6	71	(5.1') SILTY SAND (SM); fine to medium grained, with coal, some organics, very dense, gray (N3), moist, well-graded.		
5				SS	17/24	5 7 5 5	12	(7.0') LEAN CLAY (CL); stiff, moist, tan (5Y 7/2) with gray (N8) mottles.		
				SS	24/24	1 3 5 6	8	(8') As above: becomes medium stiff, orange (10YR 7/12) mottles.		
10				SS	24/24	2 5 8 6	13	(10') As above: becomes stiff, black inclusions, trace organics.		
				SS	23/24	2 4 5 7	9	(12') As above.		
				SS	24/24	2 5 6 8	11	(14') As above.		
15				SS	24/24	2 4 5 6	9	(16') As above.		
				SS	24/24	3 7 9 10	16	(18') LEAN SILT (ML); trace sand, stiff, moist, tan (5Y 7/2) with orange (10YR 7/12) and black mottling.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 2 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	3 6 8 8	14	(20.1') LEAN CLAY (CL); trace fine sand, stiff, moist, tannish orange (10YR 7/6) with gray (N8) mottles.		
				SS	27/24	2 4 6 7	10	(22') As above.	22-24 Chem	
				SS	27/24			(24') As above.	24-26 ST	
25				SS	24/24	3 4 5 7	9	(26') As above.		
				SS	24/24	3 4 6 7	10	(28') As above.		
30				SS	26/24	2 4 4 6	8	(30') As above: with increased moisture.		
				SS	24/24	2 4 4 6	8	(32') As above.		
				SS	25/24	4 5 8 7	13	(34') As above: with fine sand.		
35				SS	26/24	2 5 5 5	10	(36') As above: orange (10YR 7/12) inclusions, gray (N8) with tan orange (10YR 7/6) mottling.		
				SS	25/24	2 4 6 6	10	(38') As above: trace silt.		
40										

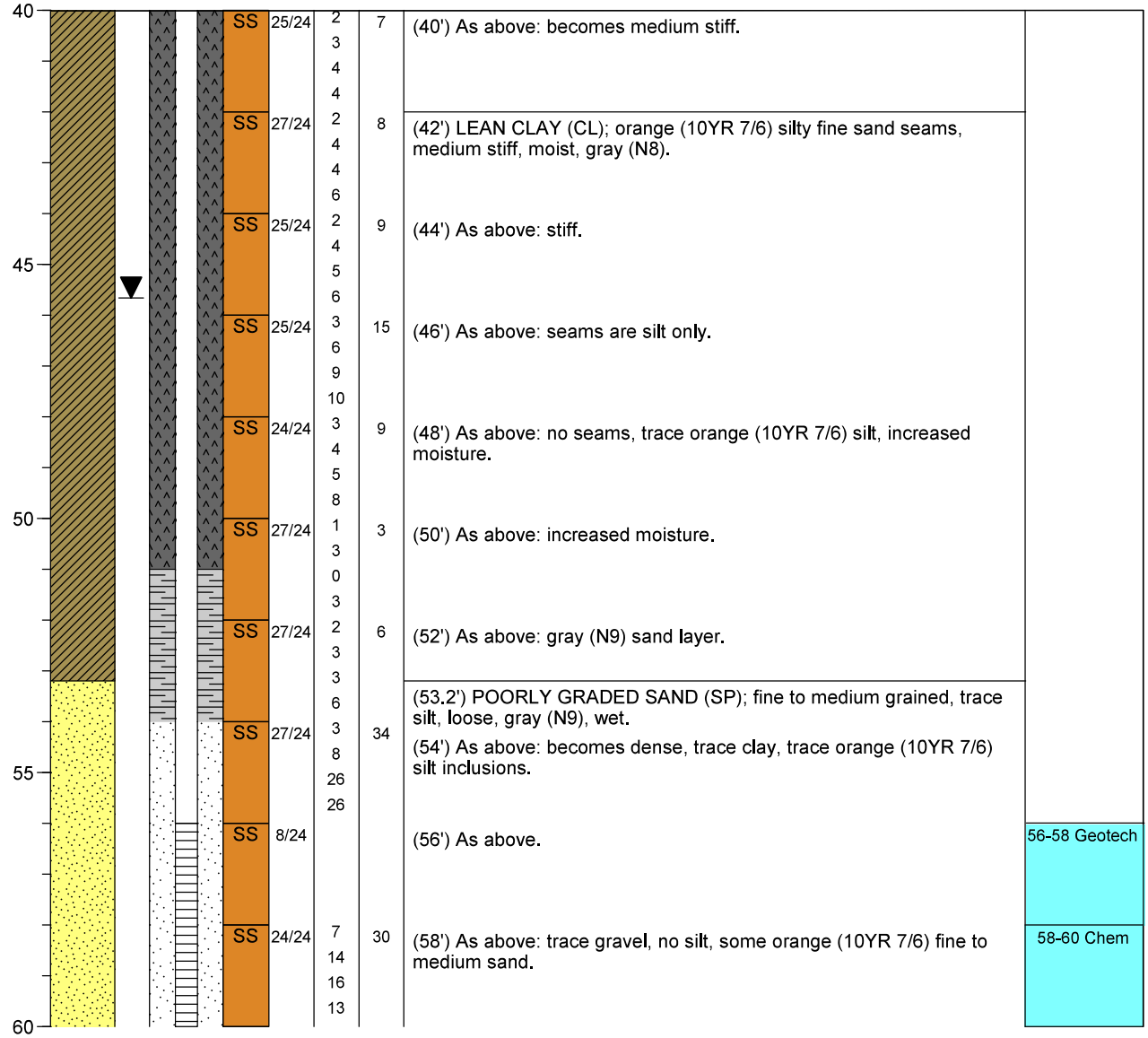
NOTES: SBG11-(24-26)-20210119: 18.5% moisture content, 415 U mg/kg total organic carbon, 109.1 pcf dry unit weight, 2.688 specific gravity, 5.6×10^{-8} cm/s vertical hydraulic conductivity, 36 LL, 15 PL, 21 PI, 0.0% gravel, 11.5% sand, 88.5% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 3 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand



NOTES:
SBG11-(56-58)-20210119: 14.4% moisture content, 679 U mg/kg total organic carbon, 110.0 pcf dry unit weight, 2.661 specific gravity, 0.2% gravel, 87.7% sand, 12.1% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 4 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	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)
60				SS	20/24	6 14 15 16	29	(60') As above: increased orange sand.		
				SS	14/24	0 6 11 13	17	(62') WELL-GRADED SAND (SW); fine to medium grained, medium dense, wet, orangish tan (7.5YR 8/8) with some gray (N9) sand layers.		
65				SS	18/24	2 10 15 11	25	(64') As above: with sandy gravel layer (~5" thick).		
								(66') End of Boring.		
70										

NOTES:

As indicated in Illinois Administrative Code Part 845 Data Gap Analysis, Joppa Power Plant, East Ash Pond - CCR Unit 401 provided by Geosyntec, G54S was blind drilled until the screened interval. G54S was advanced adjacent to G54D and a separate boring log was not provided.

FIELD BORING LO

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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	13/24 54%	ss	3-2 3-4 N=5	21			0	FILL - Black (10YR2/1), moist, medium, SILT with few clay, trace very fine- to medium-grained sand, and trace roots.			
							1	FILL - Yellowish brown (10YR5/4), moist, medium, SILT with few clay, trace very fine- to coarse-grained sand, and trace roots.		352	
2A	16/24 67%	ss	2-4 16-8 N=20	13			2				
							3	FILL - Yellowish brown (10YR5/4) with 25% gray (10YR5/1), moist, medium, SILT with few clay, trace very fine- to coarse-grained sand, trace small to large gravel, and trace roots.			
3A	18/24 75%	ss	4-4 5-8 N=9	23		2.00	4			350	
							5	Light gray (10YR7/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine- to fine-grained sand.			
4A	21/24 88%	ss	2-2 4-4 N=6	25		2.00	6			348	
							7				
5A	24/24 100%	ss	1-3 4-6 N=7	23		1.80	8			346	
							9	Brown (10YR5/3) with 20% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand.			
6A	22/24 92%	ss	1-3 4-5 N=7	22		3.00	10			344	
							11				
7A	17/24 71%	ss	1-1 2-4 N=3	22		2.00	12			342	
							13	Gray (10YR6/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand.			
8A	22/24 92%	ss	1-2 4-5 N=6	22		2.00	14			340	
							15				
9A	17/24 71%	ss	2-3 6-8 N=9	22		1.80	16			338	
							17				
							18 ▼	Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, moist, stiff, silty CLAY with trace very fine-grained sand.		336	
10A	24/24 100%	ss	2-3 6-5 N=9	20		2.50	19				
							20			334	
11A	24/24		1-3	20		1.90					

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
	100%	ss	5-6 N=8				22	Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, moist, stiff, silty CLAY with trace very fine-grained sand. *[Continued from previous page]*		332	
12A	24/24 100%	ss	1-4 6-8 N=10	19		3.00	24			330	
13A	24/24 100%	ss	1-3 4-6 N=7	19		1.80	26			328	
14A	24/24 100%	ss	2-4 7-7 N=11	21		2.00	28	Light brownish gray (10YR6/2) with 35% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with few clay, trace very fine- to medium-grained sand.		326	
15A	22/24 92%	ss	1-3 6-8 N=9	20		2.30	30			324	
16A	20/24 83%	ss	1-3 6-6 N=9	18		2.40	32			322	
17A	24/24 100%	ss	1-4 8-8 N=12	20		3.50	34			320	
18A	22/24 92%	ss	1-3 4-5 N=7	22		2.80	36	Grayish brown (10YR5/2) with 10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with little clay, trace very fine-grained sand.		318	
19A	24/24 100%	ss	3-4 8-8 N=12	19		3.00	38			316	
20A	24/24 100%	ss	1-4 7-10 N=11	19		2.50	40	Light gray (10YR7/1) with 5% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand.		314	
21A	24/24 100%	ss	1-3 10-10 N=13	17		3.80	42			312	

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
22A	24/24 100%	ss	5-8 9-10 N=17	16		3.00	44	Light gray (10YR7/1) with 5% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand. *[Continued from previous page]*		310	
23A	24/24 100%	ss	3-6 8-8 N=14	19		3.00	46			308	
24A	24/24 100%	ss	2-4 5-5 N=9	19		3.20	48	Light brownish gray (10YR6/2) with 10% dark yellowish brown (10YR4/4) mottles, moist, very stiff, silty CLAY, trace very fine- to coarse-grained sand.		306	
25A	24/24 100%	ss	4-7 7-6 N=14	18		2.40	50			304	
26A	17/24 71%	ss	1-4 6-8 N=10	18		2.00	52	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with little very fine- to coarse-grained sand and trace small gravel.		302	
27A	22/24 92%	ss	3-3 7-18 N=10	21		3.30	54	Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand.		300	
28A	21/24 88%	ss	5-11 18-20 N=29	21		4.00	56			298	
29A	11/11 100%	ss	25-50/5"	15		3.80		Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, hard, SILT with few very fine- to fine-grained sand, trace clay.			
30A	20/24 83%	ss	21-19 35-29 N=54	14			58	Gary (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, very dense, silty, very fine- to fine-grained sand, trace clay.		296	
31A	17/24 71%	ss	4-6 10-9 N=16	17		1.80	60	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand.		294	
32A	22/24		6-8	22		3.30	62			292	

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
	92%	SS	5-7 N=13				64	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand. *[Continued from previous page]*		290	
33A	24/24 100%	SS	2-4 7-9 N=11	18		2.50	66			288	
34A	24/24 100%	SS	3-5 10-15 N=15	19		2.50		Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, few very fine- to coarse-grained sand, trace small gravel.		286	
35A	22/24 92%	SS	1-3 3-5 N=6	23		1.50	68				
								Yellowish brown (10YR5/6) with 10% gray (10YR6/1) mottles, moist, stiff, SILT with little clay, trace very fine-grained sand.		284	
36A	24/24 100%	SS	woh-1 5-6 N=6	23		1.50	70				
								Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand.		282	
37A	24/24 100%	SS	woh-1 2-4 N=3	23		1.50	72				
38A	16/24 67%	SS	30-40 27-34 N=67	11						280	
							74				
39A	12/15 80%	SS	10-47 50/3"	14						278	
							76	Yellowish brown (10YR5/6), moist, very dense, silty, fine- to coarse-grained SAND and small to large GRAVEL.			
40A	5/5 100%	SS	50/5"	12						276	
	0/21 0%	BD					78				
										274	
							80				

End of boring = 80.14 feet

NOTE(S): G54D installed in borehole.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW01
Page: 1 of 3

Drilling Start Date:	01/20/2021	Boring Depth (ft):	54	Well Depth (ft):	54
Drilling End Date:	01/20/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	13.05	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	383.82	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	380.75	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21702,-88.85187	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	5 4 3 4	7	(0') SILTY SANDY WELL-GRADED GRAVEL (GM); loose, wet, gray (N4). [BOTTOM ASH]		
				SS	19/24	3 3 4 3	7	(2') As above.		
5				SS	18/24	3 2 2 4	4	(4') As above.	4-6 Chem	
				SS	24/24			(6') As above.	6-8 Geotech	
				SS	15/24	4 4 3 2	7	(8') As above.		
10				SS	18/24	1 1 1 1	2	(9.6') LEAN SILT (ML); some fine sand, very soft, wet, grayish brown (N4) with white speckling. [FLY ASH MIXTURE] (10') As above: trace organics.		
				SS	14/24	0 0 1 2	1	(12') As above: trace coarse sand.		
15				SS	14/24	0 1 1 1	2	(14') As above: trace gravel.		
				SS	4/24	1 1 1 1	2	(16') POORLY GRADED SAND (SP); fine grained, some silt, very loose, wet, grayish brown (N4) with black and orange speckles. [BOTTOM ASH]		
				SS	8/24	0 1 0 1	1	(18') As above.		
20										

NOTES: Well could not get down augers, augers were washed out using water, rig pump, tremie pipe. XPW01-(06-08)-20210120: 34.2% moisture content, 85.6 pcf dry unit weight, 2.711 specific gravity, 2.1×10^{-5} cm/s vertical hydraulic conductivity, 26.3% gravel, 45.4% sand, 58.3% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW01
Page: 2 of 3

Drilling Start Date:	01/20/2021	Boring Depth (ft):	54	Well Depth (ft):	54
Drilling End Date:	01/20/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	13.05	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	383.82	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	380.75	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21702,-88.85187	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	10/24	0 0 0	0	(20') As above.		
						1		(21.3') LEAN SILT (ML); very soft, wet, grayish brown (N4) with white and orange speckling. [FLY ASH MIXTURE]		
				SS	1/24	0 0 0 0 0	0	(22') As above: little fine sand, trace coal.		
				SS	24/24	0 0 0 0 0	0	(24') LEAN SILT (ML); very soft, wet, grayish brown (N4). [FLY ASH]		
25				SS	24/24	0 0 0 0 0	0	(26') As above.		
				SS	26/24	0 0 0 0 0	0	(28') As above.		
30				SS	26/24	0 0 0 0 0	0	(30') As above.		
				SS	26/24	0 0 0 0 0	0	(32') As above.		
35				SS	26/24	0 0 0 0 0	0	(34') As above.		
				SS	24/24	0 0 0 0 0	0	(36') As above.		
				SS	25/24	0 0 0 0 0	0	(38') As above.		
40										

NOTES: Well could not get down augers, augers were washed out using water, rig pump, tremie pipe.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW01
Page: 3 of 3

Drilling Start Date:	01/20/2021	Boring Depth (ft):	54	Well Depth (ft):	54
Drilling End Date:	01/20/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	13.05	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	383.82	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	380.75	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21702,-88.85187	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	26/24	0 0 0 0	0	(40') As above: infrequent fine sand layers.		
				SS	26/24	0 0 0 0	0	(42') As above.		
				SS	20/24	0 0 0 0	0	(44') As above.		
45				SS	26/24	0 0 0 0 1	0	(46') LEAN SILT (ML); some organics, very soft, wet, dark brown (N3), mixed with ash.	46-48 Chem and Geotech	
				SS	19/24			(48') As above.		
50				SS	24/24	0 1 1 1	2	(50') As above: color mixed (N3 and N4), increased plasticity.		
				SS	26/24	0 0 3 2	3	(52') As above.		
								(53') LEAN CLAY WITH GRAVEL (CL-ML); some sand, some ash, soft, wet, gray (N4). [TRANSITIONAL]		
55								(54') End of Boring.		
60										

NOTES: Well could not get down augers, augers were washed out using water, rig pump, tremie pipe.
XPW01-(46-48)-20210120: 31.7% moisture content, 87.7 pcf dry unit weight, 2.675 specific gravity, 2.8×10^{-7} cm/s vertical hydraulic conductivity, 25 LL, 20 PL, 5 PI, 0.0% gravel, 18.7% sand, 81.3% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW02
Page: 1 of 2

Drilling Start Date:	01/20/2021	Boring Depth (ft):	30	Well Depth (ft):	30
Drilling End Date:	01/21/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	376.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	373.23	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21575, -88.85504	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	4 17 44 22	61	(0') SANDY WELL-GRADED GRAVEL WITH SILT (GW); very dense, moist, gray (N4).		
				SS	22/24	3 9 6 7	15	(2') GRAVELLY LEAN SILT WITH SAND (ML); very soft, moist, gray (N4).		
5				SS	26/24	17 17 10 7	27	(4') As above: becomes wet.	4-6 Chem	
				SS	18/24	2 5 3 2	8	(6.2') SILTY SANDY GRAVEL (GM); loose, wet, gray (N4).		
				SS	14/24	2 1 1 1	2	(8.1') LEAN SILT WITH SAND (ML); some gravel, very soft, wet, gray (N4 to brown (10YR 3/1).		
10				SS	12/24	12 13 7 5	20	(10') As above: becomes very stiff, sandy, gravelly.		
				SS	10/24	2 5 3 2	8	(12') GRAVELLY WELL-GRADED SAND WITH SILT (ML); loose, wet, brown (10YR 3/1).		
				SS	10/24	1 2 2 2	4	(14') As above: with gravel, white speckles.		
15				SS	16/24	3 2 2 2	4	(16') As above: silty, trace coal.		
				SS	8/24	1 2 2 3	4	(18') As above: gravelly layer.		
20										

NOTES: Augers were washed out using water & tremie pipe.
Ash mixed with logged materials throughout boring

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW02
Page: 2 of 2

Drilling Start Date:	01/20/2021	Boring Depth (ft):	30	Well Depth (ft):	30
Drilling End Date:	01/21/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	376.53	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	373.23	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21575, -88.85504	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	20/24	3 7 10 9	17	(20') As above.		
								(20.4') LEAN SILT (ML); with fine sand, very stiff, wet, gray to brown (N4 to 10YR 3/1) with white speckles.		
				SS	23/24			(22') As above.		
				SS	24/24	2 5 8 8	13	(24') As above: becomes stiff, coal fragment layer.	24-26 Chem	
25				SS	24/24	6 8 8 6	16	(26') As above: very stiff.		
				SS	6/24	3 5 6 8	11	(27.8') LEAN CLAY (CL); some organics, soft, moist, tan (10YR 7/8 and gray (N8).		
30								(30') End of Boring.		
35										

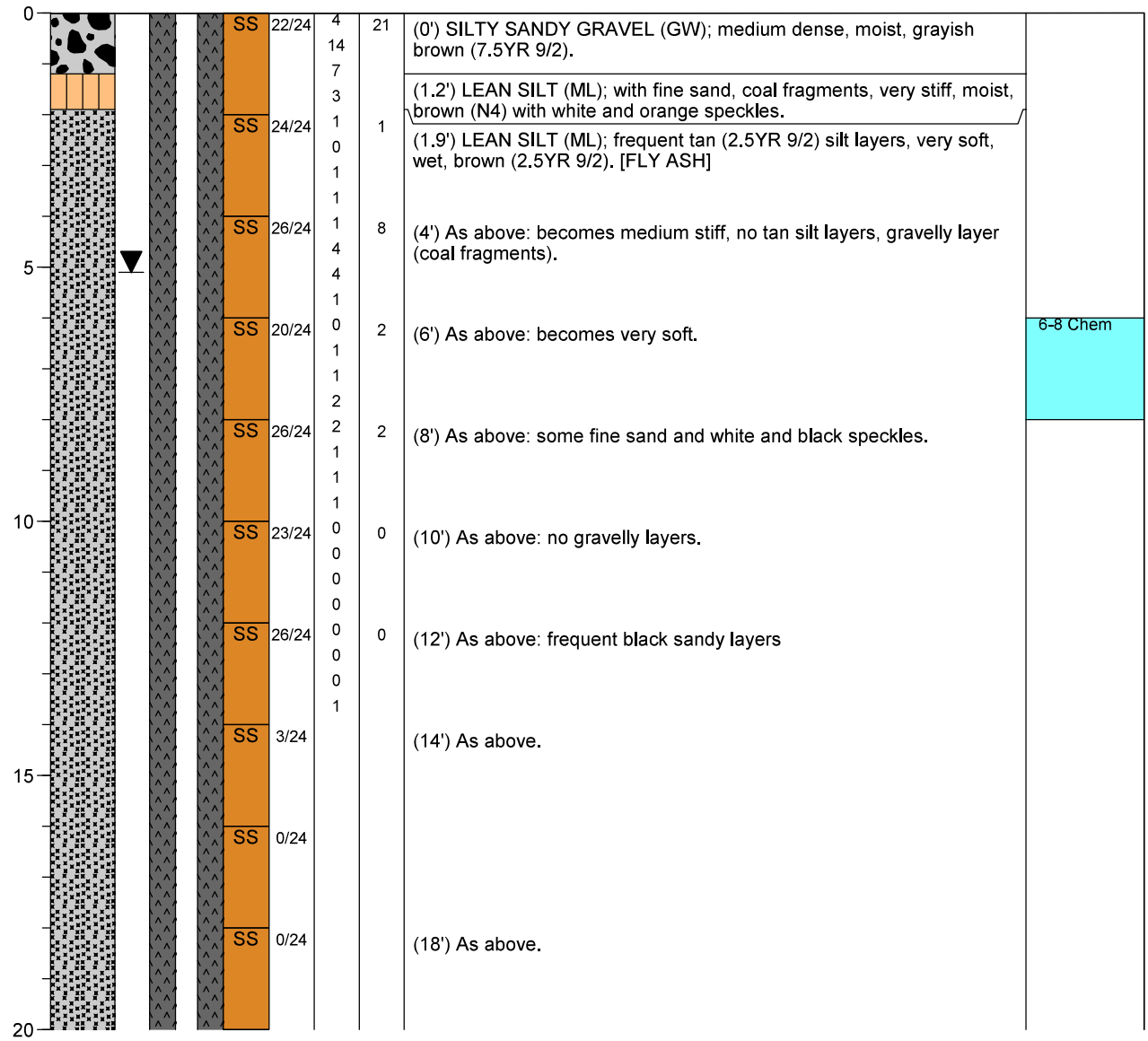
NOTES: Augers were washed out using water & tremie pipe. Ash mixed with logged materials throughout boring XPW02-(22-24)-20210120: 47.6% moisture content, 74.0 pcf dry unit weight, 2.567 specific gravity, 9.3% gravel, 74.1% sand, 16.6% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW03
Page: 1 of 2

Drilling Start Date:	01/21/2021	Boring Depth (ft):	30	Well Depth (ft):	37
Drilling End Date:	01/21/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	382.04	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	378.65	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21197, -88.85555	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
0	SS	22/24	4, 14, 7	21	(0') SILTY SANDY GRAVEL (GW); medium dense, moist, grayish brown (7.5YR 9/2).		
					(1.2') LEAN SILT (ML); with fine sand, coal fragments, very stiff, moist, brown (N4) with white and orange speckles.		
	SS	24/24	3, 1, 0	1	(1.9') LEAN SILT (ML); frequent tan (2.5YR 9/2) silt layers, very soft, wet, brown (2.5YR 9/2). [FLY ASH]		
5	SS	26/24	1, 1, 1	8	(4') As above: becomes medium stiff, no tan silt layers, gravelly layer (coal fragments).		
	SS	20/24	4, 4, 1	2	(6') As above: becomes very soft.	6-8 Chem	
	SS	26/24	0, 1, 1	2	(8') As above: some fine sand and white and black speckles.		
10	SS	23/24	2, 2, 1	0	(10') As above: no gravelly layers.		
	SS	26/24	1, 1, 1	0	(12') As above: frequent black sandy layers		
	SS	3/24	0, 0, 0		(14') As above.		
15	SS	0/24	0, 0, 0				
	SS	0/24	0, 0, 1		(18') As above.		
20							

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. XPW03
Page: 2 of 2

Drilling Start Date:	01/21/2021	Boring Depth (ft):	30	Well Depth (ft):	37
Drilling End Date:	01/21/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	382.04	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	378.65	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF	Location (Lat/Long):	37.21197, -88.85555	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				SS	0/24			(20') As above.		
				SS	26/24	0 0 0 0 0	0	(22') As above: no gravel or sand.	22-24 Geotech	
				SS	26/24	0 0 0 0 0	0	(24') As above.		
25				SS	26/24	0 0 0 0 0	0	(26') As above: infrequent black fine sand seams.		
				SS	26/24	0 0 0 0 0	0	(28') As above.		
30				SS	26/24	0 0 0 0 0	0	(30') As above.		
				SS	26/24	0 0 0 0 0	0	(32') As above.		
				SS	26/24	0 0 0 0 0	0	(34.3') LEAN SILT (ML); very soft, wet, dark brown (N2). [LOWER ASH]	34-36 Chem	
35				SS	24/24	0 0 0 0 0	0	(36') As above.	36-38 Geotech	
								(37') LEAN CLAY (CL); stiff, moist, tan (10YR 7/8) and gray (N8).		
								(38') End of Boring.		
40										

NOTES:
XPW03-(22-24)-20210121: 45.4% moisture content, 2.410 specific gravity, 0.0% gravel, 4.2% sand, 95.8% fines.
XPW03-(36-38)-20210121: 46.5% moisture content, 65.7 pcf dry unit weight, 1.999 specific gravity, 1.8×10^{-7} cm/s vertical hydraulic conductivity, 46 LL, 31 PL, 15 PI, 0.0% gravel,9.4% sand, 90.6% fines.

WELL CONSTRUCTION LOGS

R000851

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G03
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Sean Karoly
Project Number: GLP8021
Recorded By: SK

Permit Number:
Installation Date(s): 2/2/21
Drilling Method: HSA
Borehole Diameter: 4.25"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.010 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

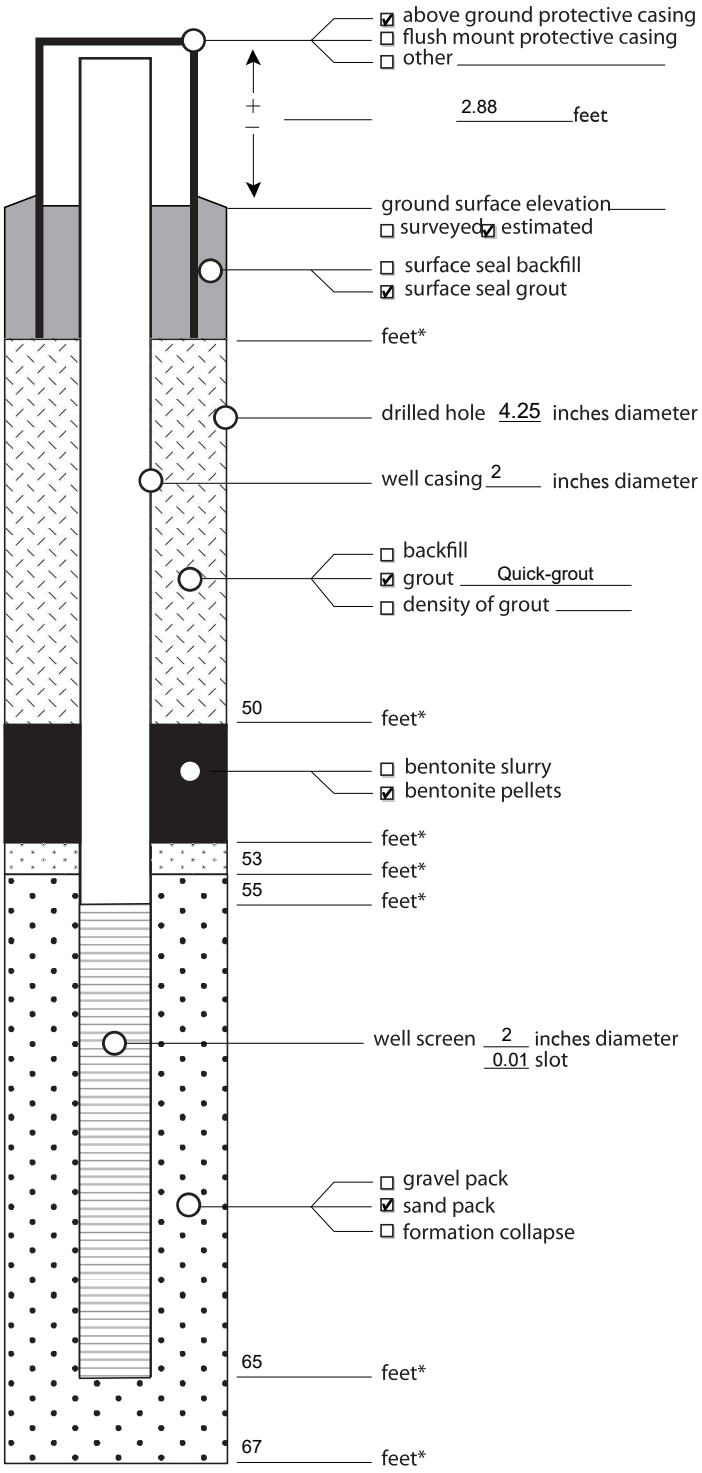
Protective Casing: Length 3.08 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack: Graded Sand
Coarse Sand: 5.5 bags of 50 lb per bag Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bucket Type Pel-plug
Bentonite Slurry: bags of lb per bag Type 1/4"

Grout:
Cement: 5 bags of 50 lb per bag Type Quick-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000852

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G04
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 2/2/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

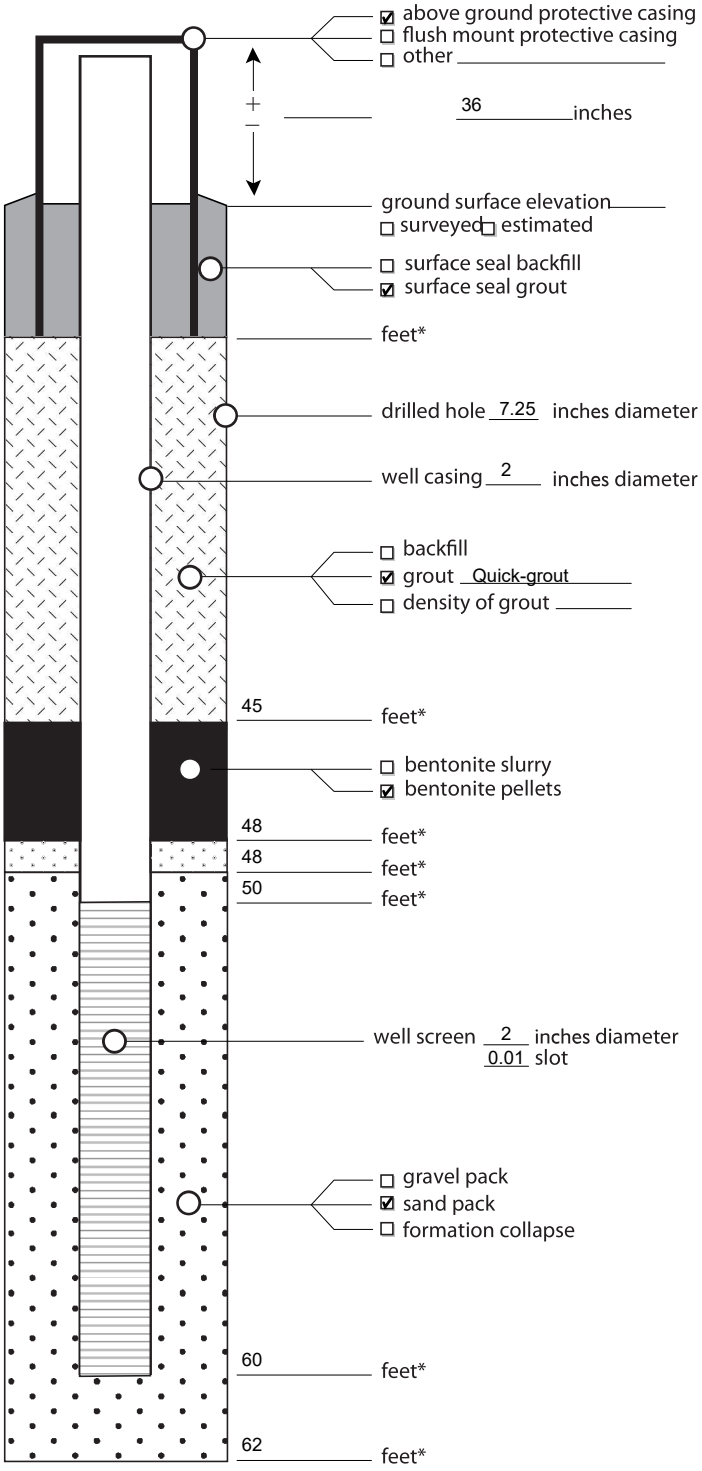
Protective Casing: Length 3 feet
Diameter inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 3 feet
Diameter inches
Material

Sandpack: Mix of coarse and fine sand
Coarse Sand: 4 bags of ___ lb per bag Size
Fine Sand: ___ bags of ___ lb per bag Size

Seal:
Bentonite Pellets: 2 bags of ___ lb per bag Type 3/8"
Bentonite Slurry: ___ bags of ___ lb per bag Type

Grout:
Cement: ___ bags of ___ lb per bag Type 2090: Quik-grout
Bentonite: ___ bags of ___ lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000853

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G05
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 2/2/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid:
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

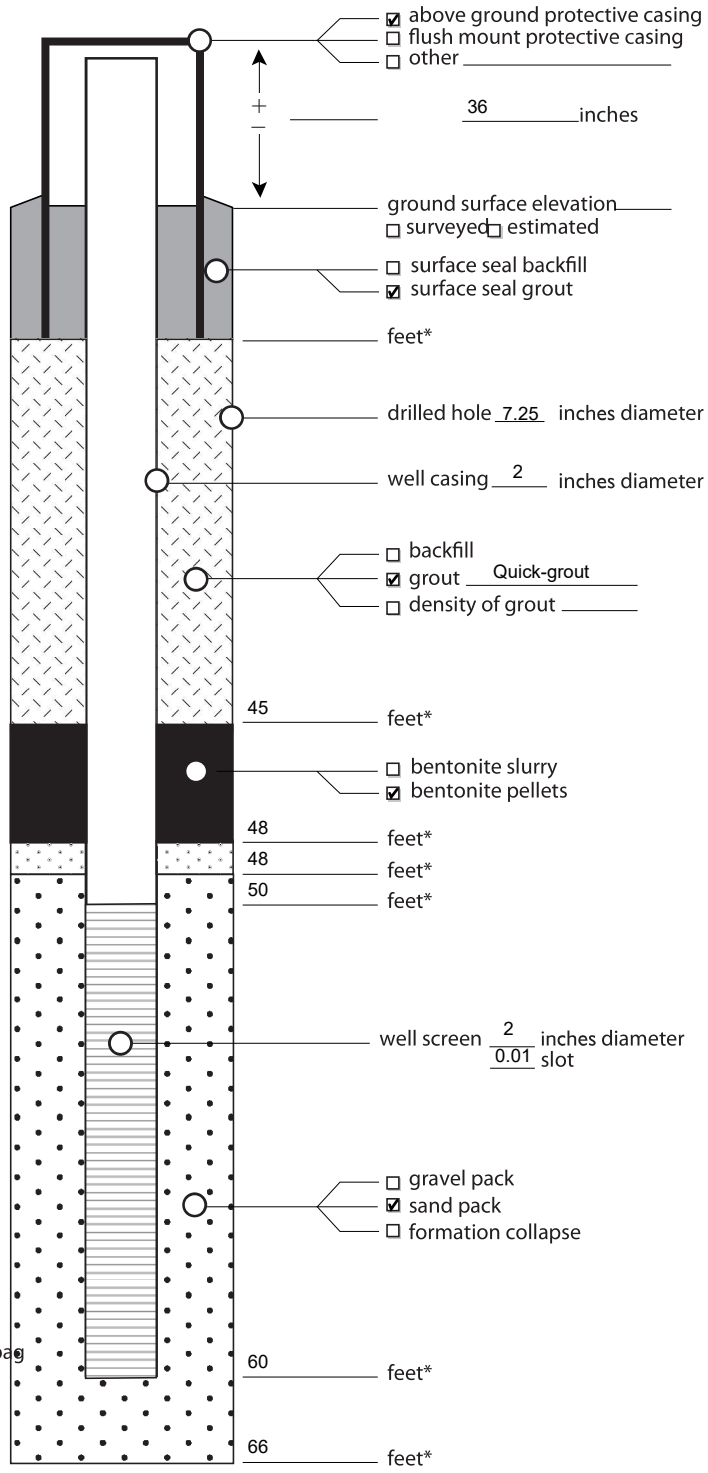
Protective Casing: Length 3 feet
Diameter inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 3 feet
Diameter inches
Material

Sandpack: Mix of coarse and fine sand
Coarse Sand: 5 bags of lb per bag Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 2.5 bags of lb per bag Type 1/4, 3/8
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 2 bags of lb per bag Type Quick-grout;
Bentonite: bags of lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000854

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G06
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 1/31/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid: Water
Fluid Loss During Drilling: ____ Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

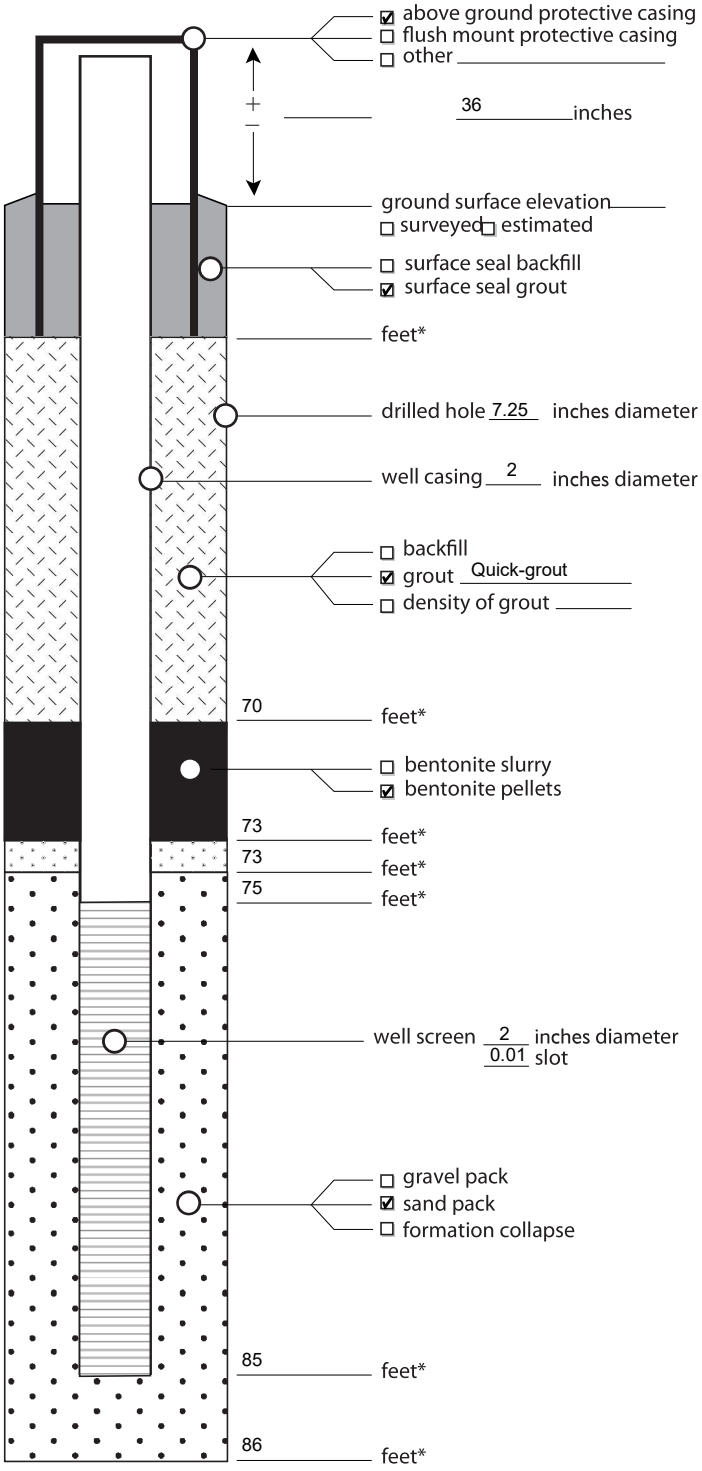
Protective Casing: Length 3 feet
Diameter ____ inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 3 feet
Diameter ____ inches
Material

Sandpack: Mix of Course and Fine Sand
Coarse Sand: 4 bags of ___ lb per bag Size
Fine Sand: ___ bags of ___ lb per bag Size

Seal:
Bentonite Pellets: 12 bags of ___ lb per bag Type
Bentonite Slurry: ___ bags of ___ lb per bag Type

Grout: Quick-grout 2 bags
Cement: ___ bags of ___ lb per bag Type Quik-grout;
Bentonite: ___ bags of ___ lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000855

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G06S
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 2/1/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

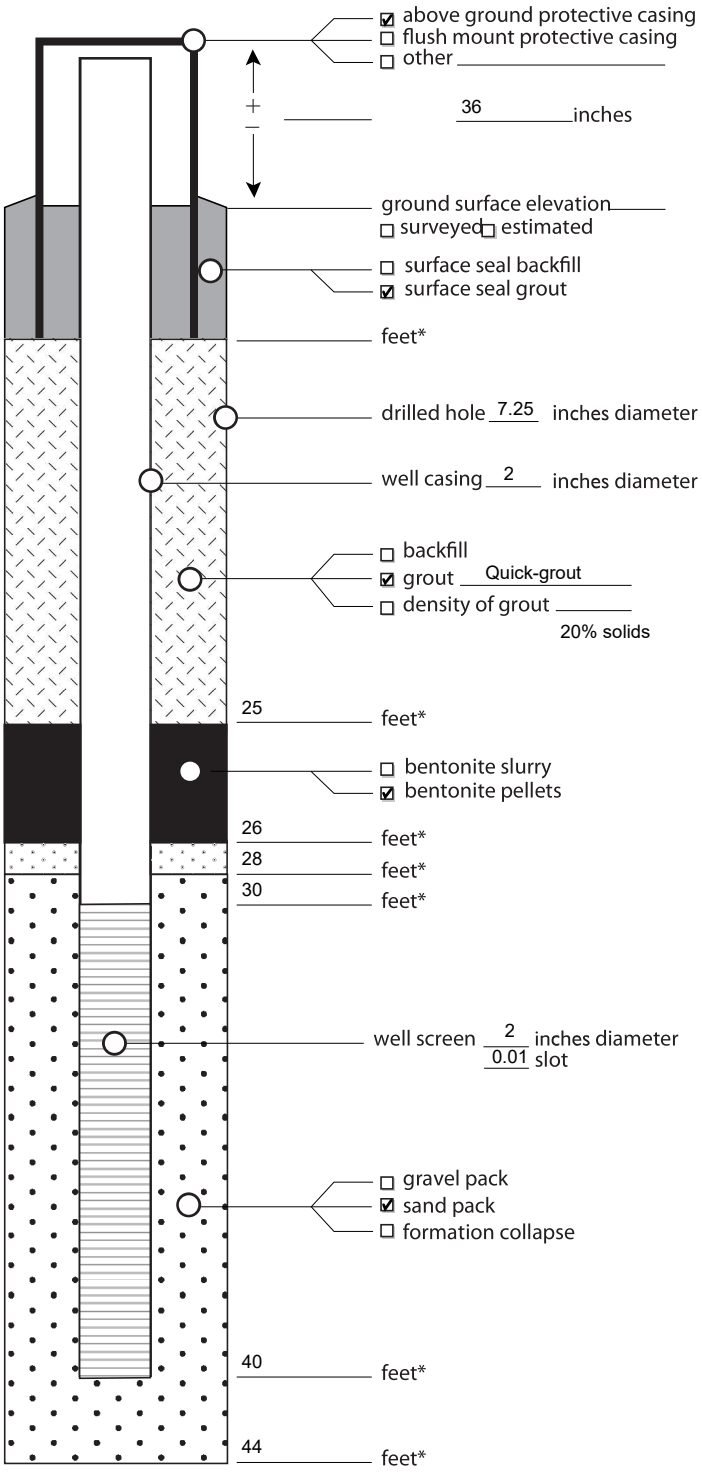
Protective Casing: Length 3 feet
Diameter inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 3 feet
Diameter inches
Material

Sandpack: Mix of Course and Fine Sand
Coarse Sand: 4 bags of ___ lb per bag Size
Fine Sand: ___ bags of ___ lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 2 lb per bag Type 3/8"
Bentonite Slurry: ___ bags of ___ lb per bag Type

Grout: Quick-grout
Cement: 2 bags of ___ lb per bag Type Quik-grout;
Bentonite: ___ bags of ___ lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000856

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G07
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 1/29/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

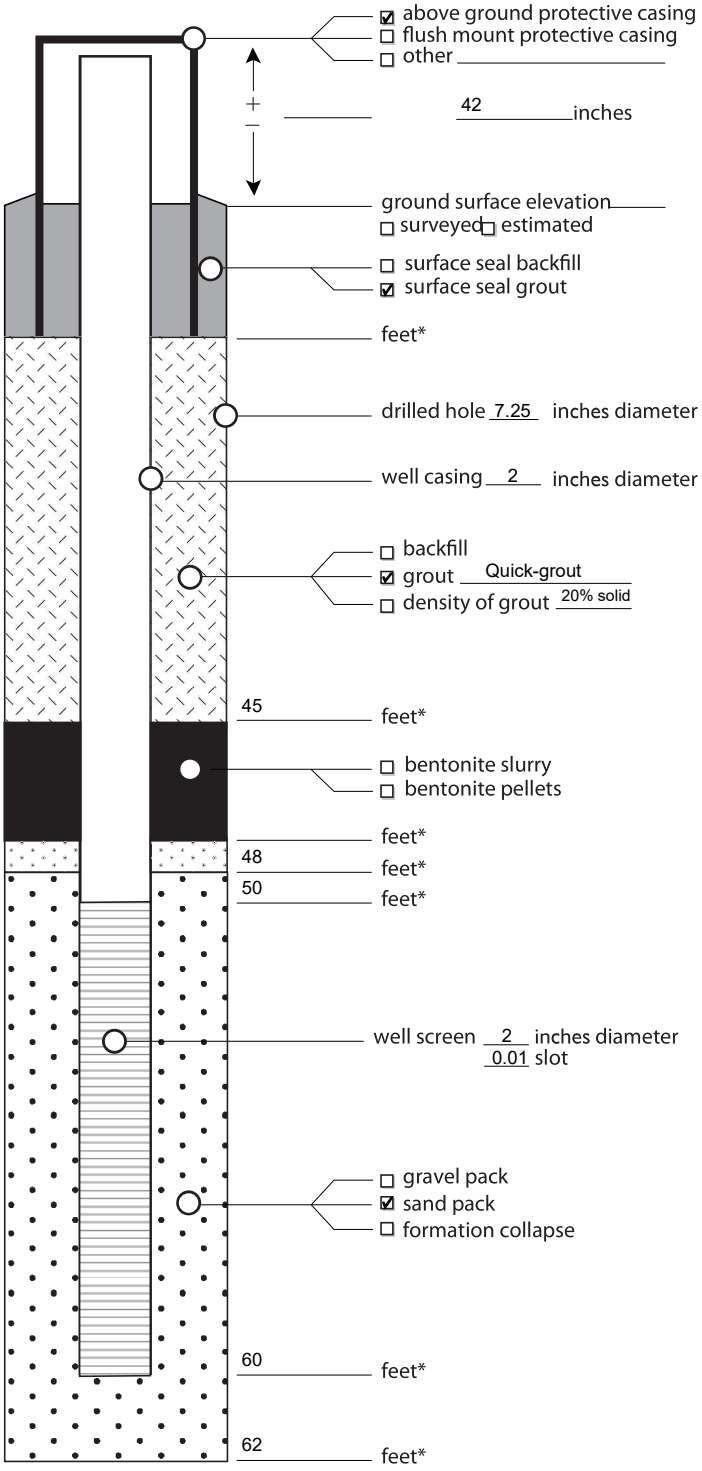
Protective Casing: Length 44 feet
Diameter inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 44 feet
Diameter inches
Material

Sandpack: Mix of Course and Fine Sand
Coarse Sand: 4 bags of ___ lb per bag Size
Fine Sand: ___ bags of ___ lb per bag Size

Seal:
Bentonite Pellets: 2 bags of ___ lb per bag Type Chips
Bentonite Slurry: ___ bags of ___ lb per bag Type

Grout: Quick-grout
Cement: ___ bags of ___ lb per bag Type Quik-grout;
Bentonite: ___ bags of ___ lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000857

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G08
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Brian Ares
Project Number: GLP8021
Recorded By: BA

Permit Number:
Installation Date(s): 1/28/21
Drilling Method: HSA
Borehole Diameter: 7.25"
Drilling Contractor: Geotechnology
Driller: Jason Smith
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

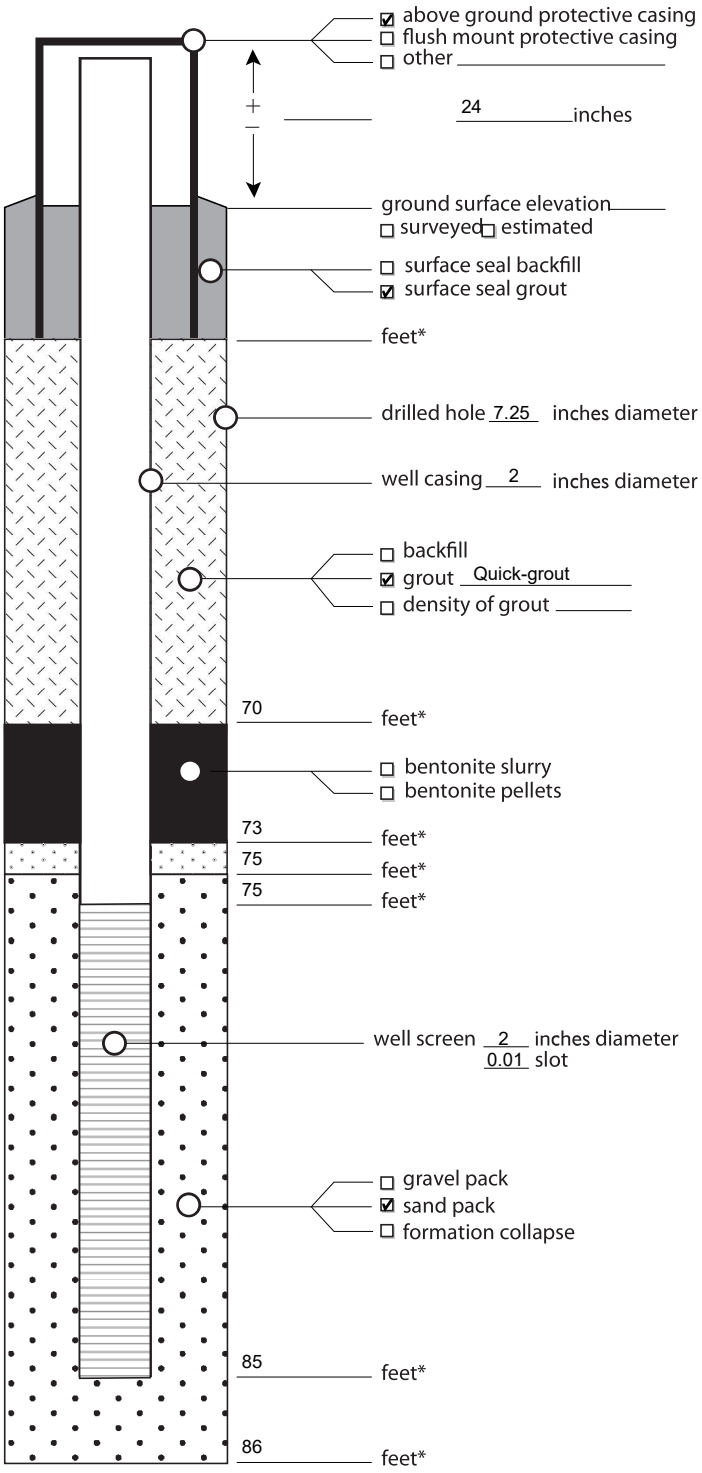
Protective Casing: Length 2 feet
Diameter inches
Construction ☐ Cast Aluminum ☐ Cast Steel ☐ Other

Casing Installation: Length 2 feet
Diameter inches
Material

Sandpack: Mix of Course and Fine Sand
Coarse Sand: bags of lb per bag Size
Fine Sand: 4 bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of lb per bag Type Chips
Bentonite Slurry: bags of lb per bag Type 3/8"

Grout:
Cement: bags of lb per bag Type Quik-grout;
Bentonite: bags of lb per bag Type 20% solid



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000858

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G09
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Sean Karoly
Project Number: GLP8021
Recorded By: SK

Permit Number:
Installation Date(s): 1/31/21
Drilling Method: HSA
Borehole Diameter: 4.25"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

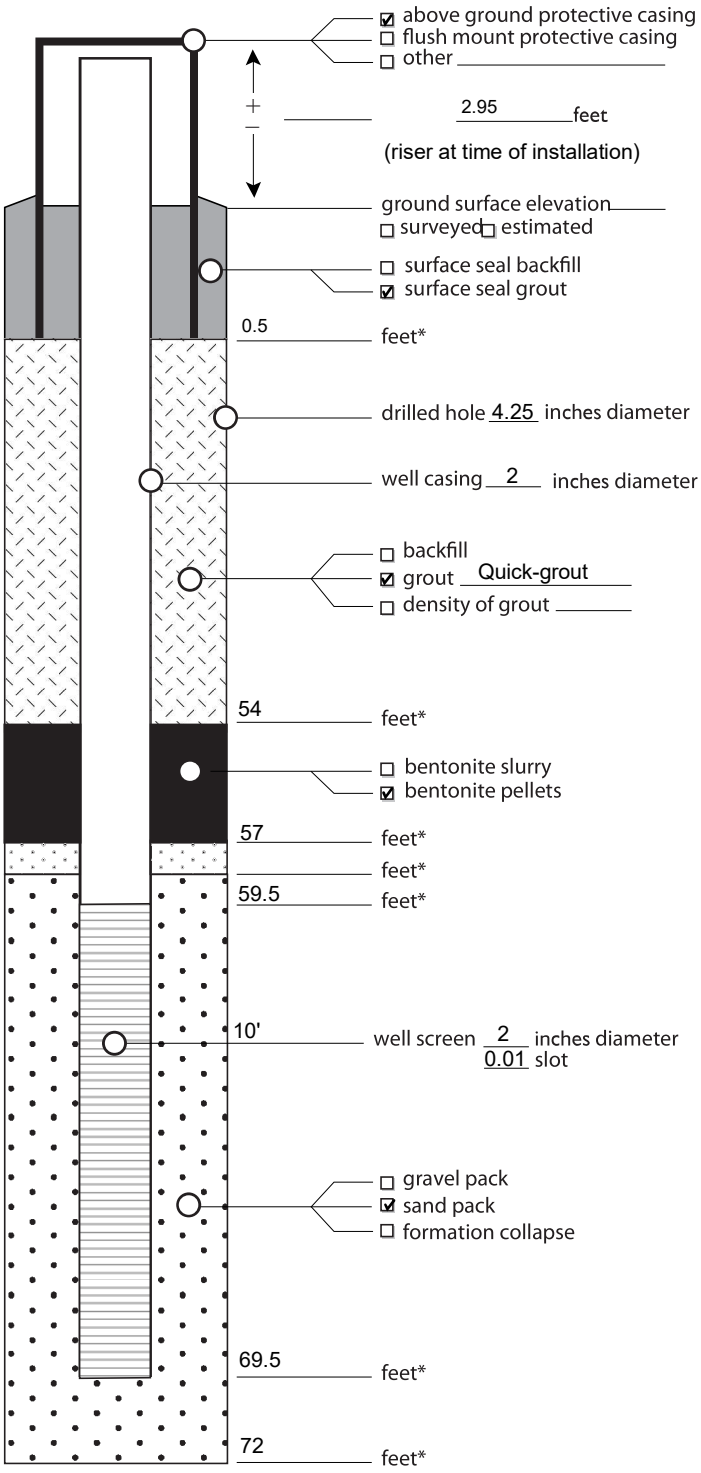
Protective Casing: Length 2.75 feet
Diameter inches
Construction
- ☐ Cast Aluminum
- ☑ Cast Steel
- ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 5.5 bags of 50 lb per bag Size graded
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bucket of 50 lb per bucket Type Pel-plug
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 5 bags of 50 lb per bag Type Quick-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000859

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G09M
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Sean Karoly, Amanda Toye
Project Number: GLP8021
Recorded By: SK

Permit Number:
Installation Date(s): 1/29/21-1/31/21
Drilling Method: HSA / Mud Rotary
Borehole Diameter: 4.25"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 80
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 inches
Construction
- ☑ PVC schedule 80
- ☐ Stainless Steel
- ☐ Other

Silt Trap Used ☐ Yes ☐ No

Bottom End Cap: ☐ Male ☑ Female ☐ Slip 4"
- ☐ PVC
- ☐ Stainless Steel
- ☐ Other

Top Cap: ☑ Male ☐ Female ☐ Slip ☑ J Plug
- ☐ PVC
- ☐ Stainless Steel
- ☐ Other

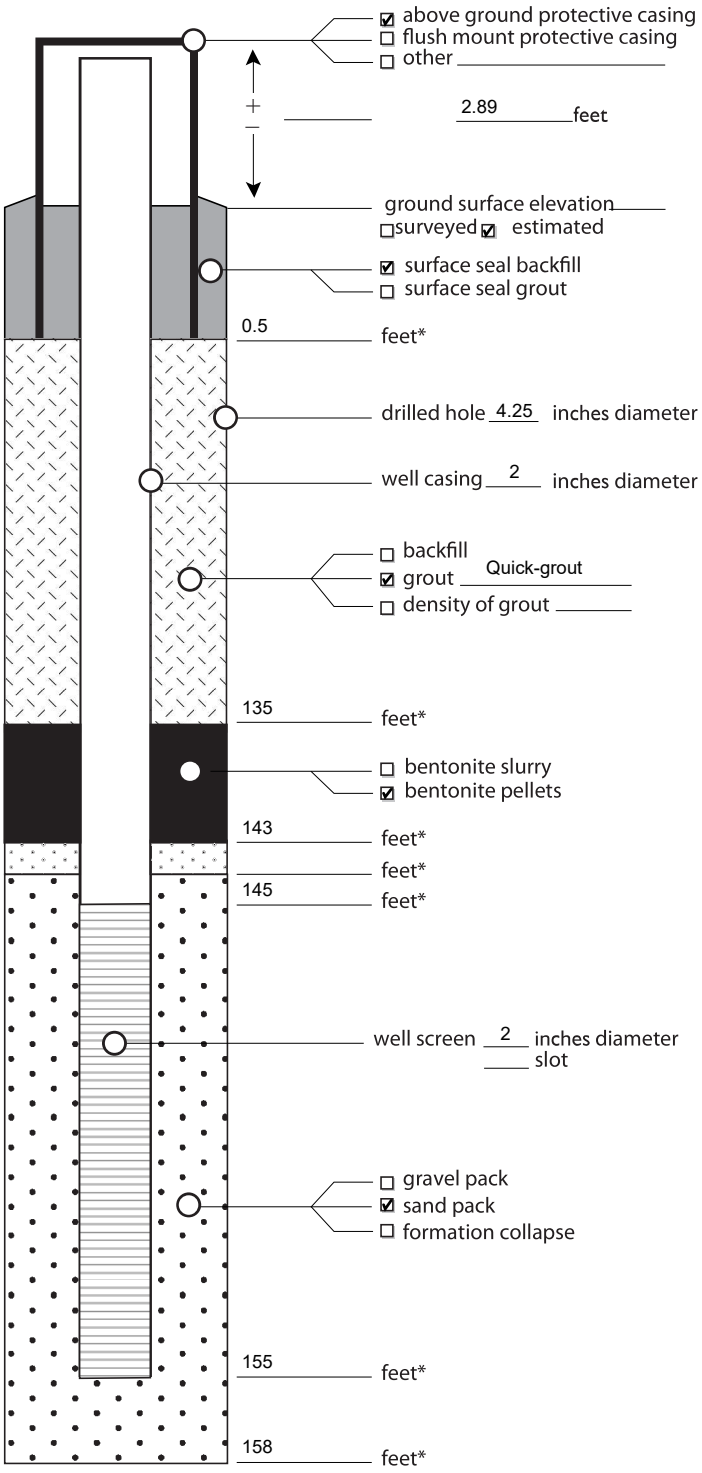
Protective Casing: Length 2.75 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 1.5 bags of 50 lb per bag Size graded
Fine Sand: bags of lb per bag Size

Seal: (bucket)
Bentonite Pellets: 1 bags of 50 lb per bag Type Pel-plug
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 6 bags of 50 lb per bag Type Quick-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000860

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G10
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Sean Karoly
Project Number: GLP8021
Recorded By: SK

Permit Number:
Installation Date(s): 2/1/21
Drilling Method: HSA
Borehole Diameter: 4.25"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☐ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

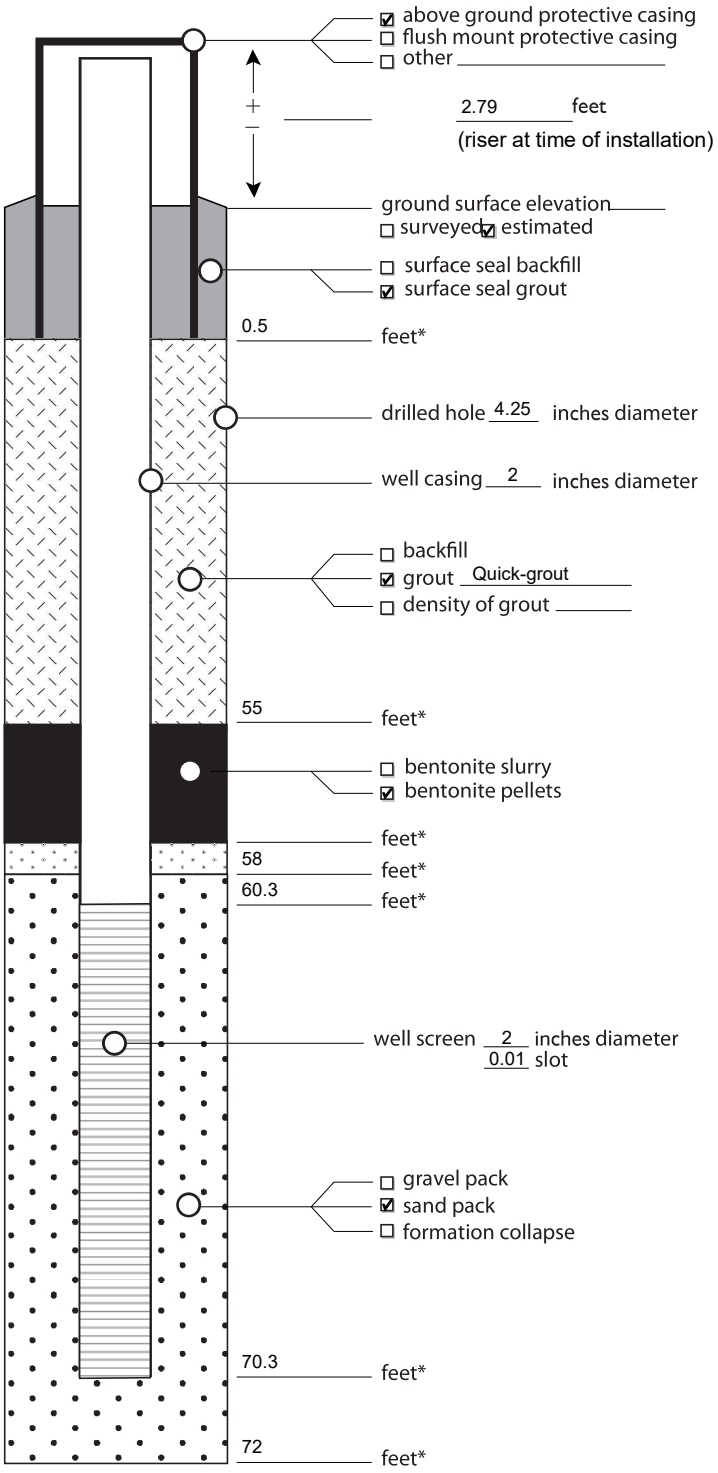
Protective Casing: Length 2.67 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 6 bags of 50 lb per bag Size graded
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 (bucket) bags of 50 lb per bag Type Pel-plug
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 5 bags of 50 lb per bag Type Quick-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000861

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G11
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Zachary Fallert and Amanda Toye
Project Number: GLP8021
Recorded By: Z. Fallert

Permit Number:
Installation Date(s): 1/19/21
Drilling Method: HSA
Borehole Diameter: 7.5"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

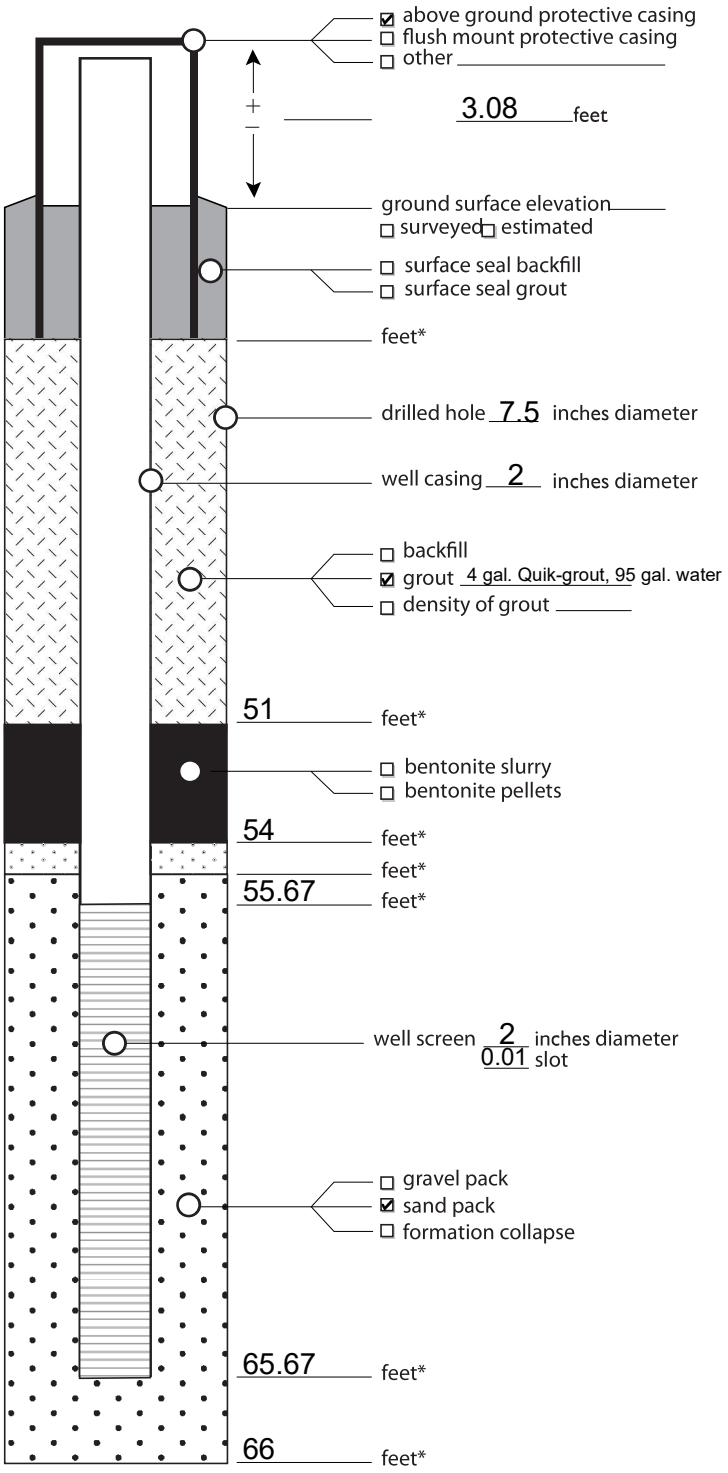
Protective Casing: Length 3.08 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 5 bags of Filter Sil lb per bag 50 Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 50 lb per bag Type Hole Plug 3/8"
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 4 bags of 50 lb per bag Type Quik-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000862

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: G54S
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Zachary Fallert and Amanda Toye
Project Number: GLP8021
Recorded By: Z. Fallert

Permit Number:
Installation Date(s): 1/22/21
Drilling Method: HSA
Borehole Diameter: 7.5"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 10 feet
Diameter 2 inches
Slot Size 0.01 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

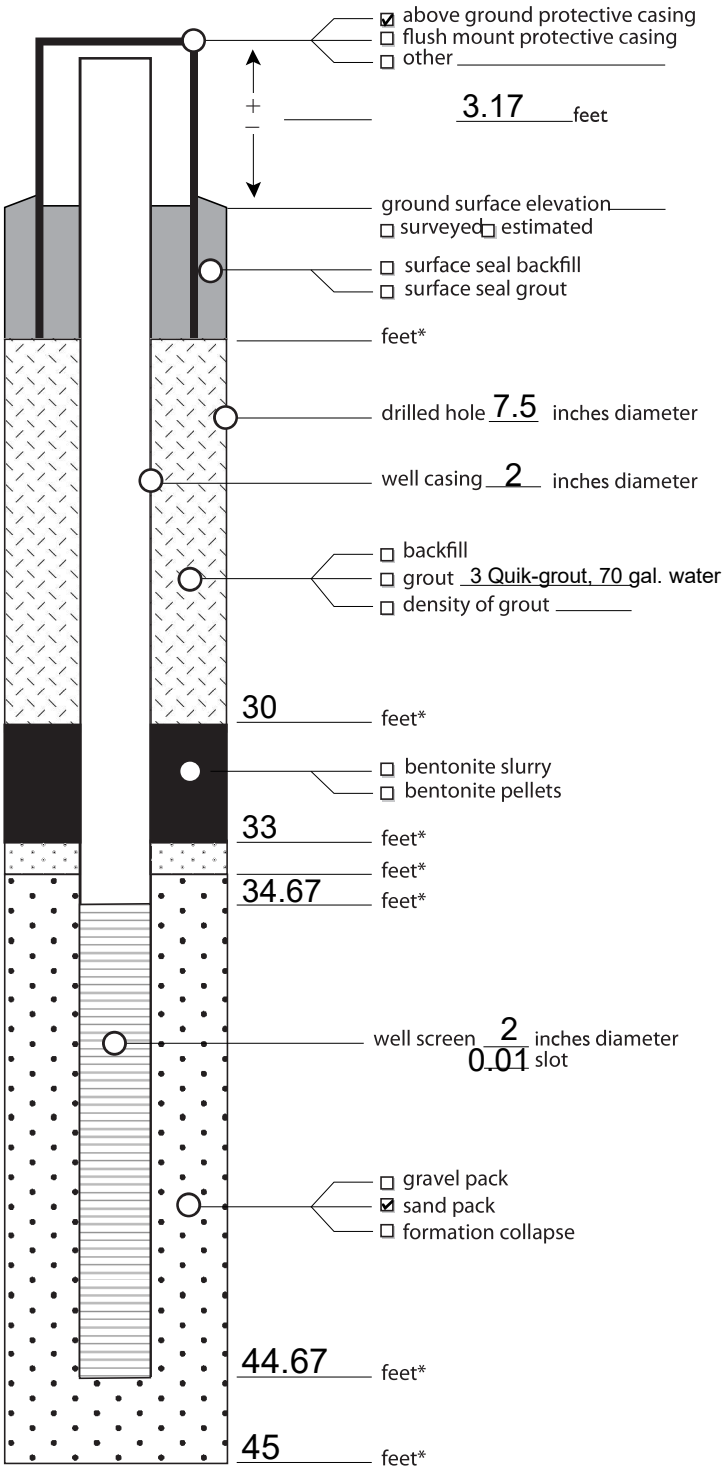
Protective Casing: Length 3.17 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 6 bags of Filter Sil lb per bag 50 Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 50 lb per bag Type Hole Plug 3/8"
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 3 bags of 50 lb per bag Type Quik-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000863

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: XPW-01
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Zachary Fallert and Amanda Toye
Project Number: GLP8021
Recorded By: Z. Fallert

Permit Number:
Installation Date(s): 1/20/21
Drilling Method: HSA
Borehole Diameter: 7.5"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 5 feet
Diameter 2 inches
Slot Size 0.01 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

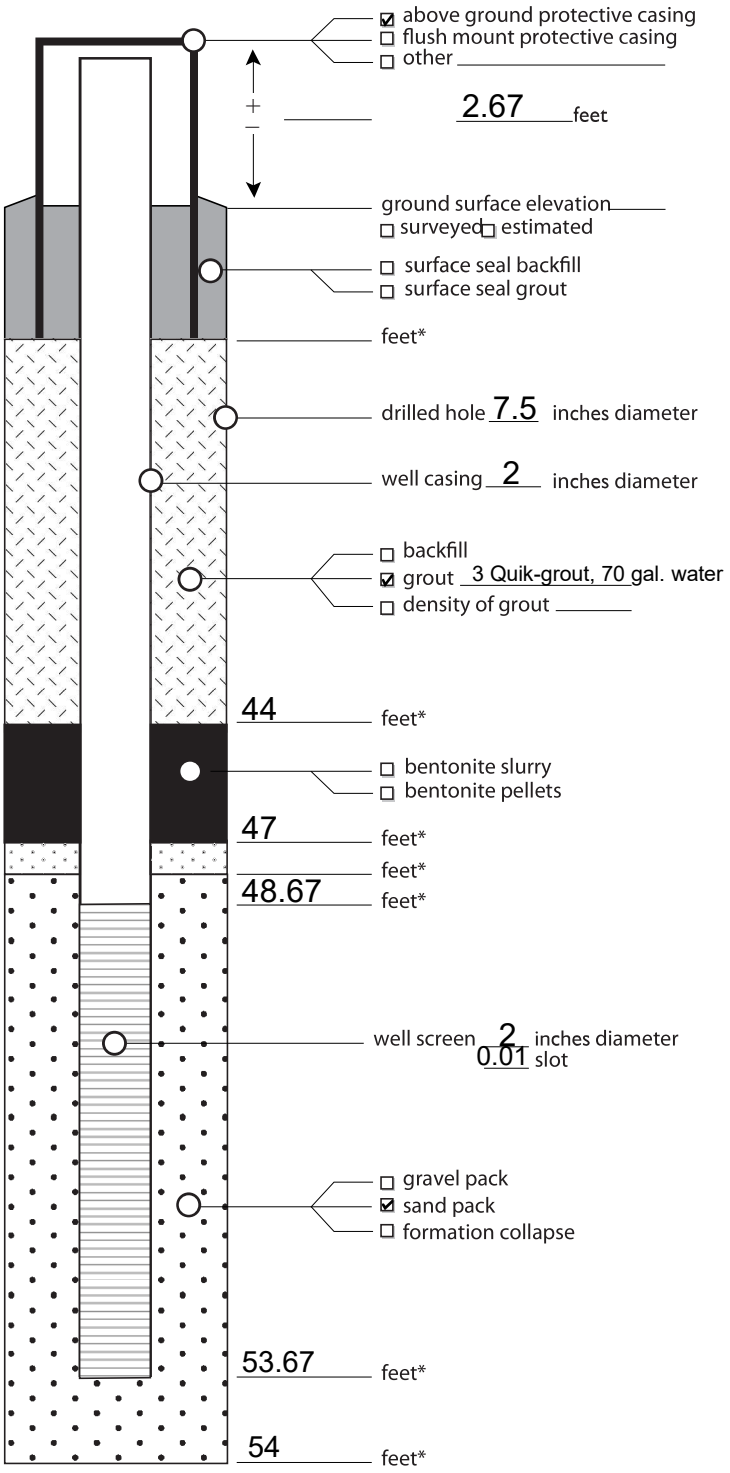
Protective Casing: Length 2.67 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 4 bags of Filter Sil lb per bag 50 Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 50 lb per bag Type Hole Plug 3/8"
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 3 bags of 50 lb per bag Type Quik-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

R000864

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: XPW-02
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Zachary Fallert and Amanda Toye
Project Number: GLP8021
Recorded By: Z. Fallert

Permit Number:
Installation Date(s): 1/21/21
Drilling Method: HSA
Borehole Diameter: 7.5"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 5 feet
Diameter 2 inches
Slot Size 0.01 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

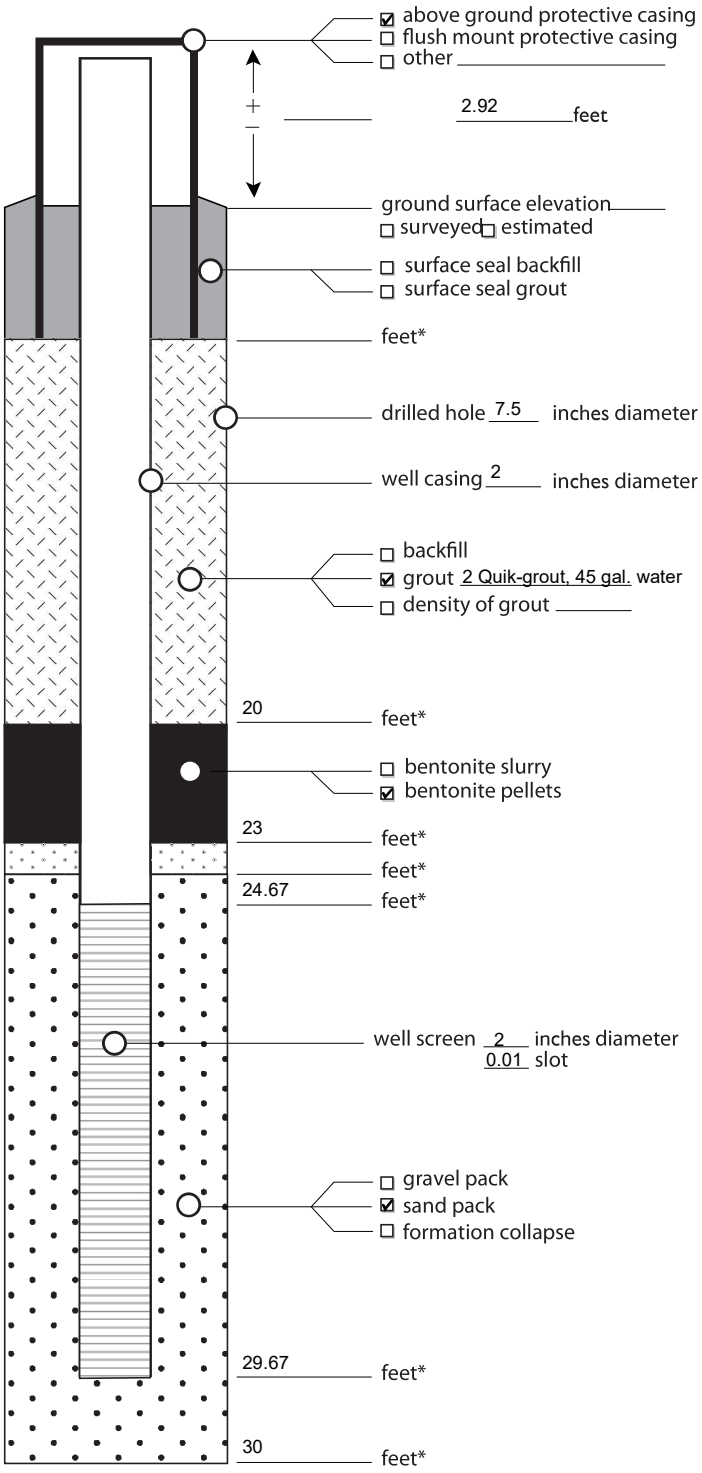
Protective Casing: Length 2.92 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 3.5 bags of Filter Sil lb per bag 50 Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 50 lb per bag Type Hole Plug 3/8"
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 2 bags of 50 lb per bag Type Quik-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing
Unless Otherwise Noted

* Depth Below Ground Surface

R000865

Geosyntec consultants

1420 Kensington Rd., Suite 103
Oak Brook, Illinois 60523
(630) 203-3340

MONITORING WELL CONSTRUCTION DETAIL

Well ID: XPW-03
Site Location: Joppa, IL
Project Name: Vistra - Joppa Power Station
Field Personnel: Zachary Fallert and Amanda Toye
Project Number: GLP8021
Recorded By: Z. Fallert

Permit Number:
Installation Date(s): 1/21/21
Drilling Method: HSA
Borehole Diameter: 7.5"
Drilling Contractor: Geotechnology
Driller: Patrick Hart
Drilling Fluid: N/A
Fluid Loss During Drilling: - Gallons

Materials Used

Riser Pipe: Diameter 2 inches
Construction
- ☑ PVC schedule 40
- ☐ Stainless Steel
- ☐ Other

Slotted Area: Length 5 feet
Diameter 2 inches
Slot Size 0.01 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

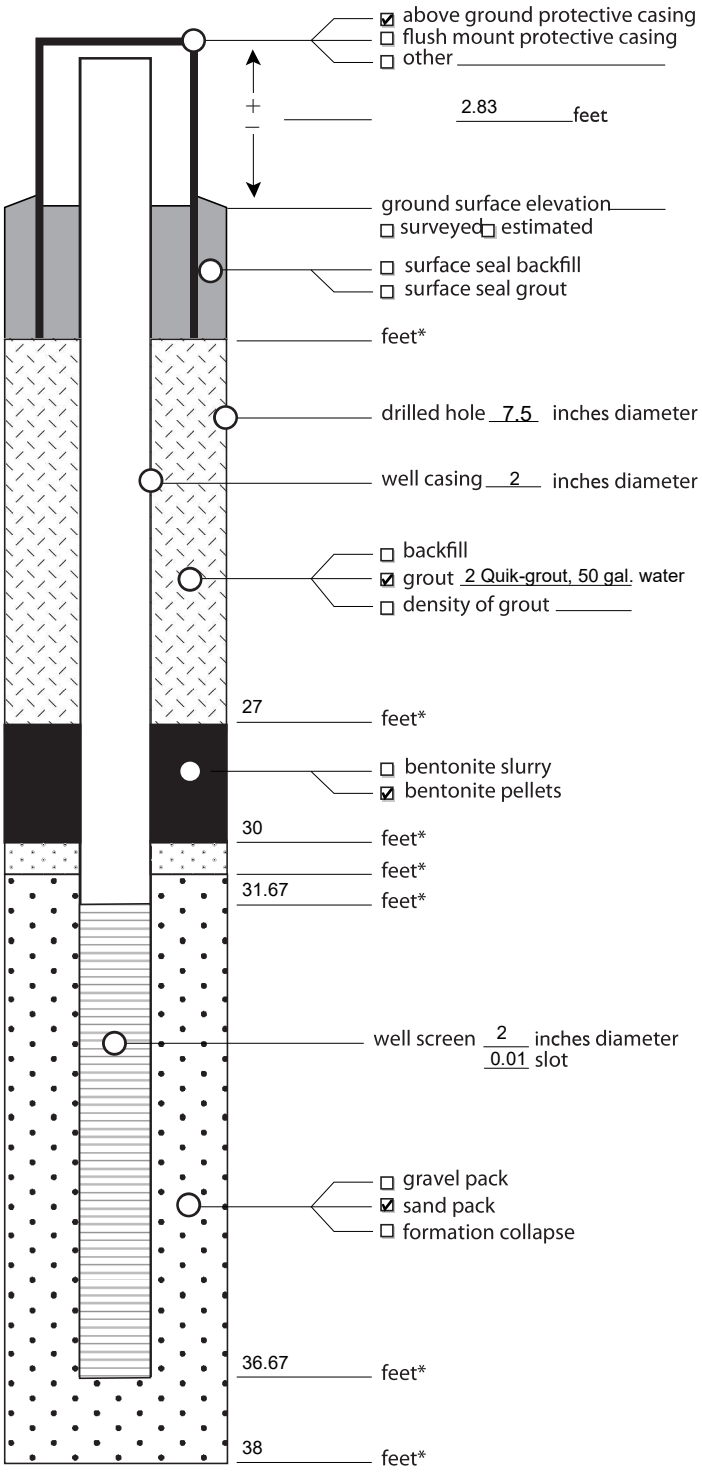
Protective Casing: Length 2.83 feet
Diameter inches
Construction ☐ Cast Aluminum ☑ Cast Steel ☐ Other

Casing Installation: Length feet
Diameter inches
Material

Sandpack:
Coarse Sand: 4.5 bags of Filter Sil lb per bag 50 Size
Fine Sand: bags of lb per bag Size

Seal:
Bentonite Pellets: 1 bags of 50 lb per bag Type Hole Plug 3/8"
Bentonite Slurry: bags of lb per bag Type

Grout:
Cement: 2 bags of 50 lb per bag Type Quik-grout
Bentonite: bags of lb per bag Type



Measuring Point is Top of Well Casing Unless Otherwise Noted

* Depth Below Ground Surface

HANSON BORING LOGS AND WELL CONSTRUCTION LOGS

BORING LOGS

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/14/2015
Finish: 8/14/2015
WEATHER: Partly cloudy, calm, warm, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G01D
Well ID: G01D
Surface Elev: 361.50 ft. MSL
Completion: 64.38 ft. BGS
Station: 202,039.30N
831,716.11E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 54.00 - During Drilling
▼ = 45.77 - 8/14/15
▽ =

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
	0/60 *0%*	BD					2			360	
	0/60 *0%*	BD					4			358	
							6			356	
							8			354	
	0/60 *0%*	BD					10	Blind drill - see G101 boring log		352	
							12			350	
							14			348	
							16			346	
	0/60 *0%*	BD					18			344	
							20			342	

NOTE(S): G01D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/14/2015
Finish: 8/14/2015
WEATHER: Partly cloudy, calm, warm, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G01D
Well ID: G01D
Surface Elev: 361.50 ft. MSL
Completion: 64.38 ft. BGS
Station: 202,039.30N
831,716.11E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 54.00 - During Drilling
▼ = 45.77 - 8/14/15
▽ =

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
	0/60 *0%*	BD					22			340	
							24			338	
							26			336	
	0/60 *0%*	BD					28			334	
							30	Blind drill - see G101 boring log *[Continued from previous page]*		332	
	0/60 *0%*	BD					32			330	
							34			328	
							36			326	
	0/60 *0%*	BD					38			324	
							40			322	

NOTE(S): G01D installed in borehole.

FIELD BORING LOG

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/14/2015
Finish: 8/14/2015
WEATHER: Partly cloudy, calm, warm, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G01D
Well ID: G01D
Surface Elev: 361.50 ft. MSL
Completion: 64.38 ft. BGS
Station: 202,039.30N
831,716.11E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 54.00 - During Drilling
▼ = 45.77 - 8/14/15
▽ =

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
	0/48 *0%*	BD					42	Blind drill - see G101 boring log *[Continued from previous page]*		320	
9A	24/24 *100%*	SS	*5-13* *6-5* N=19	13		*1.00*	44	Strong brown (7.5YR5/6), moist, medium dense, silty, very fine- to coarse-grained SAND with trace small gravel.		318	
9B				20			▼ 46			316	
10A	22/24 *92%*	SS	*2-3* *3-4* N=6	20		*1.50*		Gray (10YR6/1) with 40% yellowish brown (10YR5/6) mottles, moist, stiff, SILT, few to little clay, trace fine- to medium-grained sand.		314	
11A	24/24 *100%*	SS	*1-2* *3-3* N=5	21		*0.80*	48			312	
12A	19/24 *79%*	SS	*1-1* *2-4* N=3	20		*0.50*	50	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, medium, silty CLAY, few fine- to medium-grained sand.		310	
13A	24/24 *100%*	SS	*woh-1* *2-3* N=3	19		*0.50*	52	Gray (10YR6/1) with 25% yellowish brown (10YR5/6) mottles, moist, medium, CLAY with few very fine- to fine-grained sand and trace silt.		308	
14A	19/24 *79%*	SS	*14-18* *20-24* N=38	14			▼ 54	Light yellowish brown (10YR6/4), moist, dense, silty, very fine- to fine-grained SAND.		306	
15A	16/24 *67%*	SS	*woh-woh* *5-13*	23			56	Light yellowish brown (10YR6/4), wet, dense, silty, very fine- to fine-grained SAND.		304	
16A	20/24 *83%*	SS	*4-21* *25-21* N=46	18			58			302	
							60	Gray (10YR6/1), wet, dense, silty, very fine- to coarse-grained SAND.			

NOTE(S): G01D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/14/2015
Finish: 8/14/2015
WEATHER: Partly cloudy, calm, warm, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G01D
Well ID: G01D
Surface Elev: 361.50 ft. MSL
Completion: 64.38 ft. BGS
Station: 202,039.30N
831,716.11E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 54.00 - During Drilling
▼ = 45.77 - 8/14/15
▽ =

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
								Gray (10YR6/1), wet, dense, silty, very fine- to coarse-grained SAND. *[Continued from previous page]*			
17A	23/24 *96%*	SS	*7-15 32-37* N=47	19						300	
							62				
18A	15/18 *83%*	SS	*8-25 50/6"*	17				Light brownish gray (10YR6/2), wet, dense, silty, very fine- to coarse-grained SAND with trace small gravel.			
	0/11 *0%*	BD								298	
							64				

End of boring = 64.38 feet

NOTE(S): G01D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/12/2015
Finish: 8/13/2015
WEATHER: Sunny, warm, calm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G02D
Well ID: G02D
Surface Elev: 360.82 ft. MSL
Completion: 72.36 ft. BGS
Station: 202,137.08N
832,842.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.00 - 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
							0	Grayish brown (10YR5/2), moist, soft, SILT with few clay, trace very fine- to medium-grained sand, wood fragments, and roots.	360	
1A	20/24 83%	ss	1-1 2-3 N=3	24		2.00	2	Brown (10YR5/3) with 40% yellowish brown (10YR5/6) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand and roots.	358	
2A	24/24 100%	ss	1-3 5-5 N=8	23		2.50	4		356	
3A	24/24 100%	ss	1-3 5-5 N=8	20		2.00	6	Brown (10YR5/3) with 40% yellowish brown (10YR5/6) and 10% gray (10YR6/1) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand.	354	
4A	19/24 79%	ss	1-4 4-6 N=8	21		2.30	8		352	
5A	24/24 100%	ss	1-4 5-6 N=9	20		3.00	10	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay and trace very fine- to fine-grained sand.	350	
6A	20/24 83%	ss	1-2 5-6 N=7	20		2.50	12		348	
7A	22/24 92%	ss	1-5 7-11 N=12	18		3.00	14		346	
8A	19/24 79%	ss	2-9 13-18 N=22	15		4.50	16	Yellowish brown (10YR5/8) with 35% grayish brown (10YR5/2) mottles, moist, hard, SILT with few clay and trace very fine- to medium-grained sand.	344	
9A	24/24 100%	ss	4-8 11-15 N=19	17		3.00	18	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay and trace very fine- to fine-grained sand.	342	
10A	18/24 75%	ss	1-7 10-14 N=17	16		3.50	20			

NOTE(S): G02D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/12/2015
Finish: 8/13/2015
WEATHER: Sunny, warm, calm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G02D
Well ID: G02D
Surface Elev: 360.82 ft. MSL
Completion: 72.36 ft. BGS
Station: 202,137.08N
832,842.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.00 - 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
11A	21/24 88%	ss	2-8 12-17 N=20	15		4.00	22			340	
12A	22/24 92%	ss	4-9 12-13 N=21	16		4.00	24	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay and trace very fine- to fine-grained sand. *[Continued from previous page]*		338	
13A	24/24 100%	ss	3-8 11-11 N=19	17		3.00	26			336	
14A	20/24 83%	ss	2-6 8-9 N=14	16		2.50	28			334	
15A	22/24 92%	ss	1-5 7-8 N=12	19		3.30	30	Gray (10YR6/1) with 30% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with little clay and trace very fine- to fine-grained sand.		332	
16A	24/24 100%	ss	1-6 8-9 N=14	17		2.30	32	Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, moist, very stiff, SILT with few clay and very fine- to fine-grained sand, trace small gravel.		330	
17A	23/23 100%	ss	2-7 40-50/5" N=47	16		2.80	34	Strong brown (7.5YR4/6), moist, very stiff, SILT with little very fine- to coarse-grained sand and small to large gravel.		328	
18A	18/24 75%	ss	8-25 43-19 N=68	11			36	Strong brown (7.5YR4/6), moist, very dense, silty, very fine- to coarse-grained SAND with little small to large gravel.		326	
19A	24/24 100%	ss	1-3 4-30 N=7	22		0.80	38	Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, moist, medium, silty CLAY with few fine- to medium-grained sand, trace gravel.		324	
20A	12/16 75%	ss	6-35 50/4"	13			40	Strong brown (7.5YR4/6) moist, hard, SILT with little very fine- to coarse-grained sand and little small to large gravel.		322	

NOTE(S): G02D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/12/2015
Finish: 8/13/2015
WEATHER: Sunny, warm, calm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G02D
Well ID: G02D
Surface Elev: 360.82 ft. MSL
Completion: 72.36 ft. BGS
Station: 202,137.08N
832,842.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.00 - 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
21A	9/9 *100%*	ss	*39-50/3"*	11				Strong brown (7.5YR4/6) moist, hard, SILT with little very fine- to coarse-grained sand and little small to large gravel. *[Continued from previous page]*		320	
							42				
22A	8/24 *33%*	ss	*5-14* *17-8* N=31	15			▼	Brownish yellow (10YR6/6), moist, dense, silty, fine-grained SAND with trace medium- to coarse-grained sand.		318	
							44				
23A	24/24 *100%*	ss	*1-2* *3-4* N=5	22		*0.50*		Brownish yellow (10YR6/6), moist, medium, silty CLAY with few very fine- to medium-grained sand.		316	
							46				
24A	18/24 *75%*	ss	*woh-woh* *4-7*	18		*0.50*		Brownish yellow (10YR6/6), moist, soft, CLAY with some very fine- to medium-grained sand and trace coarse-grained sand and trace small gravel.		314	
							48				
25A	20/24 *83%*	ss	*1-2* *6-5* N=8	18		*0.80*		Brownish yellow (10YR6/6), moist, medium, CLAY with some very fine- to medium-grained sand and trace coarse-grained sand and trace small gravel.		312	
							50				
26A	17/24 *71%*	ss	*2-5* *5-8* N=10	23		*2.50*		Gray (10YR6/1) with 40% yellowish brown (10YR5/6) mottles, moist, stiff, silty CLAY with few fine-grained sand.		310	
							52				
27A	22/24 *92%*	ss	*1-3* *3-5* N=6	18		*1.50*				308	
							54				
28A	24/24 *100%*	ss	*woh-3* *3-4* N=6	17		*1.00*		Gray (10YR6/1), moist, medium, CLAY with some fine-grained sand and few silt.		306	
							56				
29A	24/24 *100%*	ss	*woh-4* *5-5* N=9	22		*3.00*				304	
							58	Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace fine-grained sand.			
30A	20/24 *83%*	ss	*2-4* *6-6* N=10	19		*2.00*				302	
							60				

NOTE(S): G02D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/12/2015
Finish: 8/13/2015
WEATHER: Sunny, warm, calm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G02D
Well ID: G02D
Surface Elev: 360.82 ft. MSL
Completion: 72.36 ft. BGS
Station: 202,137.08N
832,842.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.00 - 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
31A	19/24 79%	SS	woh-1 4-14 N=5	20			62	Gray (10YR6/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, medium, SILT with little clay and little very fine- to medium-grained sand.		300	
32A	16/24 67%	SS	3-14 18-25 N=32	20			64	Gray (10YR6/1), wet, dense, very fine- to coarse-grained SAND with some silt.		298	
33A	14/24 58%	SS	5-18 37-33 N=55	18			66	Gray (10YR6/1), wet, dense, very fine- to coarse-grained SAND with some silt and trace small to large gravel.		296	
34A	16/24 67%	SS	18-29 35-21 N=64	13			68	Brownish yellow (10YR6/6), wet, very dense, silty, very fine- to coarse-grained SAND and small to large GRAVEL.		294	
35A	14/24 58%	SS	20-24 30-30 N=54	16			70	Gray (10YR6/1), wet, very dense, silty, very fine- to coarse-grained SAND with trace small to large gravel.		292	
36A	16/24 67%	SS	12-19 37-28 N=56	14						290	
	0/4 0%	BD					72				

End of boring = 72.36 feet

NOTE(S): G02D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
	0/60 *0%*	BD					2			360	
	0/60 *0%*	BD					4			358	
							6			356	
							8			354	
							10	Blind drill - see G151 boring log		352	
	0/60 *0%*	BD					12			350	
							14			348	
							16			346	
	0/60 *0%*	BD					18			344	
							20			342	

NOTE(S): G51D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
	0/60 0%	BD					22				
							24			338	
							26			336	
	0/60 0%	BD					28			334	
							30	Blind drill - see G151 boring log *[Continued from previous page]*		332	
	0/60 0%	BD					32			330	
							34			328	
							36			326	
	0/60 0%	BD					38			324	
							40			322	
9A	24/24 100%	SS	6-7 4-4 N=11	22		1.50	42	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, medium, CLAY with few silt and little very fine- to fine-grained sand.		320	

NOTE(S): G51D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
10A	24/24 100%	SS	1-2 4-5 N=6	20		1.50	44	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, medium, CLAY with few silt and little very fine- to fine-grained sand. *[Continued from previous page]*		318	
11A	24/24 100%	SS	3-4 4-4 N=8	16		0.25	46	Yellowish brown (10YR5/8) with 50% gray (10YR6/1) mottles, moist, soft, very fine- to medium-grained SAND with some silt and little clay.		316	
12A	24/24 100%	SS	5-7 10-11 N=17	13		1.50	48	Yellowish brown (10YR5/8) with 50% gray (10YR6/1) mottles, moist, stiff, very fine- to medium-grained SAND with some silt, little clay, and trace small gravel.		314	
13A	20/24 83%	SS	5-12 14-15 N=26	15		0.25	50	Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, wet, loose, very fine- to medium-grained SAND with trace silt, trace clay and trace small gravel.		312	
14A	23/24 96%	SS	5-15 19-21 N=34	15		1.25	52			310	
15A	22/24 92%	SS	3-12 14-7 N=26	15		1.50	54			308	
16A	24/24 100%	SS	1-5 6-11 N=11	17		0.00	56	Strong brown (7.5YR5/8), wet, loose, very fine- to medium-grained SAND with trace silt, trace clay, and trace small gravel.		306	
17A	24/24 100%	SS	2-7 8-11 N=15	19		0.00	58			304	
	0/23 0%	BD								302	Drilled past end of sample interval

End of boring = 59.9 feet

NOTE(S): G51D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/18/2015
Finish: 8/19/2015
WEATHER: Overcast, humid, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G52D
Well ID: G52D
Surface Elev: 345.88 ft. MSL
Completion: 80.01 ft. BGS
Station: 198,098.93N
832,927.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 28.45 - 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	Borehole Detail	Elevation ft. MSL	Remarks
	0/60 *0%*	BD					2	Blind drill - see G152 boring log		344	
	0/60 *0%*	BD					4			342	
	0/60 *0%*	BD					6			340	
	0/60 *0%*	BD					8			338	
							10			336	
							12			334	
							14			332	
							16			330	
							18			328	
							20			326	

NOTE(S): G52D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/18/2015
Finish: 8/19/2015
WEATHER: Overcast, humid, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G52D
Well ID: G52D
Surface Elev: 345.88 ft. MSL
Completion: 80.01 ft. BGS
Station: 198,098.93N
832,927.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 28.45 - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft^3)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/60 *0%*	BD					22			324	
							24			322	
							26			320	
	0/60 *0%*	BD					28 ▼			318	
							30			316	
							32	Blind drill - see G152 boring log *[Continued from previous page]*		314	
	0/60 *0%*	BD					34			312	
							36			310	
	0/60 *0%*	BD					38			308	
							40			306	
	0/24 *0%*	BD					42			304	

NOTE(S): G52D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/18/2015
Finish: 8/19/2015
WEATHER: Overcast, humid, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G52D
Well ID: G52D
Surface Elev: 345.88 ft. MSL
Completion: 80.01 ft. BGS
Station: 198,098.93N
832,927.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 28.45 - 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
10A	24/24 100%	ss	3-3 5-6 N=8	22		3.75	44	Gray (10YR5/1) with 40% yellowish brown (10YR5/8) mottles, moist, medium, CLAY with some silt and trace very fine-grained sand.		302	
11A	24/24 100%	ss	3-3 4-6 N=7	21		3.75	46			300	
12A				20		3.50					
12B	24/24 100%	ss	3-4 4-7 N=8	23				Gray (10YR6/1), moist, medium, SILT with some very fine-grained sand and trace clay.			
13A	24/24 100%	ss	2-4 5-6 N=9	23			48	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, medium, CLAY with some silt and trace very fine-grained sand.		298	
14A	24/24 100%	ss	5-7 8-10 N=15	20		4.00	50	Gray (10YR6/1) with 15% yellowish brown (10YR5/8) mottles, moist, stiff, CLAY with some silt and trace very fine-grained sand.		296	
15A	24/24 100%	ss	1-4 4-5 N=8	24		2.50	52	Gray (10YR6/1) with 10% yellowish brown (10YR5/8) mottles, moist, medium, SILT with few very fine-grained sand and little clay.		294	
16A	24/24 100%	ss	2-3 7-7 N=10	24		2.50	54	Gray (10YR6/1), moist, soft, CLAY with some silt and trace very fine-grained sand.		292	
16B				20				Gray (10YR6/1) with 10% yellowish brown (10YR5/8) mottles, moist, soft, SILT with little clay and very fine-grained sand.			
17A	24/24 100%	ss	4-4 7-9 N=11	21		3.75	56	Gray (10YR6/1), moist, soft, CLAY with some silt and trace very fine-grained sand.		290	
18A	24/24 100%	ss	2-6 7-7 N=13	24		3.25		Gray (10YR6/1), moist, medium, SILT and very fine-grained SAND with few clay.			
19A	22/24 92%	ss	3-3 4-4 N=7	20		2.25	58			288	
	24/24		2-3				60	Gray (10YR6/1), moist, medium, interbedded (0.1-0.2') SILT and very fine-grained SAND with few clay and CLAY with some silt and trace very fine-grained sand.		286	
							62	Gray (10YR6/1), moist, medium, SILT with very fine-grained sand and few clay.		284	

NOTE(S): G52D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/18/2015
Finish: 8/19/2015
WEATHER: Overcast, humid, mid-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G52D
Well ID: G52D
Surface Elev: 345.88 ft. MSL
Completion: 80.01 ft. BGS
Station: 198,098.93N
832,927.89E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 28.45 - 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
20A	100%	SS	5-6 N=8	23		2.25	64			282	
21A	24/24 100%	SS	4-4 6-7 N=10	23		4.25	66	Gray (10YR6/1), moist, medium, SILT with very fine-grained sand and few clay. *[Continued from previous page]*		280	
22A	24/24 100%	SS	3-4 8-9 N=12	19		2.00	68			278	
23A	24/24 100%	SS	2-7 6-6 N=13	22		2.50	70			276	
24A	24/24 100%	SS	wor-6 9-9 N=15	22		2.50	72	Gray (10YR6/1) with 20% yellowish brown (10YR5/8) mottles, moist, stiff, SILT and very fine-grained SAND with few clay.		274	
25A	24/24 100%	SS	wor-3 5-7 N=8	22		2.25		Gray (10YR6/1), wet, dense, SILT and very fine-grained SAND with trace clay.			
26A				17			74	Gray (10YR6/1), wet, loose, very fine- to medium-grained SAND with trace silt.		272	
26B	24/24 100%	SS	6-7 8-9 N=15	22		3.25					
27A	24/24 100%	SS		22		2.75	76	Yellowish brown (10YR5/8) with 10% gray (10YR5/1) mottles, moist, stiff, CLAY with some silt and trace very fine-grained sand.		270	Rods dropped, no blows
28A	22/24 92%	SS	woh-3 6-7 N=9	27		3.25	78			268	
							80			266	

End of boring = 80.01 feet

NOTE(S): G52D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/20/2015
Finish: 8/21/2015
WEATHER: Sunny, mild mid-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler

FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G53D
Well ID: G53D
Surface Elev: 352.16 ft. MSL
Completion: 58.00 ft. BGS
Station: 200,075.16N
833,980.21E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.45 - 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	Borehole Detail	Elevation ft. MSL	Remarks
	0/60 *0%*	BD					0			352	
							2			350	
							4			348	
							6			346	
	0/60 *0%*	BD					8			344	
							10	Blind drill - see G153 boring log		342	
							12			340	
	0/60 *0%*	BD					14			338	
							16			336	
							18			334	
	0/60 *0%*	BD					20			332	

NOTE(S): G55D installed in borehole.

FIELD BORING LOG

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/20/2015
Finish: 8/21/2015
WEATHER: Sunny, mild mid-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G53D
Well ID: G53D
Surface Elev: 352.16 ft. MSL
Completion: 58.00 ft. BGS
Station: 200,075.16N
833,980.21E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.45 - 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
	0/60 0%	BD					22			330	
							24				
	0/60 0%	BD					26			326	
							28			324	
							30	Blind drill - see G153 boring log *[Continued from previous page]*		322	
	0/60 0%	BD					32			320	
							34			318	
	0/36 0%	BD					36			316	
							38			314	
9A	24/24 100%	SS	3-3 5-5 N=8	19		1.25		Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, dense, very fine- to medium-grained SAND with some silt and little clay.			
							40			312	
10A	21/24 88%	SS	3-6 7-8 N=13	17		1.50		Dark yellowish orange (10YR6/6) with 20% gray (10YR5/1) mottles, wet, dense, very fine- to medium-grained SAND with some silt, little clay, and trace small gravel.			
							42				

NOTE(S): G55D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/20/2015
Finish: 8/21/2015
WEATHER: Sunny, mild mid-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G53D
Well ID: G53D
Surface Elev: 352.16 ft. MSL
Completion: 58.00 ft. BGS
Station: 200,075.16N
833,980.21E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 43.45 - 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	1-3 4-5 N=7	20			44	Dark yellowish orange (10YR6/6) with 20% gray (10YR5/1) mottles, wet, dense, very fine- to medium-grained SAND with some silt, little clay, and trace small gravel. *[Continued from previous page]*		310	
12A	21/24 88%	SS	2-5 12-14 N=17	16			46	Yellowish brown (10YR5/8) with 10% gray (10YR6/10 mottles, wet, dense, very fine- to fine-grained SAND with some silt and trace clay.		308	
13A	23/24 96%	SS	1-1 6-10 N=7	20			48			306	
14A	15/24 63%	SS	wor-wor woh-3	25			50	Gray (10YR6/1) wet, loose, very fine- to medium-grained SAND (micaceous) with little silt and trace clay.		304	
15A	19/24 79%	SS	1-3 8-14 N=11	23			52			302	
16A	20/24 83%	SS	1-4 5-14 N=9	23			54	Gray (10YR6/1) wet, loose, very fine- to medium-grained SAND (micaceous) with little silt and trace clay and small gravel.		300	
17A				22						298	
17B	19/24 79%	SS	4-10 14-20 N=24	16			56	Gray (10YR6/1), wet, loose, very fine- to very coarse-grained SAND with few small to large gravel and little silt.		296	
18A				12							
18B	18/24 75%	SS	1-9 10-11 N=19	21			58	Gray (10YR6/1) wet, loose, very fine- to fine-grained SAND with little silt and trace small gravel.			

End of boring = 58.0 feet

NOTE(S): G55D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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	13/24 *54%*	ss	*3-2* *3-4* N=5	21			0	FILL - Black (10YR2/1), moist, medium, SILT with few clay, trace very fine- to medium-grained sand, and trace roots.			
							1	FILL - Yellowish brown (10YR5/4), moist, medium, SILT with few clay, trace very fine- to coarse-grained sand, and trace roots.		352	
2A	16/24 *67%*	ss	*2-4* *16-8* N=20	13			2	FILL - Yellowish brown (10YR5/4) with 25% gray (10YR5/1), moist, medium, SILT with few clay, trace very fine- to coarse-grained sand, trace small to large gravel, and trace roots.			
							3			350	
3A	18/24 *75%*	ss	*4-4* *5-8* N=9	23		*2.00*	4				
							5	Light gray (10YR7/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine- to fine-grained sand.		348	
4A	21/24 *88%*	ss	*2-2* *4-4* N=6	25		*2.00*	6				
							7			346	
5A	24/24 *100%*	ss	*1-3* *4-6* N=7	23		*1.80*	8				
							9	Brown (10YR5/3) with 20% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand.		344	
6A	22/24 *92%*	ss	*1-3* *4-5* N=7	22		*3.00*	10				
							11			342	
7A	17/24 *71%*	ss	*1-1* *2-4* N=3	22		*2.00*	12				
							13	Gray (10YR6/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with few clay, trace very fine-grained sand.		340	
8A	22/24 *92%*	ss	*1-2* *4-5* N=6	22		*2.00*	14				
							15			338	
9A	17/24 *71%*	ss	*2-3* *6-8* N=9	22		*1.80*	16				
							17			336	
10A	24/24 *100%*	ss	*2-3* *6-5* N=9	20		*2.50*	18 ▼	Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, moist, stiff, silty CLAY with trace very fine-grained sand.			
							19			334	
11A	24/24		*1-3*	20		*1.90*	20				

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
	100%	ss	*5-6* N=8				22	Yellowish brown (10YR5/6) with 30% gray (10YR6/1) mottles, moist, stiff, silty CLAY with trace very fine-grained sand. *[Continued from previous page]*		332	
12A	24/24 *100%*	ss	*1-4* *6-8* N=10	19		*3.00*	24			330	
13A	24/24 *100%*	ss	*1-3* *4-6* N=7	19		*1.80*	26			328	
14A	24/24 *100%*	ss	*2-4* *7-7* N=11	21		*2.00*	28	Light brownish gray (10YR6/2) with 35% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with few clay, trace very fine- to medium-grained sand.		326	
15A	22/24 *92%*	ss	*1-3* *6-8* N=9	20		*2.30*	30			324	
16A	20/24 *83%*	ss	*1-3* *6-6* N=9	18		*2.40*	32			322	
17A	24/24 *100%*	ss	*1-4* *8-8* N=12	20		*3.50*	34			320	
18A	22/24 *92%*	ss	*1-3* *4-5* N=7	22		*2.80*	36	Grayish brown (10YR5/2) with 10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with little clay, trace very fine-grained sand.		318	
19A	24/24 *100%*	ss	*3-4* *8-8* N=12	19		*3.00*	38			316	
20A	24/24 *100%*	ss	*1-4* *7-10* N=11	19		*2.50*	40	Light gray (10YR7/1) with 5% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand.		314	
21A	24/24 *100%*	ss	*1-3* *10-10* N=13	17		*3.80*	42			312	

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
22A	24/24 100%	ss	5-8 9-10 N=17	16		3.00	44	Light gray (10YR7/1) with 5% yellowish brown (10YR5/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand. *[Continued from previous page]*		310	
23A	24/24 100%	ss	3-6 8-8 N=14	19		3.00	46			308	
24A	24/24 100%	ss	2-4 5-5 N=9	19		3.20	48	Light brownish gray (10YR6/2) with 10% dark yellowish brown (10YR4/4) mottles, moist, very stiff, silty CLAY, trace very fine- to coarse-grained sand.		306	
25A	24/24 100%	ss	4-7 7-6 N=14	18		2.40	50			304	
26A	17/24 71%	ss	1-4 6-8 N=10	18		2.00	52	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, very stiff, silty CLAY with little very fine- to coarse-grained sand and trace small gravel.		302	
27A	22/24 92%	ss	3-3 7-18 N=10	21		3.30	54	Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, very stiff, SILT with few clay, trace very fine-grained sand.		300	
28A	21/24 88%	ss	5-11 18-20 N=29	21		4.00	56			298	
29A	11/11 100%	ss	25-50/5"	15		3.80	58	Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, hard, SILT with few very fine- to fine-grained sand, trace clay.		296	
30A	20/24 83%	ss	21-19 35-29 N=54	14			60	Gary (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, very dense, silty, very fine- to fine-grained sand, trace clay.		294	
31A	17/24 71%	ss	4-6 10-9 N=16	17		1.80	62	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand.		292	
32A	22/24		6-8	22		3.30					

NOTE(S): G54D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/11/2015
Finish: 8/11/2015
WEATHER: Sunny, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: S. Keim

BOREHOLE ID: G54D
Well ID: G54D
Surface Elev: 353.71 ft. MSL
Completion: 80.14 ft. BGS
Station: 199,066.83N
831,610.42E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 18.00 - 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
	92%	SS	5-7 N=13				64	Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand. *[Continued from previous page]*		290	
33A	24/24 100%	SS	2-4 7-9 N=11	18		2.50	66			288	
34A	24/24 100%	SS	3-5 10-15 N=15	19		2.50		Gray (10YR6/1) with 15% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, few very fine- to coarse-grained sand, trace small gravel.		286	
35A	22/24 92%	SS	1-3 3-5 N=6	23		1.50	68				
								Yellowish brown (10YR5/6) with 10% gray (10YR6/1) mottles, moist, stiff, SILT with little clay, trace very fine-grained sand.		284	
36A	24/24 100%	SS	woh-1 5-6 N=6	23		1.50	70				
								Gray (10YR6/1) with 10% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with little clay, trace very fine- to fine-grained sand.		282	
37A	24/24 100%	SS	woh-1 2-4 N=3	23		1.50	72				
										280	
38A	16/24 67%	SS	30-40 27-34 N=67	11			74				
										278	
39A	12/15 80%	SS	10-47 50/3"	14			76	Yellowish brown (10YR5/6), moist, very dense, silty, fine- to coarse-grained SAND and small to large GRAVEL.			
										276	
40A	5/5 100%	SS	50/5"	12			78				
	0/21 0%	BD								274	
							80				

End of boring = 80.14 feet

NOTE(S): G54D installed in borehole.

WELL CONSTRUCTION LOGS

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Massac County Well #: G01D

Site Name: Joppa Power Station Borehole #: G01D

State Plane Coordinate: X 831,716.1 Y 202,039.3 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Suzanna L. Keim Date Started: 8/14/2015 Date Finished: 8/14/2015

Report Form Completed By: Suzanna L. Keim Date: 8/18/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: >48 hours

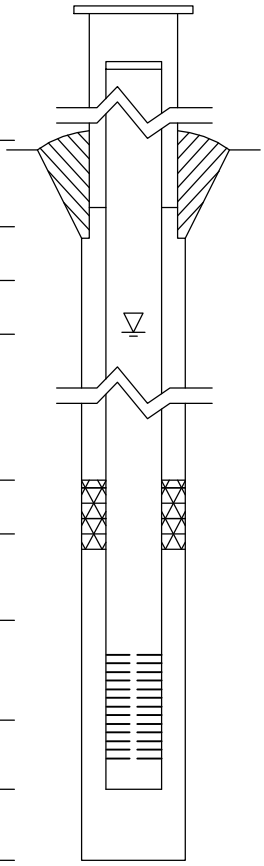
Type of Sand Pack: Quartz Sand

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.)	
364.50	-3.00	Top of Protective Casing
364.19	-2.69	Top of Riser Pipe
361.50	0.00	Ground Surface
359.50	2.00	Top of Annular Sealant
311.42	50.08	Static Water Level (After Completion) 10/5/2015
310.15	51.35	Top of Seal
308.90	52.60	Top of Sand Pack
307.31	54.19	Top of Screen
297.65	63.85	Bottom of Screen
297.12	64.38	Bottom of Well
297.12	64.38	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)	56.88
Bottom of Screen to End Cap	(feet)	0.53
Screen Length (1st slot to last slot)	(feet)	9.66
Total Length of Casing	(feet)	67.07
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: Massac County Well #: G02D

Site Name: Joppa Power Station Borehole #: G02D

State Plane Coordinate: X 832,843.0 Y 202,137.1 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Suzanna L. Keim Date Started: 8/12/2015 Date Finished: 8/13/2015

Report Form Completed By: Suzanna L. Keim Date: 8/18/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 45 minutes

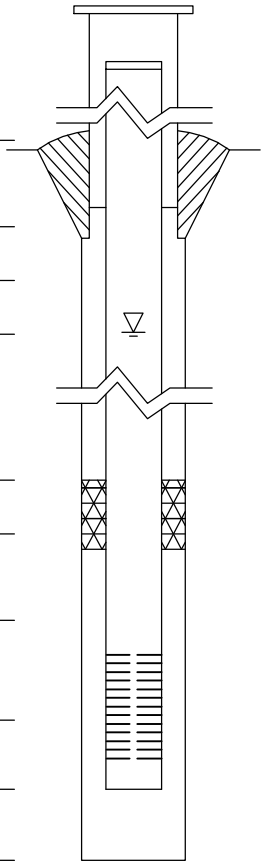
Type of Sand Pack: Quartz Sand

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.)
364.09	-3.27	Top of Protective Casing
363.65	-2.83	Top of Riser Pipe
360.82	0.00	Ground Surface
358.82	2.00	Top of Annular Sealant
312.82	48.00	Static Water Level (After Completion) 10/5/2015
301.82	59.00	Top of Seal
300.42	60.40	Top of Sand Pack
298.61	62.21	Top of Screen
288.98	71.84	Bottom of Screen
288.46	72.36	Bottom of Well
288.46	72.36	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)	65.04
Bottom of Screen to End Cap	(feet)	0.52
Screen Length (1st slot to last slot)	(feet)	9.63
Total Length of Casing	(feet)	75.19
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Massac County Well #: G51D

Site Name: Joppa Power Station Borehole #: G51D

State Plane Coordinate: X 832,151.5 Y 200,430.1 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Rhonald W. Hasenyager Date Started: 8/17/2015 Date Finished: 8/18/2015

Report Form Completed By: Suzanna L. Keim Date: 8/28/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 70 minutes

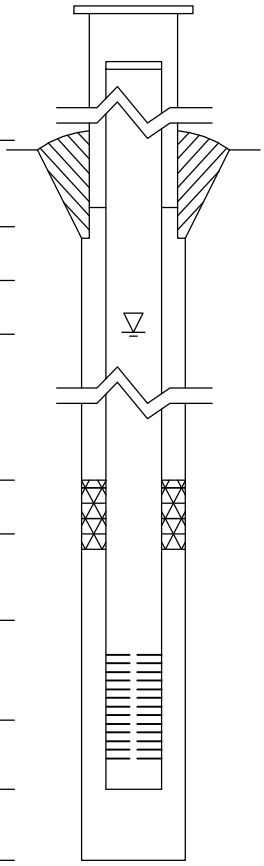
Type of Sand Pack: Quartz Sand

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.)	
364.22	-3.12	Top of Protective Casing
363.85	-2.75	Top of Riser Pipe
361.10	0.00	Ground Surface
359.10	2.00	Top of Annular Sealant
311.65	49.45	Static Water Level (After Completion) 10/5/2015
315.42	45.68	Top of Seal
313.59	47.51	Top of Sand Pack
311.49	49.61	Top of Screen
301.83	59.27	Bottom of Screen
301.20	59.90	Bottom of Well
301.20	59.90	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)	52.36
Bottom of Screen to End Cap	(feet)	0.63
Screen Length (1st slot to last slot)	(feet)	9.66
Total Length of Casing	(feet)	62.65
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Massac County Well #: G52D

Site Name: Joppa Power Station Borehole #: G52D

State Plane Coordinate: X 832,927.9 Y 198,098.9 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Rhonald W. Hasenyager Date Started: 8/18/2015 Date Finished: 8/19/2015

Report Form Completed By: Suzanna L. Keim Date: 8/28/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 32 minutes

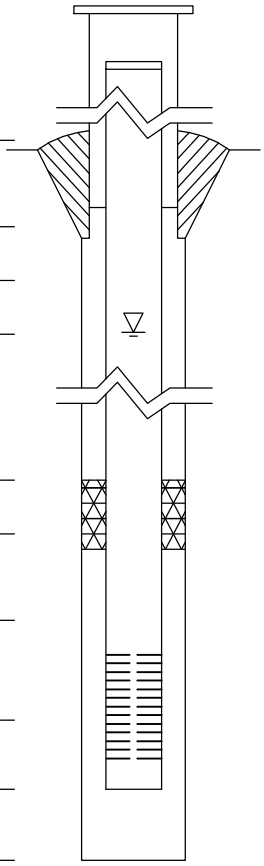
Type of Sand Pack: Quartz Sand

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.)	
348.67	-2.79	Top of Protective Casing
348.41	-2.53	Top of Riser Pipe
345.88	0.00	Ground Surface
343.88	2.00	Top of Annular Sealant
313.46	32.42	Static Water Level (After Completion) 10/5/2015
278.91	66.97	Top of Seal
277.22	68.66	Top of Sand Pack
276.03	69.85	Top of Screen
266.33	79.55	Bottom of Screen
265.87	80.01	Bottom of Well
265.87	80.01	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)	72.38
Bottom of Screen to End Cap	(feet)	0.46
Screen Length (1st slot to last slot)	(feet)	9.70
Total Length of Casing	(feet)	82.54
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Massac County Well #: G53D

Site Name: Joppa Power Station Borehole #: G53D

State Plane Coordinate: X 833,980.2 Y 200,075.2 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Rhonald W. Hasenyager Date Started: 8/20/2015 Date Finished: 8/21/2015

Report Form Completed By: Suzanna L. Keim Date: 8/28/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 65 minutes

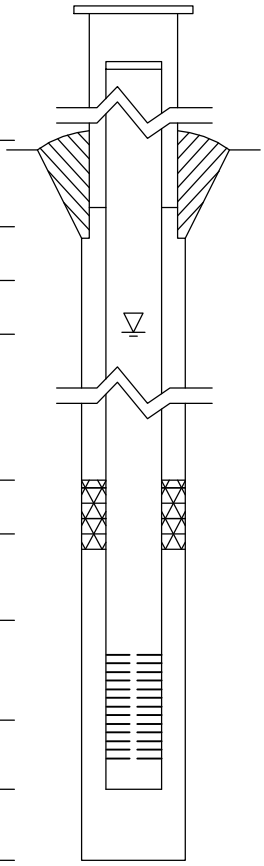
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Formation (if applicable)

Installation Method: Drilling



	Elevations (MSL)*	Depths (BGS) (0.01 ft.)
Top of Protective Casing	355.82	-3.66
Top of Riser Pipe	355.47	-3.31
Ground Surface	352.16	0.00
Top of Annular Sealant	350.16	2.00
Static Water Level (After Completion) 10/6/2015	309.91	42.25
Top of Seal	309.77	42.39
Top of Sand Pack	307.85	44.31
Top of Screen	304.87	47.29
Bottom of Screen	295.27	56.89
Bottom of Well	294.83	57.33
Bottom of Borehole	294.16	58.00

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (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)	50.60
Bottom of Screen to End Cap	(feet)	0.44
Screen Length (1st slot to last slot)	(feet)	9.60
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: Massac County Well #: G54D

Site Name: Joppa Power Station Borehole #: G54D

State Plane Coordinate: X 831,610.4 Y 199,066.8 (or) Latitude: _____ Longitude: _____

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): Water

Logged By: Suzanna L. Keim Date Started: 8/11/2015 Date Finished: 8/11/2015

Report Form Completed By: Suzanna L. Keim Date: 8/18/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: >48 hours

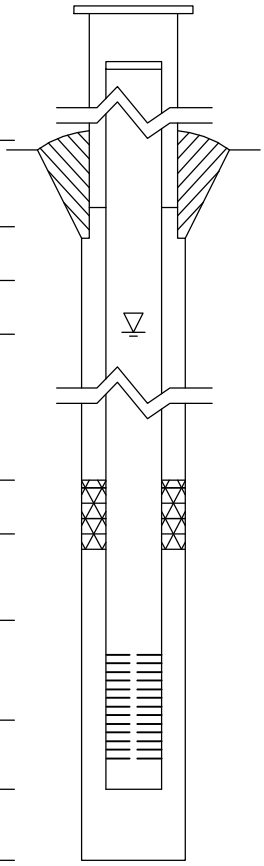
Type of Sand Pack: Quartz Sand

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.)
357.39	-3.68	Top of Protective Casing
357.03	-3.32	Top of Riser Pipe
353.71	0.00	Ground Surface
351.71	2.00	Top of Annular Sealant
304.50	49.21	Static Water Level (After Completion) 10/5/2015
286.76	66.95	Top of Seal
285.71	68.00	Top of Sand Pack
283.75	69.96	Top of Screen
274.05	79.66	Bottom of Screen
273.57	80.14	Bottom of Well
273.57	80.14	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)	73.28
Bottom of Screen to End Cap	(feet)	0.48
Screen Length (1st slot to last slot)	(feet)	9.70
Total Length of Casing	(feet)	83.46
Screen Slot Size **	(inches)	0.010

Well Completion Form (revised 02/06/02)

**Hand-Slotted Well Screens Are Unacceptable

AECOM BORING LOGS AND WELL CONSTRUCTION LOGS

Q:\Projects\DOE\0 Projects\Dynegy\Joppa\09_Data\GIS\Maps\Joppa_Boring_Locations • North.mxd

Legend

- AECOM Boring Location
- AECOM CPT Location

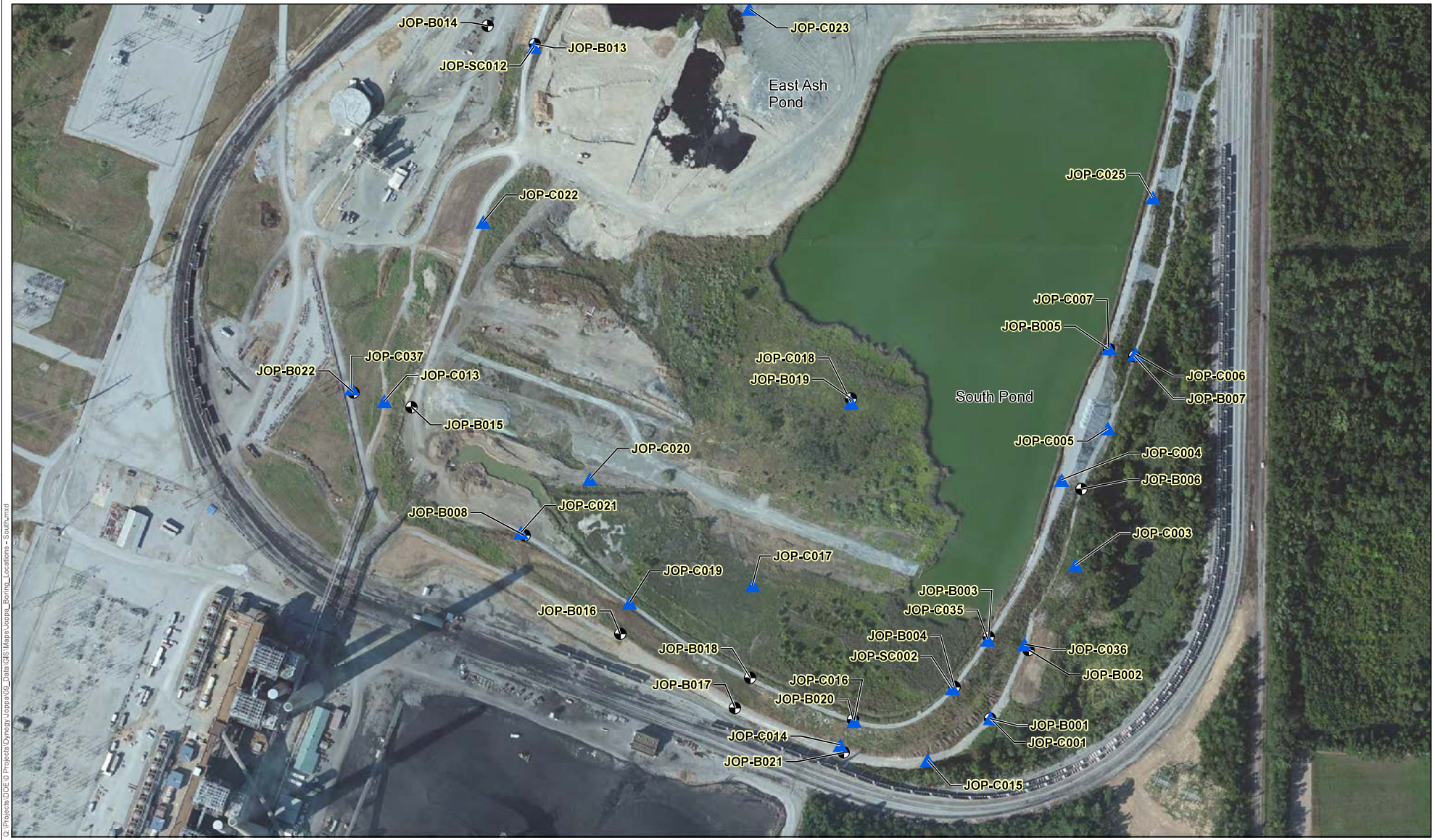
250 0 250 500 Feet

Figure D-01
Exploration Locations - North Pond
Joppa Power Station
Massac County, Illinois

DYNEGY

AECOM

R000898



Legend

- AECOM Boring Location
- AECOM CPT Location

N
W E
S

250 0 250 500 Feet

DYNEGY

Figure D-01
Exploration Locations - South Pond
Joppa Power Station
Massac County, Illinois

AECOM

R000899

Q:\Projects\DOE10 Projects\Dynegy\Joppa\09_Data\GIS\Maps\Joppa_Boring_Locations - South.mxd

Project: Dynegy

Project Location: Joppa Energy Complex, Massac County, IL

Project Number: 60428794

Log of Boring JOP-B019

Sheet 1 of 3

Date(s) Drilled	08/08/2015 10:00 AM to 08/08/2015 4:10 PM	Logged By	Gabriel Cuestas	Checked By	David Pieczynski
Drilling Method	HSA/Mud rotary	Drill Bit Size/Type	4 3/4 in HSA	Borehole Depth	100.0 ft
Drill Rig Type	CME 75 truck-mounted	Drilling Contractor	Geotechnology, Inc.	Surface Elevation	376.091 ft NAVD88
Borehole Backfill	Bentonite/Grout with vibrating wire piezometer	Sampling Method(s)	SPT, Shelby Tube	Hammer Data	Standard Auto 140 lbs, 30" drop
Boring Location	N 199211.282 E 832989.788 (ft NAD83)	Groundwater Level(s)	3.2 ft on 10/2/2015		

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) 376.1 / Depth (feet) 0.0								
375	0					[ASH] Sandy SILT to Silt (ML), very loose, gray to dark gray, wet, non-plastic								*Begin 8/8/15 @ 10:44 AM*
		S-1	1 0 1	100										*P200 = 51.4*
370	5													*Observed water*
		ST-1		11										*P200 = 94.5*
365	10													
		S-2	0 1 1	100										
360	15													
		S-3	WFR	100										
355	20													
		S-4	WFR	100										*Switch to mud rotary* *Vibrating wire piezometer installed at 25' on 8/8/2015 (Serial number 1520846)*
350	25													
		S-5	WFR	100										*P200 = 97.6*
	30													

Report: GEO_SOIL; File Q:\PROJECTS\DOE\0 PROJECTS\DYNEGY\JOPPA\05_ANALYSIS AND ENGINEERING\FIELD INVESTIGATION\BORING LOGS\DYNEGY_2015_GINT\DYNEGY_2015-12012015.GPJ; 12/29/2015 4:37:27 PM

Project: Dynegy

Project Location: Joppa Energy Complex, Massac County, IL

Project Number: 60428794

Log of Boring JOP-B019

Sheet 2 of 3

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
345	30													
	35	S-6		0										*Sample fell out of tube, recovered with split spoon*
340														
	40	S-7	WFR	100										*P200 = 70.8*
335														
	45	ST-2		50										
330														
	50	S-8	WFR	100		325.6 / 50.5 [FOUNDATION] Sandy Lean CLAY (CL), stiff, yellow, wet								
325														
	55	S-9	10 5 4	100										*Driller reports drilling getting harder* *P200 = 64.2*
320		S-10												*Sample fell out of tube at surface. Bagged and labeled*
	60	S-11	2 3 4	33										*P200 = 61.1*
315		ST-3		75		vibrant orange, moist/saturated, medium sand								
	65	S-12	10 15 20			312.1 / 64.0 Silty SAND (SM), dense, gray, wet								

Report: GEO_SOIL; File Q:\PROJECTS\DOE\0 PROJECTS\DYNEGY\JOPPA\05_ANALYSIS AND ENGINEERING\FIELD INVESTIGATION\BORING LOGS\DYNEGY_2015_GINT\DYNEGY_2015-12012015.GPJ; 12/29/2015 4:37:27 PM

Project: Dynegy

Project Location: Joppa Energy Complex, Massac County, IL

Project Number: 60428794

Log of Boring JOP-B019

Sheet 3 of 3

Depth (feet)	Elevation (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)								
70	310	S-13		15 19 17	28		304.1 / 72.0 Silty CLAY with Sand (CL-ML), stiff, gray, low to medium plasticity, fine sand, vertical orange stripping								
75	305	S-14		1 6 6	100										*P200 = 71.5*
80	300	S-15		17 28 21	56		299.1 / 77.0 Poorly-Graded SAND with Clay (SP-SC), very dense, yellow, medium to coarse sand, angular								
85	295	S-16		14 30 30	28										*End of Day 8/8/15 at 5:20 PM* *P200 = 7.6* *Begin 8/9/15 7:20 PM*
90	290	S-17		24 24 23	33										
95	285	S-18		11 10 11	33										
100	280	S-19		13 19 18	33		278.1 / 98.0 Poorly-Graded SAND with Gravel (SP), dense, burnt yellow/orange, angular 276.1 / 100.0								*End 8/9/15 at 9:10 AM*

End of Boring at 100 ft

AECOM

Report: GEO_SOIL; File Q:\PROJECTS\DOE\0 PROJECTS\DYNEGY\JOPPA\05_ANALYSIS AND ENGINEERING\FIELD INVESTIGATION\BORING LOGS\DYNEGY_2015_GINT\DYNEGY_2015-12012015.GPJ; 12/29/2015 4:37:27 PM

NATURAL RESOURCE TECHNOLOGY BORING LOGS AND WELL CONSTRUCTION LOGS

R000904

SOIL BORING LOG INFORMATION

NATURAL RESOURCE TECHNOLOGY

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Joppa Power Station (EEI)		G152B

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Matt Cooper Bulldog Drilling, Inc.	1/28/2013	1/30/2013	hollow stem auger

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
G152B	312.3 Feet (NAVD88)	345.2 Feet (NAVD88)	7.8 inches

Local Grid Origin ☒ (estimated: ☐) or Boring Location ☐
State Plane Illinois East Zone N, E S / C / N
1/4 of 1/4 of Section , T N, R
Lat ° ' "
Long ° ' "
Local Grid Location ☒ N ☒ E
198094.58 Feet ☐ S 832931.61 Feet ☐ W

Facility ID	County	State	Civil Town/City/ or Village
	Massac	Illinois	Joppa

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1	42 19		0 1 2 3	0 - 0.75' **SILTY CLAY** CL, disturbed with gravel, tree limbs, wood from clearing activities; dark brown, wet. 0.75 - 4.5' **SILTY CLAY** CL, light yellowish brown (10YR 6/4), high plasticity, very soft to soft, silty clay with organics (roots), soft, high plasticity, light yellowish brown (10YR 6/4), moist.	CL CL									PP 2 - 2.25
2	60 56		4 5 6 7	4' Silty Clay grading to a Clayey Silt, low plasticity, stiff, light gray (10YR 7/1), with 50% reddish brown mottling, moist. 4.5 - 12.5' **SILT:** ML, non plastic, stiff, very pale brown (10YR 8/2), dry. 7.3' soil horizon with small rootlets, 50% reddish brown mottling.					3.25 3 3 2					
3	60 58		8 9 10 11 12	7.5' very pale brown (10YR 8/2), non plastic, stiff, dry. 9' silt with clay, very stiff, non plastic, very pale brown (10YR 7/3) with 10-25% reddish brown mottling.	ML				1.75 4 3.5 2					

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature	Firm	
	Natural Resource Technology 23713 W. Paul Road Suite D, Pewaukee, WI 53072	Tel: (262) 523-9000 Fax: (262) 523-9001

SOIL BORING LOG INFORMATION SUPPLEMENT

NATURAL RESOURCE TECHNOLOGY

Boring Number G152B

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
									2					
			13	12.5 - 28.5' **SILTY CLAY** CL, medium to stiff, low to medium plasticity, light gray (10YR 7/1), with 50% mottling, moist.					2					
4	60 60		14	13.5' 10-50% reddish brown mottling.					2.5					
			15	15' light gray (10YR 7/1).					2.25					
			16						2.25					
			17						3.25					
			18	18' yellowish brown (10YR 6/8) mottling, moist.										PP 2.5 - 3.5
5	60 60		19	18.5' medium to stiff, medium to high plasticity, light gray (10YR 7/1), with 10-25% reddish brown mottling, moist.					2.25					
			20						2.5					
			21		CL				1.75					
			22						1.75					
			23						1.75					
6	60 60		24	23.5' medium to stiff, high plasticity, light gray (10YR 7/1), with 25-50% reddish brown mottling, moist.					2					
			25						1.5					
			26						1.5					
			27						2.5					
			28						2					
NR	12 0		29	28.5 - 29.5' CL.	CL									stopped sampling for the day (1/28/13), cleaned hole with augers to 29.5' resumed sampling on 1/30/2013
7	60 44		30	29.5 - 44.5' **SILTY CLAY** CL, stiff, medium to high plasticity, gray with >75% light yellowish brown (10YR 6/4) mottling, moist.					2.75					
			31		CL				3.25					
			32	31.5' 25-75% mottling.										

SOIL BORING LOG INFORMATION SUPPLEMENT

NATURAL RESOURCE TECHNOLOGY

Boring Number G152B

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	29.5 - 44.5' **SILTY CLAY** CL, stiff, medium to high plasticity, gray with >75% light yellowish brown (10YR 6/4) mottling, moist. *(continued)*					3.5					
				33' very stiff to hard, gray (10YR 6/1), with < 25% yellowish brown (10YR 6/8) mottling.					4.5					
			34						2.5					
8	60 57		35	34.5' stiff to very stiff, high plasticity.					3.5					
			36						2.5					
			37						4.25					
			38	38' hard, < 10% mottling.	CL				2.5					
			39											PP is >4.5
9	60 55		40	39.5' very stiff to hard, high plasticity, gray (10YR 6/1) with < 10% yellowish brown (10YR 5/6) mottling, moist.					3					
			41						3					
			42						3					
			43						4.5					
			44						3.75					
				44.5' End of Boring.										

R000907

NATURAL RESOURCE TECHNOLOGY

MONITORING WELL CONSTRUCTION

Facility/Project Name: Joppa Power Station (EEI)	Local Grid Location of Well: 198094.58 ft. ☒ N. ☐ S. 832931.61 ft. ☒ E. ☐ W.	Well Name: G152B
Facility License, Permit or Monitoring No.	Local Grid Origin ☒ (estimated: ☐) or Well Location ☐ Lat. ° ' " Long. ° ' " or St. Plane Illinois East Zone ft. N, ft. E. S / C / (N)	Date Well Installed: 01/30/2013
Facility ID	Section Location of Waste/Source: 1/4 of 1/4 of Sec. , T. N, R. ☐ E ☐ W	Well Installed By: (Person's Name and Firm): Matt Cooper, Kelron Environmental
Type of Well: Well Code 11/mw	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number
Distance from Waste/Source ft. / State: Illinois		

A. Protective pipe, top elevation ____ ft. (NAVD88)

B. Well casing, top elevation 347.48 ft. (NAVD88)

C. Land surface elevation 345.2 ft. (NAVD88)

D. Surface seal, bottom 344.2 ft. (NAVD88) or 1.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☒ Other ☐ ____

15. Drilling fluid used: Water ☐ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☒

16. Drilling additives used? ☒ Yes ☐

Describe N

17. Source of water (attach analysis, if required):
n/a

E. Bentonite seal, top 344.2 ft. (NAVD88) or 1.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 313.1 ft. (NAVD88) or 32.1 ft.

H. Screen joint, top 310.8 ft. (NAVD88) or 34.4 ft.

I. Well bottom 300.6 ft. (NAVD88) or 44.6 ft.

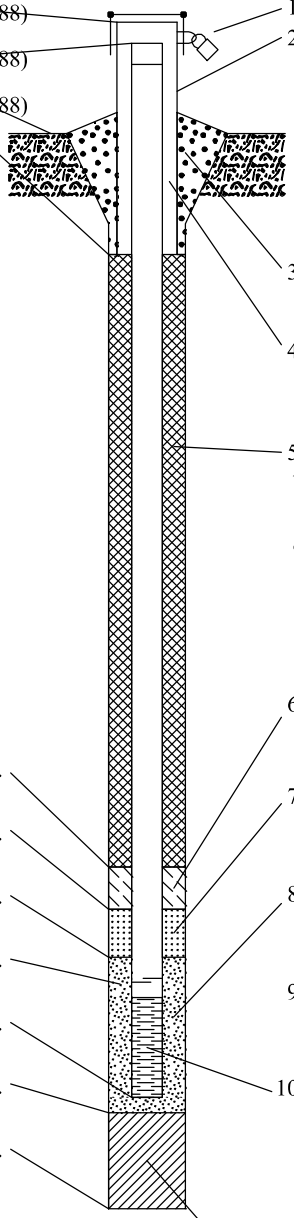
J. Filter pack, bottom 300.7 ft. (NAVD88) or 44.5 ft.

K. Borehole, bottom 300.7 ft. (NAVD88) or 44.5 ft.

L. Borehole, diameter 7.8 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



Casing depth (well bottom) is greater than borehole bottom because the bottom well cap was pushed into the soft material at the base of the borehole.

1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
a. Inside diameter: ____ in.
b. Length: ____ ft.
c. Material: Steel ☒ Other ☐ ____
d. Additional protection? ☐ Yes ☒ No
If yes, describe: ____
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐ ____
4. Material between well casing and protective pipe: Bentonite ☐ Other ☐ ____
5. Annular space seal: a. Granular/Chipped Bentonite ☒
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 14.5 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒
6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☐ 3/8 in. ☐ 1/2 in. Bentonite chips ☐
c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
a. ____
b. Volume added ____ ft^3
8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil Silica
b. Volume added 7 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐ ____
10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐ ____
b. Manufacturer ____
c. Slot size: 0.010 in.
d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☐ Other ☐ ____

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 2/19/2013

Signature | Firm: Natural Resource Technology, 23713 W. Paul Road Suite D, Pewaukee, WI 53072 | Tel: (262) 523-9000 Fax: (262) 523-9001

GEOTECHNOLOGY BORING LOGS AND WELL CONSTRUCTION LOGS

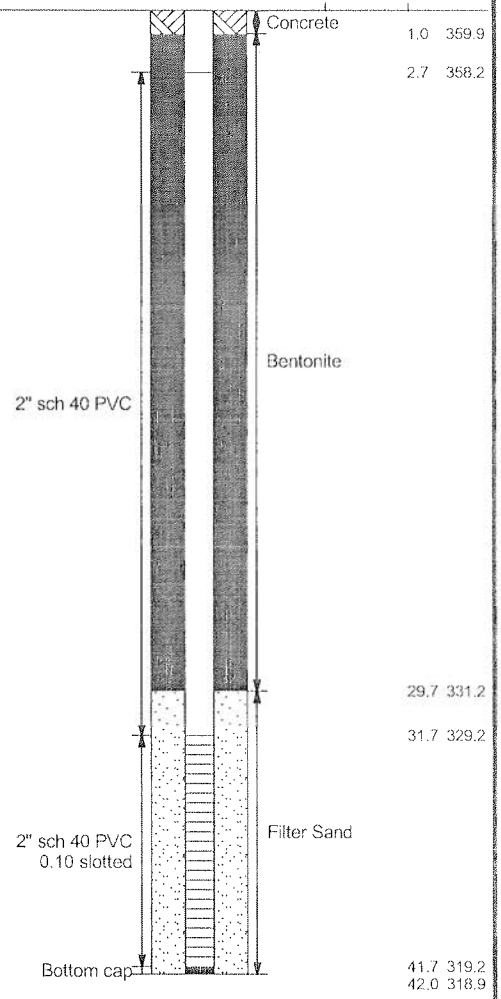
Surface Elevation: 360.9 | Completion Date: 6/19/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	GRAVEL			SS1
	Medium stiff to stiff, brown and gray, silty CLAY - (CL)		3-4-4-5	SS2
5			2-3-3-5	SS3
			3-3-4-4	SS4
	- k = 1.6 x 10^{-8}cm/s		1-2-3-5	SS5
10			3-5-5-6	SS6
			2-4-5-6	SS7
15			2-3-4-5	SS8
	Medium stiff to stiff, brown and gray, silty CLAY, trace sand - CL		3-4-6-7	SS9
			3-4-6-6	SS10
20			3-5-7-8	SS11
			3-5-7-9	SS12
25			2-3-5-6	SS13
			3-5-7-6	SS14
			3-5-8-8	SS15
30			4-7-9-4	SS16
			4-4-6-7	SS17
35			2-4-3-5	SS18
	Medium stiff to very stiff, brown and gray, sandy CLAY with silt - CL		5-5-7-14	SS19
			13-13-10 -8	SS20
40			2-4-6-7	SS21
	Boring terminated at 42 feet.			
45				
50				

WELL DIAGRAM

Flushmount



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 J017150.02ENV - EEI JOPPA.GPJ GTINC 063301.GPJ 9/22/10

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

___ AUGER ___ HOLLOW STEM

WASHBORING FROM ___ FEET

PH DRILLER BGF LOGGER

___ DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RJP	App'vd. by: RAP
Date: 7/14/10	Date: 9/20/10	Date: 9/20/10

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ash Pond Evaluation
EEI Facility
Joppa, Illinois

LOG OF BORING: G-151

Project No. J017150.02

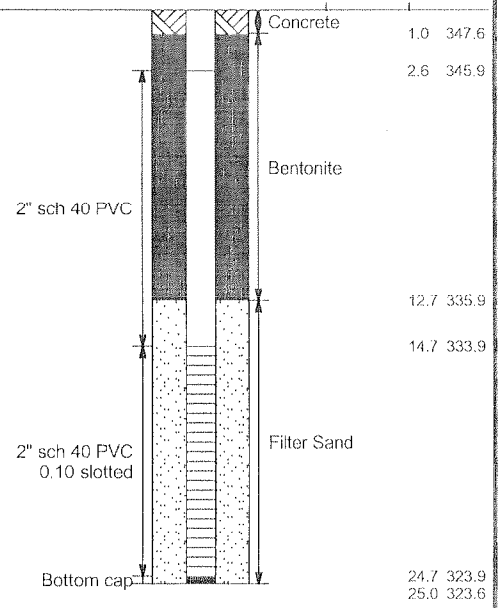
Surface Elevation: 348.56 | Completion Date: _____

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff, brown CLAY with organics - CH		2-3-3-4	SS1
	Medium stiff, brown and gray, silty CLAY - (CL)		1-1-2-3	SS2
5			1-2-3-5	SS3
			2-3-4-5	SS4
			1-3-4-4	SS5
10			2-3-5-5	SS6
	becoming stiff		2-5-8-9	SS7
15			2-5-3-6	SS8
			3-5-5-7	SS9
	trace sand to 25 feet		3-4-7-6	SS10
20	k = 1.1 x 10^{-8}cm/s ▽		3-6-10-9	SS11
			2-4-5-5	SS12
25	Boring terminated at 25 feet.			
30				
35				
40				
45				
50				

WELL DIAGRAM

Flushmount



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 J017150.02ENV - EEI JOPPA.GPJ GTINC 0638301.GPJ 9/22/10

GROUNDWATER DATA

ENCOUNTERED AT 20 FEET ▽

DRILLING DATA

___ AUGER ___ HOLLOW STEM

WASHBORING FROM ___ FEET

PH DRILLER BGF LOGGER

ATV DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: KBF	App'vd. by: KBF
Date: 7/14/10	Date: 9/20/10	Date: 9/20/10

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ash Pond Evaluation
EEI Facility
Joppa, Illinois

LOG OF BORING: G-152

Project No. J017150.02

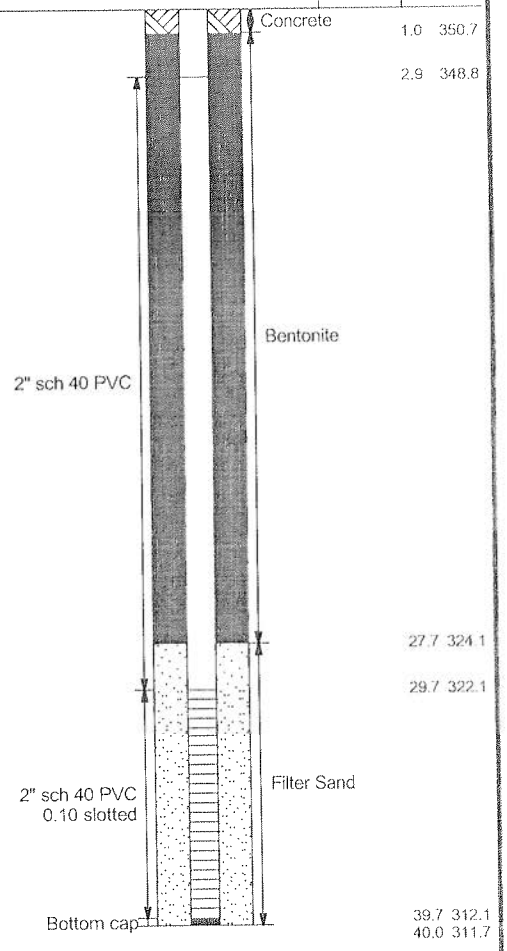
Surface Elevation: 351.73 | Completion Date: 6/18/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff, brown and gray CLAY - CH		2-2-3-4	SS1
	Soft, brown and gray CLAY - CH		1-1-2-1	SS2
5	Medium stiff to stiff, brown, silty CLAY, trace sand - (CL)		1-2-4-4	SS3
			2-4-4-5	SS4
10			2-3-6-6	SS5
			3-5-5-6	SS6
			1-4-4-8	SS7
15	k = 1.2 x 10^{-8}cm/s		2-4-5-8	SS8
			2-6-6-7	SS9
20			3-5-7-7	SS10
			2-5-7-8	SS11
			3-5-6-7	SS12
25			4-4-6-6	SS13
	Very stiff to stiff, brown, silty CLAY - CL		4-8-8-11	SS14
			3-4-7-9	SS15
30			4-6-8-10	SS16
	Stiff, brown, sandy CLAY with silt - CL		5-6-6-8	SS17
			3-4-6-8	SS18
35			5-5-7-7	SS19
	Stiff, brown clayey SILT - ML		2-3-6-7	SS20
40	Boring terminated at 40 feet.			
45				
50				

WELL DIAGRAM

Flushmount



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 J017150.02ENV - EEI JOPPA.GPJ GTINC 0638301.GPJ 9/22/10

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

___ AUGER ___ HOLLOW STEM

WASHBORING FROM ___ FEET

PH DRILLER BGF LOGGER

ATV DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: KGP	App'vd. by: KGP
Date: 7/14/10	Date: 9/20/10	Date: 9/20/10

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ash Pond Evaluation
EEI Facility
Joppa, Illinois

LOG OF BORING: G-153

Project No. J017150.02

APPENDIX C
GEOTECHNICAL LABORATORY REPORTS

GEOTECHNOLOGY INC
FROM THE GROUND UP

Via email: akreinberg@geosyntec.com

March 29, 2021

Ms. Allison Kreinberg
Geosyntec Consultants, Inc.
941 Chatham Lane Suite 103
Columbus, Ohio 43221

Re: Laboratory Testing Services
Vistra Energy
Joppa, Illinois
Geotechnology Project No. J037936.01

Dear Ms. Kreinberg:

Provided herein are the laboratory test results for the referenced project. Our services were performed in accordance with ASTM procedures.

This report has been prepared for the exclusive use of Geosyntec Consultants, Inc. Our scope of services was limited to performing specific tests on the provided samples and did not include engineering or interpretation of the test results.

Our services shall not be construed to constitute an expressed or implied warranty, including, but not limited to, any warranty for merchantability or fitness for a particular use. We do not accept responsibility for the manner in which the test results are used.

It has been our pleasure to provide laboratory testing services to you, and we would welcome the opportunity to provide other services during the course of the project. Please contact us if you need further information or clarification about this document.

* * * * *

Yours very truly,
GEOTECHNOLOGY, INC.

Erin Grimes
Laboratory Manager

EKG/CKK:ekg

Attachments: Appendix A – Summary of Laboratory Results
Appendix B – Atterberg Limits Results
Appendix C – Grain Size Distribution
Appendix D – Test Report

Copies submitted: PDF

APPENDIX A

Summary of Laboratory Results

Borehole	Depth	Liquid Limit	Plastic Limit	Plasticity Index	Maximum Size (mm)	%<#200 Sieve	Class-ification	Moisture Content (%)	Dry Unit Weight (pcf)	Qu/2 (tsf)	Specific Gravity (20°C)
G03	32.0	27	16	11	9.5	45.6	SC	15.5	113.0		2.659
G03	60.0				12.5	4.1	SP	20.0			2.671
G09M	16.0	39	16	23	2	95.0	CL	20.6	105.0		2.666
G09M	46.0	35	15	20	2	82.8	CL	19.8	106.0		2.715
G09M	84.0				9.5	1.9	SP	7.6	100.0		2.686
G09M	112.0				9.5	15.2		25.5	87.0		2.675
G11	24.0	36	15	21	2	88.5	CL	18.5	109.0		2.688
G11	56.0	NP	NP	NP	9.5	12.1	SM	14.4	110.0		2.661
XPW01	6.0	NP	NP	NP	25	28.3	SM	34.7	85.0		2.711
XPW01	48.0	25	20	5	2	81.3	CL-ML	31.7	88.0		2.675
XPW02	22.0	NP	NP	NP	12.5	16.6	SM	47.6	74.0		2.567
XPW03	22.0				2	95.8		45.4			2.410
XPW03	36.0	46	31	15	2	90.6	ML	46.5	66.0		1.999

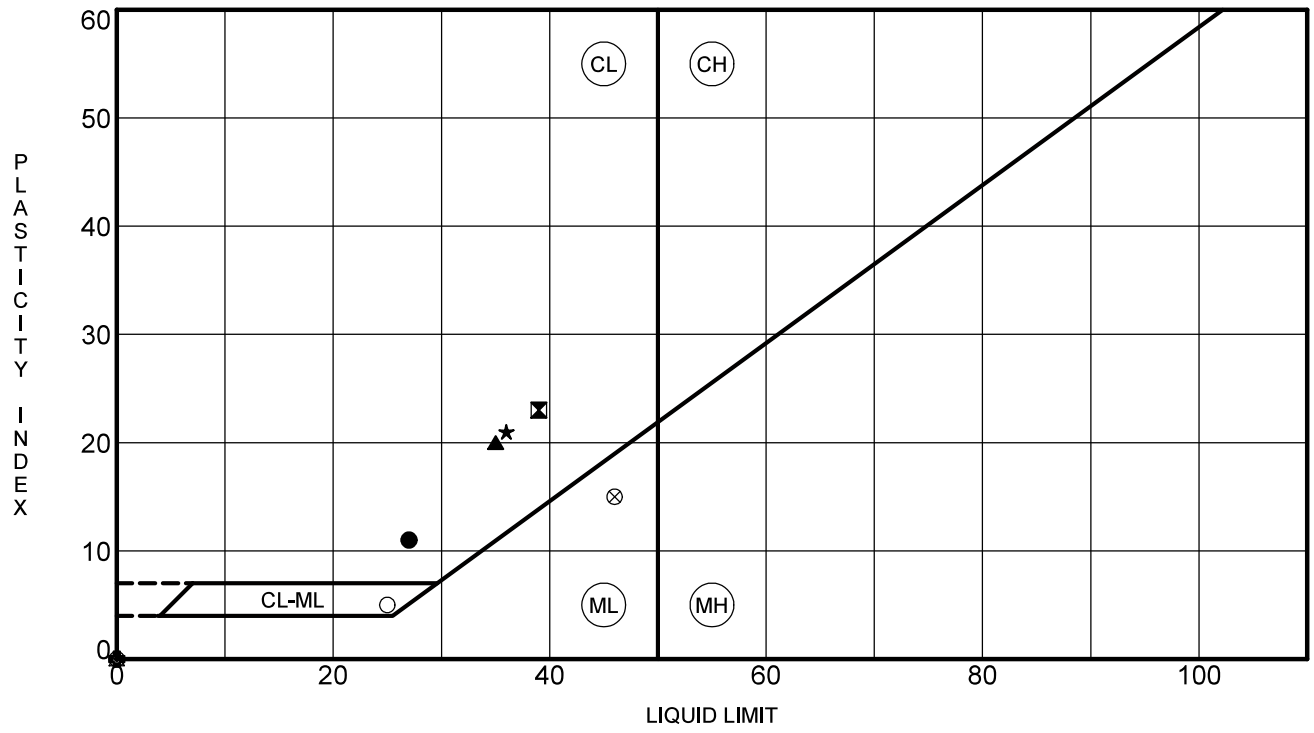
GEOTECHNOLOGY INC
FROM THE GROUND UP

Summary of Laboratory Results

Vistra Energy
Joppa, Illinois
J037936.01

APPENDIX B

Atterberg Limits Results



	Boring	Depth (ft.)	LL	PL	PI	Fines	Sample Description
●	G03	32.0	27	16	11	46	CLAYEY SAND(SC)
⧓	G09M	16.0	39	16	23	95	LEAN CLAY(CL)
▲	G09M	46.0	35	15	20	83	LEAN CLAY with SAND(CL)
★	G11	24.0	36	15	21	89	LEAN CLAY(CL)
⊙	G11	56.0	NP	NP	NP	12	SILTY SAND(SM)
✿	XPW01	6.0	NP	NP	NP	28	SILTY SAND with GRAVEL(SM)
○	XPW01	48.0	25	20	5	81	SILTY CLAY with SAND(CL-ML)
△	XPW02	22.0	NP	NP	NP	17	SILTY SAND(SM)
⊗	XPW03	36.0	46	31	15	91	SILT(ML)

GEOTECHNOLOGY INC
FROM THE GROUND UP

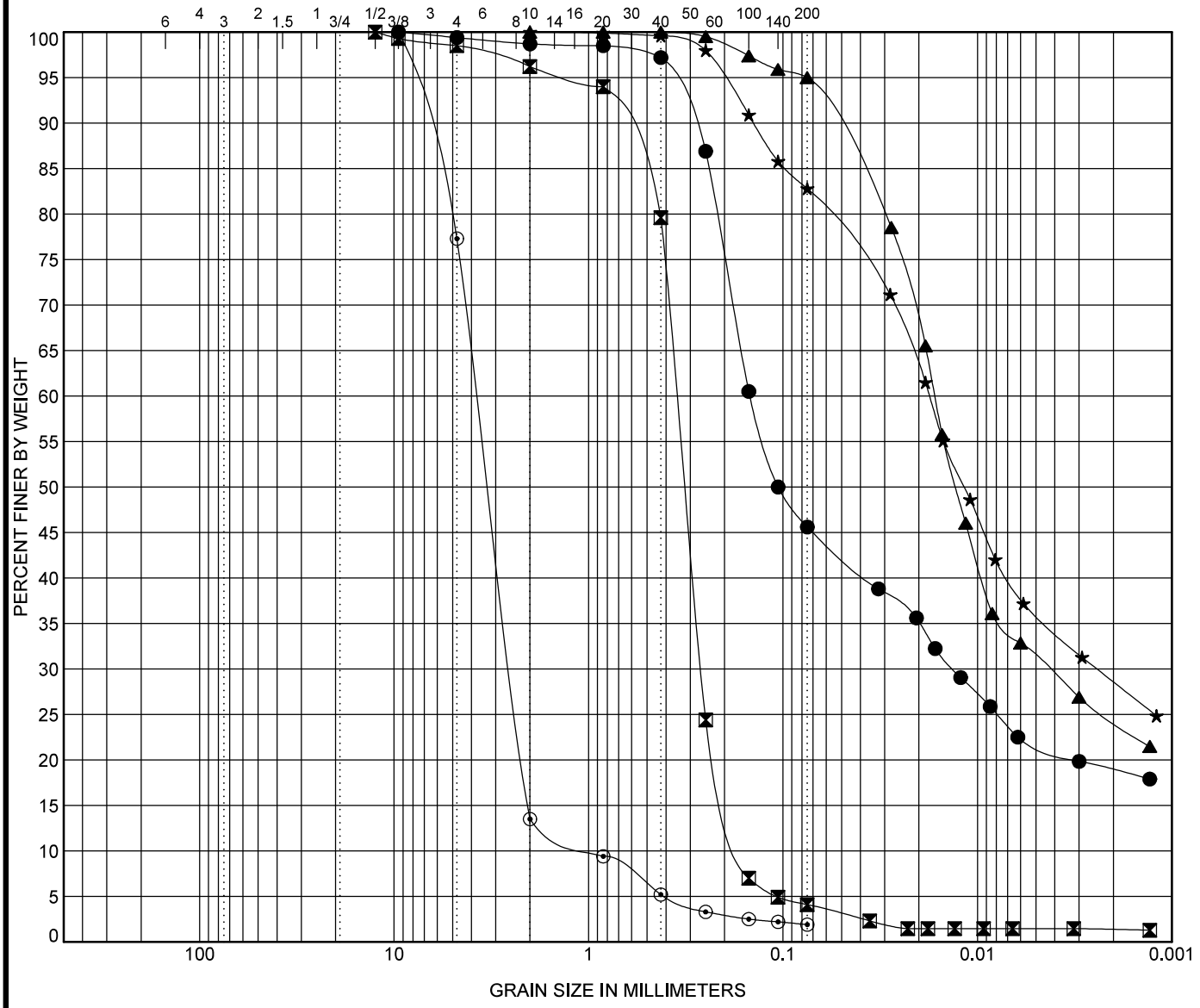
ATTERBERG LIMITS RESULTS

Vistra Energy
Joppa, Illinois
J037936.01

ATTERBERG LIMIT 2018 J037936.01 - VISTRA JOPPA.GPJ 00 CLONE ME.GPJ 3/25/21

APPENDIX C

Grain Size Distribution



	Boring	Depth (ft.)	Sample Description	LL	PL	PI	Cc	Cu
●	G03	32.0	CLAYEY SAND(SC)	27	16	11		
⊠	G03	60.0	POORLY GRADED SAND(SP)				1.21	2.15
▲	G09M	16.0	LEAN CLAY(CL)	39	16	23		
★	G09M	46.0	LEAN CLAY with SAND(CL)	35	15	20		
⊙	G09M	84.0	POORLY GRADED SAND with GRAVEL(SP)				1.75	3.94

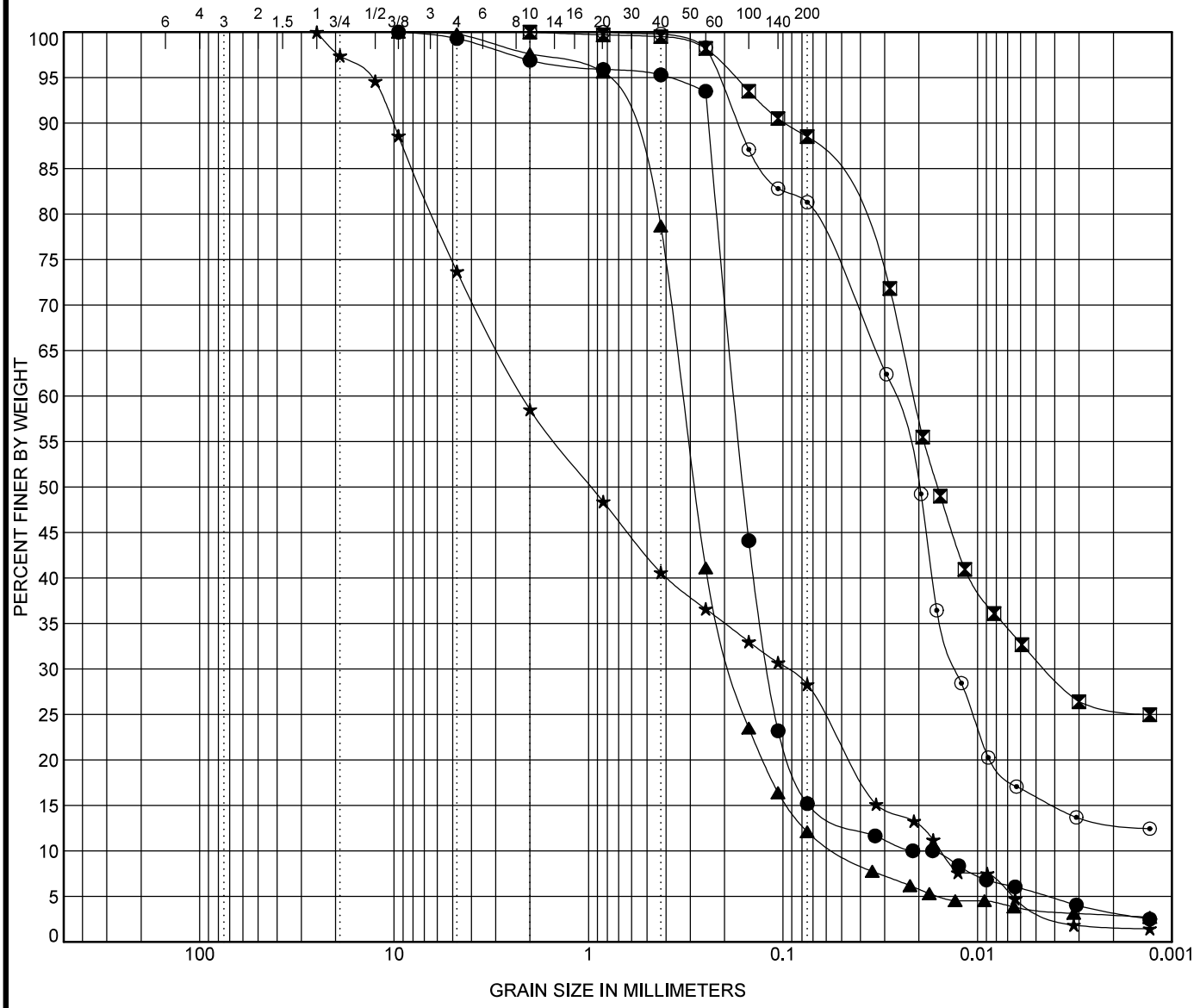
	Boring	Depth (ft.)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	G03	32.0	9.5	0.15	0.01		0.6	53.8	23.9	21.7
⊠	G03	60.0	12.5	0.35	0.26	0.164	1.5	94.4	2.6	1.5
▲	G09M	16.0	2	0.02	0		0.0	5.0	63.7	31.3
★	G09M	46.0	2	0.02	0		0.0	17.2	46.9	35.9
⊙	G09M	84.0	9.5	3.76	2.5	0.954	22.7	75.4	1.9	

GEOTECHNOLOGY INC
FROM THE GROUND UP

GRAIN SIZE DISTRIBUTION

Vistra Energy
Joppa, Illinois
J037936.01

GRAIN SIZE 2018 J037936.01 - VISTRA JOPPA.GPJ 00 CLONE ME.GPJ 3/25/21



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Boring	Depth (ft.)	Sample Description	LL	PL	PI	Cc	Cu
●	G09M	112.0					4.69	10.42
⊠	G11	24.0	LEAN CLAY(CL)	36	15	21		
▲	G11	56.0	SILTY SAND(SM)	NP	NP	NP	1.94	6.30
★	XPW01	6.0	SILTY SAND with GRAVEL(SM)	NP	NP	NP	0.28	142.34
⊙	XPW01	48.0	SILTY CLAY with SAND(CL-ML)	25	20	5		

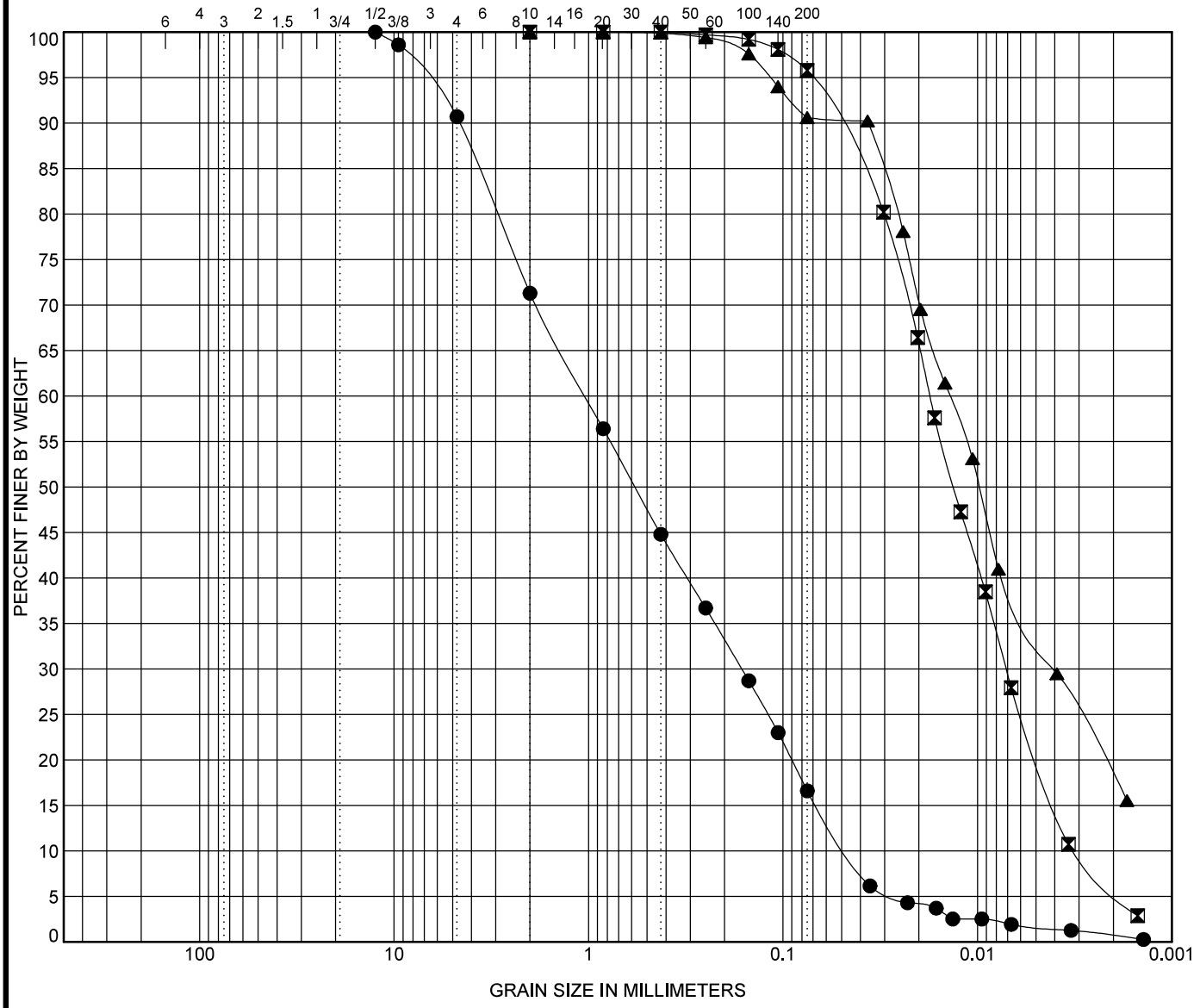
	Boring	Depth (ft.)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	G09M	112.0	9.5	0.18	0.12	0.017	0.7	84.1	9.8	5.4
⊠	G11	24.0	2	0.02	0		0.0	11.5	57.4	31.1
▲	G11	56.0	9.5	0.33	0.18	0.052	0.2	87.7	8.5	3.6
★	XPW01	6.0	25	2.18	0.1	0.015	26.3	45.4	24.6	3.7
⊙	XPW01	48.0	2	0.03	0.01		0.0	18.7	65.3	16.0

GEOTECHNOLOGY INC
FROM THE GROUND UP

GRAIN SIZE DISTRIBUTION

Vistra Energy
Joppa, Illinois
J037936.01

GRAIN SIZE 2018 J037936.01 - VISTRA JOPPA.GPJ 00 CLONE ME.GPJ 3/25/21



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Boring	Depth (ft.)	Sample Description	LL	PL	PI	Cc	Cu
●	XPW02	22.0	SILTY SAND(SM)	NP	NP	NP	0.55	22.08
⊠	XPW03	22.0					0.91	5.56
▲	XPW03	36.0	SILT(ML)	46	31	15		

	Boring	Depth (ft.)	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	XPW02	22.0	12.5	1.04	0.16	0.047	9.3	74.1	15.0	1.6
⊠	XPW03	22.0	2	0.02	0.01	0.003	0.0	4.2	75.3	20.5
▲	XPW03	36.0	2	0.01	0		0.0	9.4	57.0	33.6

GEOTECHNOLOGY INC
FROM THE GROUND UP

GRAIN SIZE DISTRIBUTION

Vistra Energy
Joppa, Illinois
J037936.01

GRAIN SIZE 2018 J037936.01 - VISTRA JOPPA.GPJ 00 CLONE ME.GPJ 3/25/21

APPENDIX D

Test Report

Geotechnology, Inc.
11816 Lackland Road, Suite 150
St. Louis, MO 63146
314-997-7440

TEST REPORT

Prepared For:
Geosyntec Consultants, Inc.
941 Chatham Lane Suite 103
Columbus, Ohio 43221

Project No.:	**J037936.01**	**March 29, 2021**
Project Name:	**Vistra Energy - Joppa**	**Page 1 of 1**
Sampled By:	**Geotechnology, Inc.**	
Attention:	**Ms. Allison Kreinberg**	

HYDRAULIC CONDUCTIVITY (PERMEABILITY) TEST & DENSITY DETERMINATION (UNIT WEIGHT) ASTM D5084 & D7263

Sample #	Moisture Content (%)	Initial Wet Density (pcf)	Initial Dry Density (pcf)	Hydraulic Conductivity (cm/s)
G03-(32-34)	15.5	130.2	112.7	4.7×10^{-7}
G09M-(16-18)	20.6	127.1	105.4	8.3×10^{-8}
G09M-(46-48)	19.8	126.6	105.7	3.5×10^{-7}
G11-(24-26)	18.5	129.4	109.1	5.6×10^{-8}
XPW01-(6-8)*	34.2	114.8	85.6	2.1×10^{-5}
XPW01-(48-50)	31.7	115.5	87.7	2.8×10^{-7}
XPW03-(36-38)	46.5	96.3	65.7	1.8×10^{-7}

* Remolded sample.

APPENDIX D
INFORMATION PERTINENT TO 35 I.A.C. § 845.220(a)(3)

TABLES

Table A-1. Surrounding Surface Water Bodies

Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

HUC	Surface Water ID	Distance from Unit (m)	Physical Orientation to Unit	Hydraulic Orientation to Unit	Classification Code	Size (acres)	Notes
05140206	Riverine 1	0	SSE	Downgradient	R4SBC	0.29	
05140206	Freshwater Pond 1	0	SE	Downgradient	PUSCx	12.94	
05140206	Lake 1	0	NNE	Upgradient	L1UBHx	16.33	
05140206	Riverine 2	0	SSE	Downgradient	R5UBH	0.22	
05140206	Lake 2	0	NNW	Upgradient	L2USCx	34.52	
05140206	Riverine 3	0	ENE	Sidegradient	R5UBH	0.04	
05140206	Riverine 4	0	NNE	Upgradient	R5UBH	0.13	
05140206	Riverine 5	2	NE	Upgradient	R4SBC	5.43	
05140206	Freshwater Emergent Wetland 1	20	SE	Downgradient	PEM1Cx	1.20	
05140206	Freshwater Pond 2	40	SSE	Downgradient	PUBGx	1.41	
05140206	Freshwater Emergent Wetland 2	48	SSE	Downgradient	PEM1Cx	1.18	
05140206	Freshwater Forested/Shrub Wetland 1	97	N	Upgradient	PFO1A	6.04	
05140206	Freshwater Pond 3	105	N	Upgradient	PUBGh	2.70	
05140206	Freshwater Forested/Shrub Wetland 2	122	S	Downgradient	PSS1C	5.22	
05140206	Riverine 6	183	S	Downgradient	R4SBC	0.42	
05140206	Freshwater Forested/Shrub Wetland 3	281	S	Downgradient	PFO1A	9.86	
05140206	Riverine 7	296	WSW	Sidegradient	R4SBC	1.81	
05140206	Freshwater Emergent Wetland 3	317	NW	Sidegradient	PEM1A	7.39	
05140206	Riverine 8	342	SE	Downgradient	R5UBH	0.06	
05140206	Riverine 9	351	SSE	Downgradient	R4SBC	1.53	
05140206	Freshwater Pond 4	393	WNW	Sidegradient	PUSCx	22.54	
05140206	Freshwater Pond 5	402	E	Sidegradient	PUBGx	0.24	
05140206	Freshwater Pond 6	431	NNW	Upgradient	PUBGx	0.22	
05140206	Riverine 10	453	S	Downgradient	R4SBC	0.11	
05140206	Freshwater Pond 7	456	NNW	Upgradient	PUBGx	0.27	
05140206	Freshwater Pond 8	476	NE	Upgradient	PUBGh	0.95	
05140206	Freshwater Pond 9	481	NNW	Upgradient	PUBGx	0.24	
05140206	Freshwater Pond 10	490	SSW	Downgradient	PUBGx	4.22	
05140206	Riverine 11	498	S	Downgradient	R4SBC	0.15	
05140206	Freshwater Pond 11	506	NW	Upgradient	PUBGh	1.88	
05140206	Freshwater Pond 12	534	NNW	Upgradient	PUBGx	0.21	
05140206	Riverine 12	556	S	Downgradient	R4SBC	0.14	
05140206	Freshwater Pond 13	562	NW	Sidegradient	PUBGx	1.66	
05140206	Freshwater Pond 14	565	NNW	Upgradient	PUBGx	0.22	
05140206	Freshwater Pond 15	571	WSW	Sidegradient	PUBGx	0.55	
05140206	Freshwater Pond 16	574	E	Sidegradient	PUBGx	0.29	
05140206	Freshwater Pond 17	575	NW	Upgradient	PUBGh	2.33	
05140206	Riverine 13 (Ohio River)	601	S	Downgradient	R2UBH	26072.13	
05140206	Freshwater Forested/Shrub Wetland 4	601	S	Downgradient	PFO1Ah	18.54	
05140206	Freshwater Emergent Wetland 4	612	WSW	Sidegradient	PEM1Cx	4.35	
05140206	Freshwater Forested/Shrub Wetland 5	621	NNW	Upgradient	PSS1C	4.71	
05140206	Freshwater Pond 18	625	ESE	Sidegradient	PUBGh	0.26	
05140206	Freshwater Forested/Shrub Wetland 6	626	WSW	Sidegradient	PFO1Ch	4.83	

R0000927

Table A-1. Surrounding Surface Water Bodies

Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

HUC	Surface Water ID	Distance from Unit (m)	Physical Orientation to Unit	Hydraulic Orientation to Unit	Classification Code	Size (acres)	Notes
05140206	Freshwater Pond 19	630	N	Upgradient	PUBGh	1.30	
05140206	Freshwater Pond 20	633	ENE	Sidegradient	PUBGx	1.43	
05140206	Riverine 14	636	ESE	Sidegradient	R4SBC	0.53	
05140206	Freshwater Pond 21	644	NNE	Upgradient	PUBGh	0.24	
05140206	Freshwater Pond 22	648	WSW	Sidegradient	PUBGx	1.85	
05140206	Riverine 15	660	E	Sidegradient	R4SBC	1.52	
05140206	Freshwater Pond 23	685	ENE	Sidegradient	PUBGx	0.72	
05140206	Freshwater Emergent Wetland 5	713	SE	Sidegradient	PEM1A	2.54	
05140206	Freshwater Pond 24	740	NE	Upgradient	PUBGh	1.99	
05140206	Riverine 16	766	SE	Sidegradient	R4SBC	0.08	
05140206	Freshwater Emergent Wetland 6	818	NE	Sidegradient	PEM1F	0.26	
05140206	Riverine 17	858	ESE	Sidegradient	R4SBC	0.05	
05140206	Freshwater Forested/Shrub Wetland 7	924	ESE	Sidegradient	PFO1A	9.16	
05140206	Freshwater Emergent Wetland 7	988	WSW	Sidegradient	PEM1Ch	5.10	

Notes:

List of wetlands and water bodies obtained from the US Fish and Wildlife Service. Distance and direction were calculated by Geosyntec.
Based on groundwater elevation contour maps in the vicinity of the EAP from 2015 to 2020, groundwater predominantly flows to the south, towards the Ohio River (Ramboll, 2020).
Distance and direction from EAP were calculated by Geosyntec.
Wetlands and surface water features located within 1,000 meters of the Joppa EAP are included in this table.
Watershed codes are provided as HUC8
m = meter/meters
EAP = East Ash Pond
HUC = Hydrologic Unit Code
E = east
ENE = east-northeast
ESE = east-southeast
N = north
NE = northeast
NNE = north-northeast
NNW = north-northwest
NW = northwest
S = south
SE = southeast
SSE = south-southeast
SSW = south-southwest
W = west
WNW = west-northwest
WSW = west-southwest

R000928

Table A-2. Surrounding Wells

Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

Well Number	Date Constructed	Ground Elevation (ft NAVD88/ GEOID 12A)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft NAVD88/ GEOID 12A)	Screen Bottom Elevation (ft NAVD88/ GEOID 12A)	Bottom of Boring Elevation (ft NAVD88/ GEOID 12A)	Screen Length (ft)	Screen Diameter (inches)	Well Depth from Ground Surface (ft bgs)
121270005000	12/31/1950	--	--	--	--	--	--	--	--	350
121270003100	3/31/1941	340	--	--	--	--	184	--	--	156
121270005300	12/31/1950	348	--	--	--	--	113	--	--	235
121270003000	12/31/1940	--	--	--	--	--	--	--	--	153
121270015800	6/30/1971	--	--	--	--	--	--	--	--	160
121270005100	12/31/1950	355	--	--	--	--	-48	--	--	403
121270000100	6/30/1955	--	--	--	--	--	--	--	--	304
121270011100	8/20/1969	--	58	78	--	--	--	20	--	78
121272067500	10/8/1994	--	85	94	--	--	--	9	--	94
121270005200	3/31/1940	340	--	--	--	--	202	--	--	138
121270005400	5/31/1940	340	--	--	--	--	203	--	--	137
121272106100	--	--	89	92	--	--	--	3	--	92
121272094200	--	--	0	0	--	--	--	--	--	90
121270005500	12/31/1940	340	--	--	--	--	275	--	--	65
121270014600	--	--	0	0	--	--	--	--	--	150
121272103000	3/29/2000	--	175	200	--	--	--	25	--	202
121272103900	2/28/2000	380	228	238	152	142	142	10	--	238

Notes:

Water well information obtained from the Illinois Geological Survey (ISGS) Illinois Water Wells (ILWATER) database.
Based on groundwater elevation contour maps in the vicinity of the EAP from 2015 to 2020, groundwater predominantly flows to the south, towards the Ohio River (Ramboll, 2020).
Distance and direction from EAP were calculated by Geosyntec.
Wells located within 1,000 meters of the Joppa EAP are included in this table.
bgs = below ground surface
EAP = East Ash Pond
D = downgradient
DD = decimal degrees
m = meter/meters
S= Source water (Porewater or Pond water)
Sd= Sidegradient
U = upgradient
-- = information not available

R000929

Table A-2. Surrounding Wells

Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

Well Number	Total Boring Depth (ft BGS)	State Planar Northing - Y (NAD83/ East Zone)	State Planar Easting - X (NAD 83/ East Zone)	Latitude (DD)	Longitude (DD)	X, Y Survey Date	Hydraulic Position Designation (B/Sd/U/D/P)	Distance From Unit (m)
121270005000	350	832181.9016	198703.512	37.211275	-88.855516	--	D	31
121270003100	156	834193.2389	199582.7676	37.21372	-88.848626	--	Sd	135
121270005300	235	831120.9491	198963.8992	37.211974	-88.859164	--	Sd	172
121270003000	153	834531.0745	199909.0024	37.214621	-88.847472	--	Sd	202
121270015800	160	834566.0707	201903.8157	37.2201	-88.847389	--	U	265
121270005100	403	834758.5822	199868.0796	37.214512	-88.84669	--	Sd	272
121270000100	304	831780.3209	197864.2513	37.208964	-88.856879	--	D	311
121270011100	78	834190.3525	202959.6159	37.222994	-88.848699	--	U	336
121272067500	94	833923.7478	203248.3576	37.223783	-88.84962	--	U	382
121270005200	138	835331.0223	198557.073	37.21092	-88.8447	--	Sd	559
121270005400	137	833533.3056	196430.9199	37.205054	-88.850833	--	D	586
121272106100	92	835895.5226	201878.7907	37.220051	-88.842823	--	Sd	646
121272094200	90	834126.7172	196134.2069	37.204248	-88.84879	--	D	733
121270005500	65	834126.7172	196134.2069	37.204248	-88.84879	--	D	733
121270014600	150	836570.23	202533.8594	37.22186	-88.840518	--	Sd	906
121272103000	202	831277.4113	203965.296	37.225712	-88.858722	--	U	912
121272103900	238	829190.2249	201364.3963	37.218537	-88.86584	--	Sd	971

Notes:

Water well information obtained from the Illinois Geological Survey (ISGS) Illinois Water Wells (ILWATER) database.
Based on groundwater elevation contour maps in the vicinity of the EAP from 2015 to 2020, groundwater predominantly flows to the south, towards the Ohio River (Ramboll, 2020).
Distance and direction from EAP were calculated by Geosyntec.
Wells located within 1,000 meters of the Joppa EAP are included in this table.
bgs = below ground surface
EAP = East Ash Pond
D = downgradient
DD = decimal degrees
m = meter/meters
S= Source water (Porewater or Pond water)
Sd= Sidegradient
U = upgradient
-- = information not available

R000930

Table A-3 Threatened and Endangered Species

Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

Scientific Name	Common Name	Status	Distance from Unit (m)	Physical Orientation to Unit	Hydraulic Orientation to Unit	Occurences	Last Observed	Notes
Actaea rubifolia	Black Cohosh	LE	--	--	--	1	August 2013	Habitat identified at the county level only
Amorpha nitens	Smooth False Indigo	LE	--	--	--	1	June 2004	Habitat identified at the county level only
Asio flammeus	Short-eared Owl	LE	--	--	--	1	December 2005	Habitat identified at the county level only
Carex gigantea	Large Sedge	LE	--	--	--	2	June 2018	Habitat identified at the county level only
Carex intumescens	Swollen Sedge	LE	--	--	--	1	July 2018	Habitat identified at the county level only
Carex reniformis	Sedge	LE	--	--	--	3	June 2010	Habitat identified at the county level only
Carya aquatica	Water Hickory	LT	--	--	--	4	July 1905	Habitat identified at the county level only
Chamaelirium luteum	Fairy Wand	LE	--	--	--	2	June 2015	Habitat identified at the county level only
Cryptobranchus alleganiensis	Hellbender	LE	--	--	--	1	April 1956	Habitat identified at the county level only
Cyclonaias tuberculata	Purple Wartyback	LT	--	--	--	2	October 2016	Habitat identified at the county level only
Cyperus lancastriensis	Galingale	LT	--	--	--	1	October 2005	Habitat identified at the county level only
Ellipsaria lineolata	Butterfly	LT	--	--	--	4	November 2018	Habitat identified at the county level only
Elliptio crassidens	Elephant-ear	LE	--	--	--	3	November 2018	Habitat identified at the county level only
Eryngium prostratum	Eryngo	LE	--	--	--	1	August 2002	Habitat identified at the county level only
Euonymus americanus	American Strawberry Bush	LT	--	--	--	2	August 2013	Habitat identified at the county level only
Eurynia dilatata	Spike	LE	--	--	--	1	September 2014	Habitat identified at the county level only
Faxonius placidus	Bigclaw Crayfish	LE	--	--	--	3	July 2001	Habitat identified at the county level only
Galactia mohlenbrockii	Boykin's Dioclea	LE	--	--	--	2	July 1905	Habitat identified at the county level only
Gallinula galeata	Common Gallinule	LE	--	--	--	1	July 2013	Habitat identified at the county level only
Halesia carolina	Silverbell Tree	LE	--	--	--	2	April 2016	Habitat identified at the county level only
Helianthus angustifolius	Narrow-leaved Sunflower	LE	--	--	--	4	October 2015	Habitat identified at the county level only
Hyla avivoca	Bird-voiced Treefrog	LT	--	--	--	1	September 2019	Habitat identified at the county level only
Iresine rhizomatosa	Bloodleaf	LE	--	--	--	1	June 1905	Habitat identified at the county level only
Ixobrychus exilis	Least Bittern	LT	--	--	--	1	June 2005	Habitat identified at the county level only
Lanius ludovicianus	Loggerhead Shrike	LE	--	--	--	1	June 1986	Habitat identified at the county level only
Lepomis miniatus	Redspotted Sunfish	LT	--	--	--	2	July 1987	Habitat identified at the county level only
Malus angustifolia	Narrow-leaved Crabapple	LE	--	--	--	1	June 2019	Habitat identified at the county level only
Margaritifera monodonta	Spectaclecase	LE	--	--	--	1	August 1994	Habitat identified at the county level only
Melanthera nivea	White Melanthera	LE	--	--	--	1	October 2005	Habitat identified at the county level only
Melica mutica	Two-flowered Melic Grass	LE	--	--	--	3	April 2016	Habitat identified at the county level only
Melothria pendula	Squirting Cucumber	LT	--	--	--	1	May 2004	Habitat identified at the county level only
Myotis austroriparius	Southeastern Myotis	LE	--	--	--	1	June 2005	Habitat identified at the county level only
Myotis septentrionalis	Northern Long-eared Myotis	LT	--	--	--	1	July 2005	Habitat identified at the county level only
Nemophila triloba	Baby blue-eyes	LE	--	--	--	1	April 2010	Habitat identified at the county level only
Nerodia fasciata	Southern Watersnake	LE	--	--	--	1	March 2004	Habitat identified at the county level only
Notropis maculatus	Taillight Shiner	LE	--	--	--	1	July 1988	Habitat identified at the county level only
Noturus stigmosus	Northern Madtom	LE	--	--	--	1	2009-07	Habitat identified at the county level only
Nyctanassa violacea	Yellow-crowned Night-Heron	LE	--	--	--	1	July 1998	Habitat identified at the county level only
Pandion haliaetus	Osprey	LT	--	--	--	5	July 1905	Habitat identified at the county level only
Phaeophyscia leana	Lea's Bog Lichen	LT	--	--	--	2	February 2002	Habitat identified at the county level only
Phemeranthus parviflorus	Small Flower-of-an-hour	LT	--	--	--	1	May 1952	Habitat identified at the county level only
Planera aquatica	Water Elm	LT	--	--	--	2	October 2005	Habitat identified at the county level only
Platanthera flava	Tubercled Orchid	LT	--	--	--	1	June 1976	Habitat identified at the county level only

R000931

Table A-3 Threatened and Endangered Species

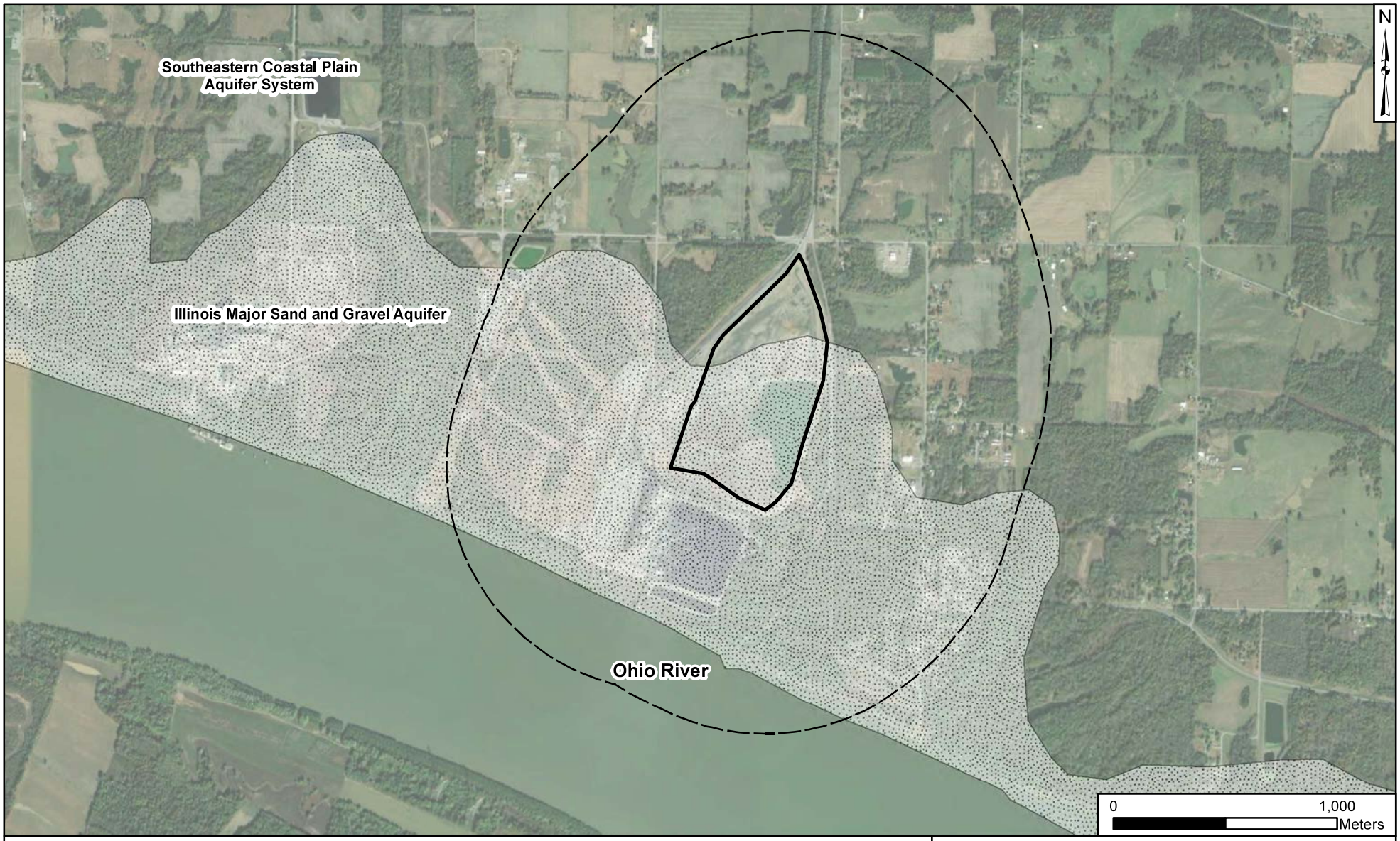
Part 845
Joppa East Ash Pond (Unit ID: 401)
Joppa Power Station
Joppa, Illinois

Scientific Name	Common Name	Status	Distance from Unit (m)	Physical Orientation to Unit	Hydraulic Orientation to Unit	Occurences	Last Observed	Notes
Plethobasus cooperianus	Orange-foot Pimpleback	LE	--	--	--	1	October 2015	Habitat identified at the county level only
Plethobasus cyphyus	Sheepnose	LE	--	--	--	3	July 1905	Habitat identified at the county level only
Pleurobema cordatum	Ohio Pigtoe	LE	--	--	--	2	November 2018	Habitat identified at the county level only
Potamilus capax	Fat Pocketbook	LE	--	--	--	3	November 2018	Habitat identified at the county level only
Pseudemys concinna	River Cooter	LE	--	--	--	3	April 2019	Habitat identified at the county level only
Quadrula metanevra	Monkeyface	LT	--	--	--	3	August 1998	Habitat identified at the county level only
Quercus phellos	Willow Oak	LT	--	--	--	7	November 2019	Habitat identified at the county level only
Rallus elegans	King Rail	LE	--	--	--	1	June 2006	Habitat identified at the county level only
Reginaia ebenus	Ebonyshell	LE	--	--	--	4	November 2018	Habitat identified at the county level only
Rhexia mariana	Dull Meadow Beauty	LE	--	--	--	1	July 2018	Habitat identified at the county level only
Scirpus polyphyllus	Leafy Bulrush	LE	--	--	--	1	September 2019	Habitat identified at the county level only
Scleria pauciflora	Carolina Whipgrass	LE	--	--	--	1	June 2004	Habitat identified at the county level only
Setophaga cerulea	Cerulean Warbler	LT	--	--	--	1	1993-07	Habitat identified at the county level only
Sternula antillarum	Least Tern	LE	--	--	--	1	June 1996	Habitat identified at the county level only
Styrax americana	Storax	LT	--	--	--	5	September 2010	Habitat identified at the county level only
Thamnophis saurita	Eastern Ribbon Snake	LT	--	--	--	2	August 2020	Habitat identified at the county level only
Theliderma cylindrica	Rabbitsfoot	LE	--	--	--	3	July 1905	Habitat identified at the county level only
Tilia heterophylla	White Basswood	LE	--	--	--	1	October 2005	Habitat identified at the county level only

Notes:

List of endangered species obtained from the Illinois Department of Natural Resources (IDNR)
-- = not provided/cannot be determined
m = meter/meters
LE = listed endangered
LT = listed threatened

FIGURES



Legend

- Illinois Major Sand and Gravel Aquifer
- East Ash Pond (EAP)
- Joppa EAP 1000-meter Buffer

Notes:

- The entire extent of the map is located on a designated Principal Aquifer.
- Principal Aquifer dataset was obtained from the United States Geologic Survey (USGS).
- Illinois Major Sand and Gravel Aquifer dataset was obtained from the Illinois Geological Survey (ISGS) .

Aquifers within 1,000 meters of the Joppa East Ash Pond

Joppa Power Station
Joppa, Illinois

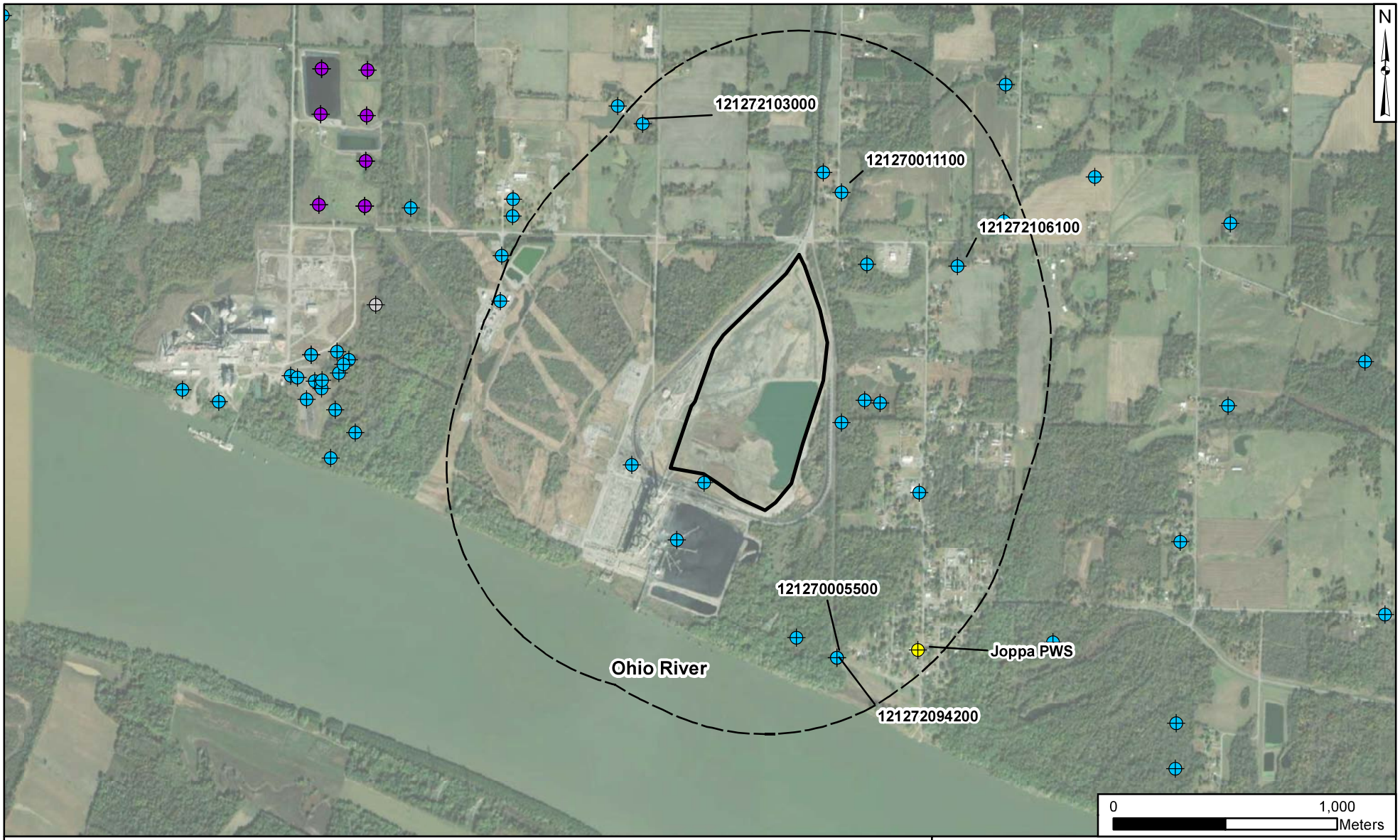
Geosyntec consultants

GLP8021	March 2021

Figure D-1

C:\Users\CCua\Desktop\Projects\Vistra\GIS\MXD Joppa\Fig A-3 Aquifers Joppa.mxd 3/25/2021 4:57:27 PM

R000934



Legend

- Water Well
- Water Well Monitoring Well
- Water Well Test Hole
- Public Water Supply (PWS) Wells
- East Ash Pond (EAP)
- Joppa EAP 1000-meter Buffer

Notes:

- Water well data obtained from Illinois Geological Survey (ISGS) Illinois Water and Related Wells (ILWATER) database.
- Two wells (121270005500 and 121272094200) are indicated to have the same location coordinates.
- Wells resulting in a significant finding are called out.
- PWS wells were obtained from the United States Environmental Protection Agency (USEPA) Safe Drinking Water Information System (SDWIS) and the Illinois Environmental Protection Agency (IEPA) Illinois Drinking Water Watch (DWW) databases. Locations were geocoded from the addresses provided, which may correspond with the location of the water system, or with a contact address.

Water Wells within 1,000 meters of the Joppa East Ash Pond

Joppa Power Station
Joppa, Illinois

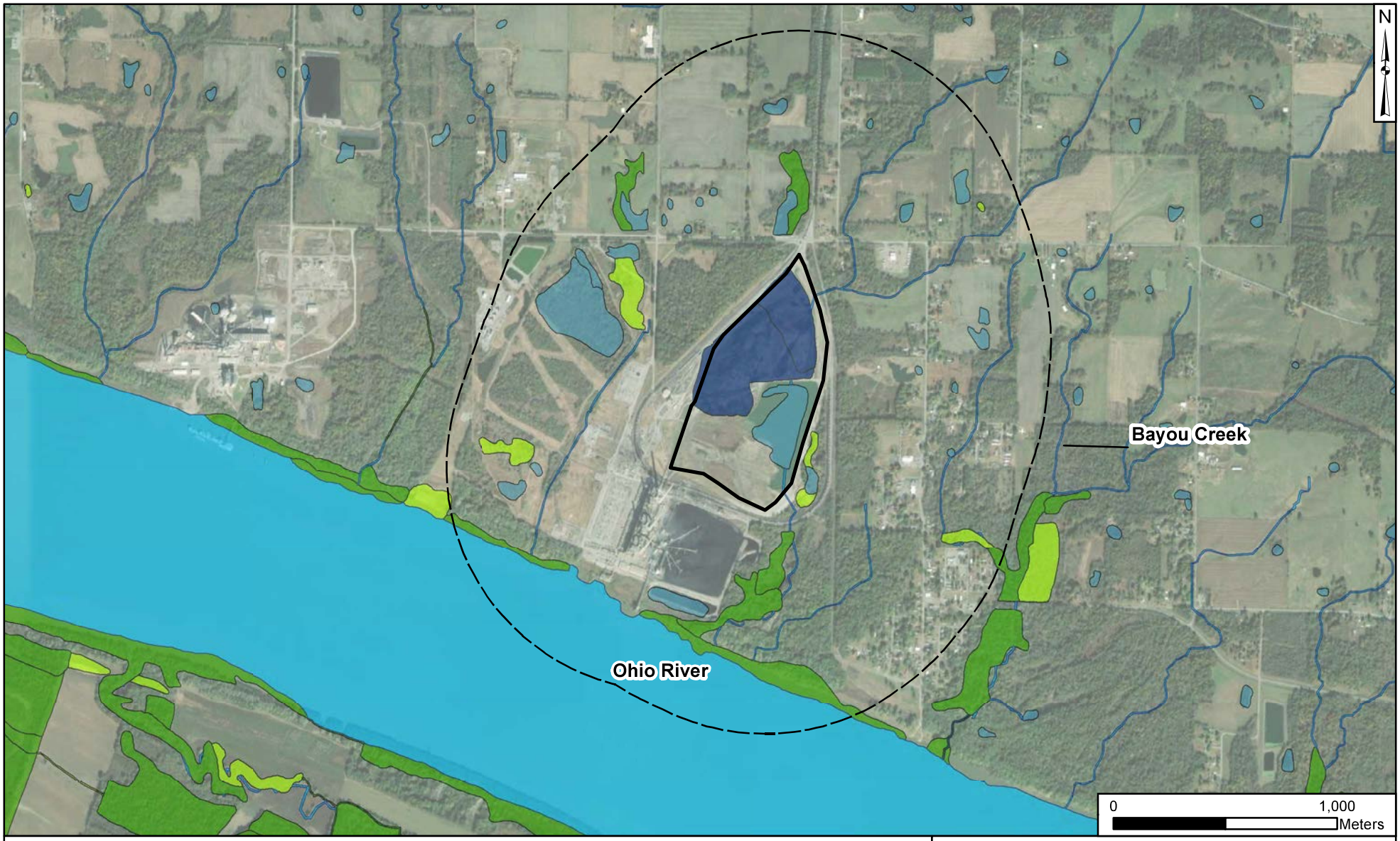
Geosyntec consultants

GLP8021	March 2021

Figure D-2

C:\Users\CCua\Desktop\Projects\Vistra\GIS\MXD Joppa\Fig A-4 Surrounding Wells Joppa.mxd 3/25/2021 4:57:47 PM

R000935



Legend

- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Freshwater Pond
- Lake
- Riverine
- East Ash Pond (EAP)
- Joppa EAP 1000-meter Buffer

Notes:
- Wetlands and Surface data were provided by the United States Fish and Wildlife Service (USFWS) Data Mapper and the United States Geologic Survey (USGS) National Hydrography Dataset (NHD).

Surface Water and Wetlands within 1,000 meters of the Joppa East Ash Pond

Joppa Power Station
Joppa, Illinois

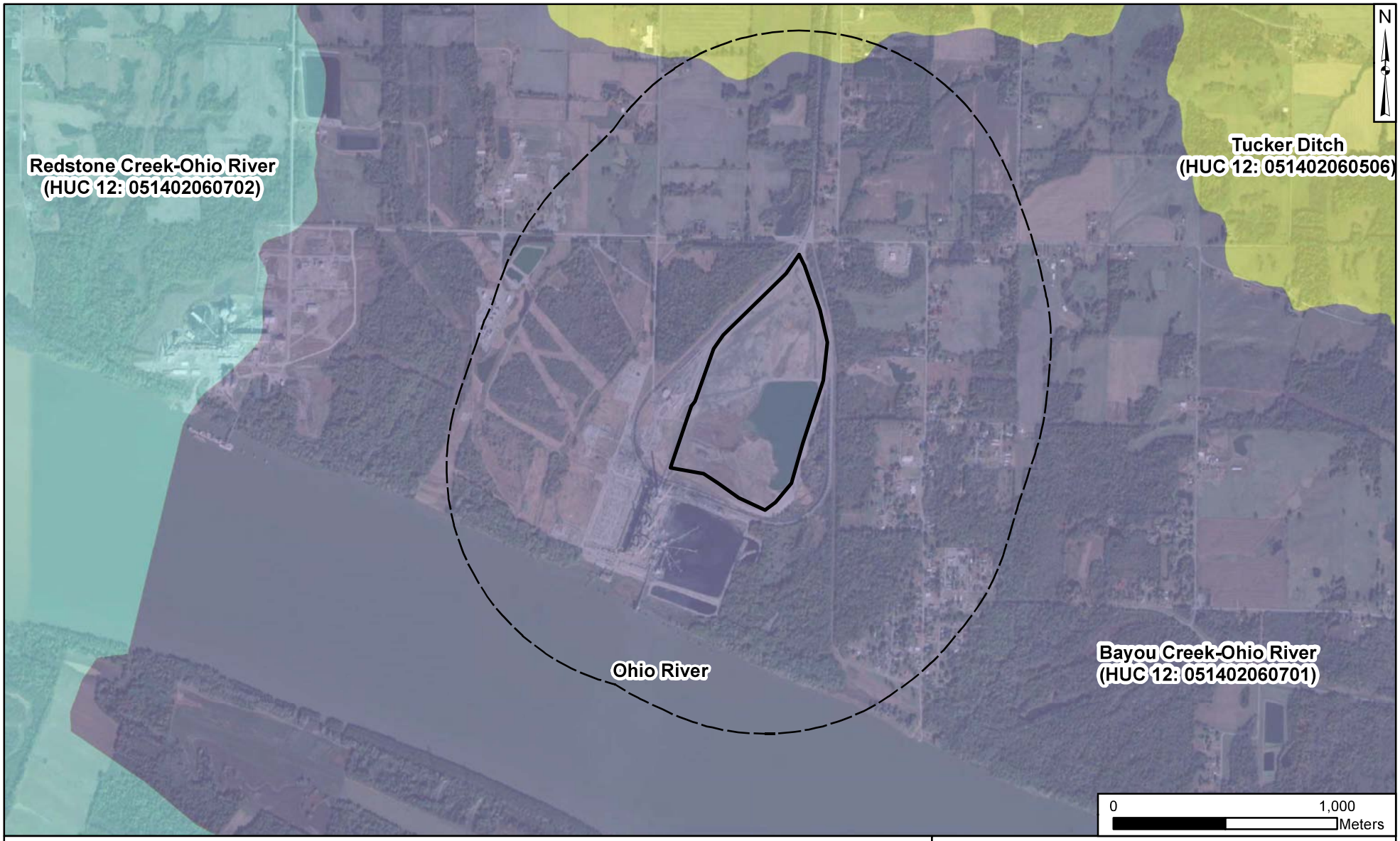
Geosyntec consultants

GLP8021	March 2021

Figure D-3

C:\Users\CCua\Desktop\Projects\Vistra\GIS\MXD Joppa\Fig A-1 Wetlands Joppa.mxd 3/25/2021 4:57:32 PM

R000936



Legend

- Bayou Creek-Ohio River
- Redstone Creek-Ohio River
- Tucker Ditch
- East Ash Pond (EAP)
- Joppa EAP 1000-meter Buffer

Notes:
- Watershed boundary data was obtained from the United States Geologic Survey (USGS) Watershed Boundary Dataset.
- HUC 12 = Hydrologic Unit Code 12

Watersheds within 1,000 meters of the Joppa East Ash Pond

Joppa Power Station
Joppa, Illinois

Geosyntec consultants

GLP8021 | March 2021

Figure D-4

C:\Users\CCua\Desktop\Projects\Vistra\GIS\MXD Joppa\Fig A-2 Watersheds Joppa.mxd 3/25/2021 4:57:29 PM

R000937

ISGS BORING LOGS

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		304
Driller's Log filed		
Survey Sample Study filed		
Sample set # 25675 (0' - 304') Received: July 29, 1955		

Image viewing help: New users please read this.

GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.

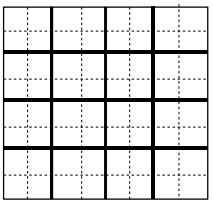
FARM Bechtel Corp

DATE DRILLED July 1, 1955 **NO.** 4

ELEVATION 0 **COUNTY NO.** 00001

LOCATION 4400'N line, 275'W line of section

LATITUDE 37.208964 **LONGITUDE** -88.856879



COUNTY Massac **API** 121270000100 **14 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		153
Driller's Log filed		

Permit Date: **Permit #:**

COMPANY Smith & Cunningham

FARM Bunchman A J

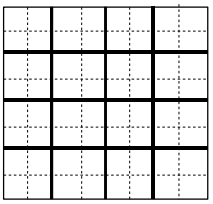
DATE DRILLED January 1, 1941 **NO.**

ELEVATION 0 **COUNTY NO.** 00030

LOCATION SW SW NE

LATITUDE 37.214621 **LONGITUDE** -88.847472

COUNTY **Massac** **API 121270003000** **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

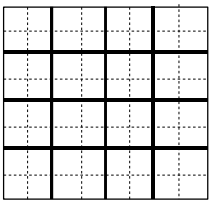
Water Well	Top	Bottom
Total Depth		156

Driller's Log filed
Survey Sample Study filed
Sample set # 6594 (1' - 156') Received: September 25, 1941

Image viewing help: New users please read this.
GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Smith & Cunningham
FARM Roberts M G
DATE DRILLED April 1, 1941 **NO.** 1
ELEVATION 340GL **COUNTY NO.** 00031
LOCATION
LATITUDE 37.21372 **LONGITUDE** -88.848626
COUNTY Massac **API** 121270003100 **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

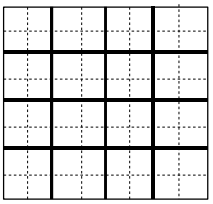
Water Well	Top	Bottom
Total Depth		350

Driller's Log filed
Survey Sample Study filed
Sample set # 21219 (0' - 350') Received: January 9, 1951

Image viewing help: New users please read this.
GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Electric Enrgy Inc
DATE DRILLED January 1, 1951 **NO.** 2
ELEVATION 0 **COUNTY NO.** 00050
LOCATION 910'N line, 660'W line of NW SW
LATITUDE 37.211275 **LONGITUDE** -88.855516
COUNTY Massac **API** 121270005000 **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

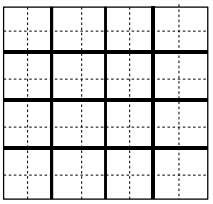
Water Well	Top	Bottom
Total Depth		403

Driller's Log filed
Survey Sample Study filed
Sample set # 21445 (0' - 405') Received: January 9, 1951

Image viewing help: New users please read this.
GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Electric Energy Inc
DATE DRILLED January 1, 1951 **NO.** 3
ELEVATION 355GL **COUNTY NO.** 00051
LOCATION 2352'N line, 2088'E line of NE
LATITUDE 37.214512 **LONGITUDE** -88.84669
COUNTY Massac **API** 121270005100 **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		138
Driller's Log filed		
Survey Sample Study filed		
Sample set # 4599 (5' - 138') Received: June 4, 1940		

Permit Date: **Permit #:**

COMPANY Smith & Cunningham

FARM Joppa Grade School

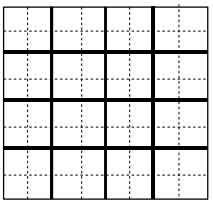
DATE DRILLED April 1, 1940 **NO.**

ELEVATION 340GL **COUNTY NO.** 00052

LOCATION 1000'N line, 1150'W line of SE

LATITUDE 37.21092 **LONGITUDE** -88.8447

COUNTY Massac **API** 121270005200 **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		235
Driller's Log filed		
Sample set # 21218 (0' - 235') Received: July 11, 1951		

Image viewing help: New users please read this.

GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.

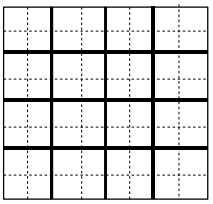
FARM Electric Energy Inc

DATE DRILLED January 1, 1951 **NO.** 1

ELEVATION 348GL **COUNTY NO.** 00053

LOCATION 675'N line, 400'E line of NE SE

LATITUDE 37.211974 **LONGITUDE** -88.859164



COUNTY Massac **API** 121270005300 **15 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		137
Driller's Log filed		
Survey Sample Study filed		
Sample set # 4671 (0' - 137') Received: June 20, 1940		

Image viewing help: New users please read this.

GET FILE Related File - Survey Core Study

Permit Date: **Permit #:**

COMPANY Smith & Cunningham

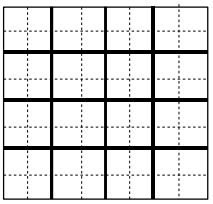
FARM Joppa Colored Schl

DATE DRILLED June 1, 1940 **NO.** 1

ELEVATION 340GL **COUNTY NO.** 00054

LOCATION 500'N line, 600'E line of NW

LATITUDE 37.205054 **LONGITUDE** -88.850833



COUNTY Massac **API** 121270005400 23 - 15S - 3E

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		65
Driller's Log filed		
Survey Sample Study filed		
Sample set # 6595 (1' - 65') Received: September 25, 1941		

Permit Date: **Permit #:**

COMPANY Smith & Cunningham

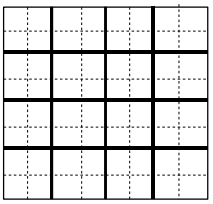
FARM Wilson Marie

DATE DRILLED January 1, 1941 **NO.** 1

ELEVATION 340GL **COUNTY NO.** 00055

LOCATION

LATITUDE 37.204248 **LONGITUDE** -88.84879



COUNTY **Massac** **API 121270005500** **23 - 15S - 3E**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
soil	0	11
yellow clay	11	26
gravel	26	31
yellow clay	31	38
sandy clay	38	45
gravel & sand	45	78
Total Depth		**78**

Casing: 6" PVC from 30' to -2'
24" CONCRETE from 78' to 30'

Grout: TILE 24" from 78 to 30.

Grout: PVC 6" from 30 to -2.

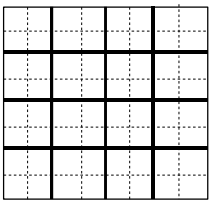
Water from gravel & sand at 58' to 78'.
Static level 20' below casing top which is 2' above GL
Pumping level 15' when pumping at 10 gpm for 1 hour

Driller's Log filed

Owner Address: Joppa, IL
Location source: Location from permit

Permit Date: August 11, 1969 **Permit #:** 06803

COMPANY Jennings, James E.
FARM Adams, Guy
DATE DRILLED August 21, 1969 **NO.** 19
ELEVATION 0 **COUNTY NO.** 00111
LOCATION 50'N 60'W SE/c NE SE SW
LATITUDE 37.222994 **LONGITUDE** -88.848699
COUNTY **Massac** **API 121270011100** **11 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
clay	0	20
gravel	20	130
sand	130	150
Total Depth		**150**

Casing: 7" NEW STEEL 23# FT from 0' to 104'

Size hole below casing: 6.25"

Water from sand gravel at 0' to 0'.
Static level 60' below casing top which is 1' above GL
Pumping level 100' when pumping at 15 gpm for 4 hours

Permanent pump installed at 120'
on , with a capacity of 15 gpm

Driller's Log filed

Owner Address: Joppa, IL

Location source: Location from permit

Permit Date: **Permit #:** 12094

COMPANY Sergent, William E.

FARM Kapley, Homer & Levina

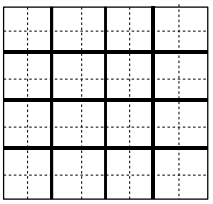
DATE DRILLED **NO.** 1

ELEVATION 0 **COUNTY NO.** 00146

LOCATION SE SE SE

LATITUDE 37.22186 **LONGITUDE** -88.840518

COUNTY **Massac** **API 121270014600** **11 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		160
Driller's Log filed		

Permit Date: **Permit #:**

COMPANY Geer, Alonzo

FARM Mathes David L

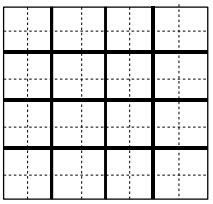
DATE DRILLED July 1, 1971 **NO.** 1

ELEVATION 0 **COUNTY NO.** 00158

LOCATION NW NW NE

LATITUDE 37.2201 **LONGITUDE** -88.847389

COUNTY **Massac** **API 121270015800** **14 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Private Water Well	Top	Bottom
dirt & clay	0	18
clay & soapstone	18	72
brown pea gravel	72	94
Total Depth		**94**

Casing: 6" SDR 21 from -1' to 88'
6" PVC SCREEN from 88' to 94'
Screen: 6' of 6" diameter .02 slot
Grout: BENSEAL/SLRY from 0 to 72.
Grout: GRAVEL PACK from 72 to 94.

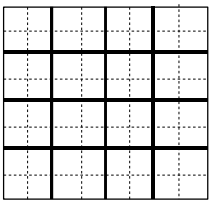
Size hole below casing: 6"

Water from gravel at 85' to 94'.
Static level 52' below casing top which is 1' above GL
Pumping level 70' when pumping at 0 gpm for 24 hours
Permanent pump installed at 80'
on October 21, 1994, with a capacity of 10 gpm

Owner Address: Rt. #1 Box #468 Metropolis, IL
Address of well:
Joppa, IL
Location source: Location from permit

Permit Date: October 7, 1994 **Permit #:**

COMPANY Beanland, Leonard Ralph
FARM Jewel, William
DATE DRILLED October 9, 1994 **NO.**
ELEVATION 0 **COUNTY NO.** 20675
LOCATION NE SE SW
LATITUDE 37.223783 **LONGITUDE** -88.84962
COUNTY Massac **API** 121272067500 **11 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

	Top	Bottom
Total Depth		90

Sample set # 23753 (5' - 90') Received: January 9, 1952

Owner Address: ,

Permit Date: **Permit #:**

COMPANY Layne Western

FARM Electrical Energy Corp (Joppa)

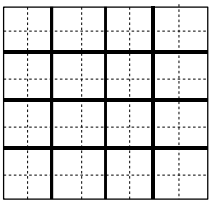
DATE DRILLED **NO.** 3

ELEVATION 0 **COUNTY NO.** 20942

LOCATION

LATITUDE 37.204248 **LONGITUDE** -88.84879

COUNTY **Massac** **API** **121272094200** **23 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Irrigation Well	Top	Bottom
yellow clay	0	27
gravel	27	28
white clay	28	36
yellow sandy clay/gravel	36	58
yellow sandy clay/coarse ylw sand	58	65
yellow sandy clay/white streaks	65	105
fine yellow sand & clay streaks	105	118
chert	118	142
chert w/yellow/white clay streaks	142	160
chert w/gravel clay streaks	160	178
weathered limestone	178	180
chert w/gray clay	180	191
fractured gray limestone	191	202
Total Depth		**202**

Casing: 6.12" PVC from -1' to 140'
4" PVC from 135' to 195'

Grout: BENTONITE from 0 to 139.

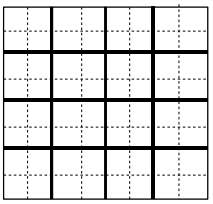
Water from limestone at 175' to 200'.
Static level 41' below casing top which is 1' above GL
Pumping level 100' when pumping at 15 gpm for 72 hours

Remarks: driller's est. well yield 30 gpm

Owner Address: 4242 Green Acres Ln. Grand Chain, IL
Address of well: same as above
Location source: Location from permit

Permit Date: February 8, 2000 **Permit #:**

COMPANY Beanland, Ronald D.
FARM Snell, Arnold
DATE DRILLED March 30, 2000 **NO.**
ELEVATION 0 **COUNTY NO.** 21030
LOCATION SE NE SE
LATITUDE 37.225712 **LONGITUDE** -88.858722
COUNTY **Massac** **API 121272103000** **10 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Non Potable Water Well	Top	Bottom
topsoil & clay w/silty sand	0	22
clay w/fine to medium sand	22	136
fine to medium sand w/clay seams	136	220
weathered limestone	220	225
fractured limestone	225	238
Total Depth		**238**

Casing: 12" STAINLESS #49.56/FT from -2' to 228'

Grout: CEMENT from 1 to 228.

Size hole below casing: 12"

Water from limestone at 228' to 238'.
Static level 40' below casing top which is 2' above GL
Pumping level 44' when pumping at 603 gpm for 12 hours

Permanent pump installed at 150'
on , with a capacity of 600 gpm

Owner Address: P. O. Box 355 Joppa, IL

Address of well: 2100 Portland Rd
Joppa IL

Location source: Location from permit

Permit Date: November 18, 1999 **Permit #:**

COMPANY Stollhans, Jeff

FARM Midwest Electric Power Co.

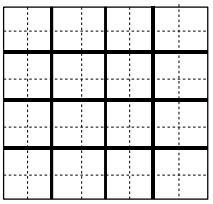
DATE DRILLED February 29, 2000 **NO.** 6

ELEVATION 380 **COUNTY NO.** 21039

LOCATION SW NW NE

LATITUDE 37.218537 **LONGITUDE** -88.86584

COUNTY Massac **API 121272103900** **15 - 15S - 3E**



ILLINOIS STATE GEOLOGICAL SURVEY

Private Water Well	Top	Bottom
dirt & clay	0	42
sandy clay	42	50
gravel & clay	50	62
sand & clay	62	87
gravel	87	92
Total Depth		**92**

Casing: 6.25" PVC from 1' to 89'
6.25" PVC SCREEN from 89' to 92'

Screen: 3' of 6.25" diameter .03 slot

Grout: CLAY from 0 to 3.

Grout: ENVIROPLUG from 3 to 85.

Grout: WASHED PEA GVL from 85 to 92.

Water from gravel at 89' to 92'.

Static level 60' below casing top which is 1' above GL

Pumping level 70' when pumping at 10 gpm for 24 hours

Permanent pump installed at 83'

on , with a capacity of 10 gpm

Remarks: driller's est. well yield 30 gpm

Owner Address: 4173 Joppa Bypass Rd. Metropolis, IL

Address of well: same as above

Location source: Location from permit

Permit Date: September 17, 2001 **Permit #:**

COMPANY Beanland, Leonard Ralph

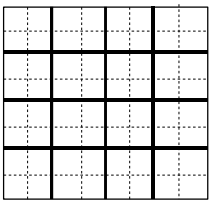
FARM Terbrak, Rodger

DATE DRILLED **NO.**

ELEVATION 0 **COUNTY NO.** 21061

LOCATION NW NE NE

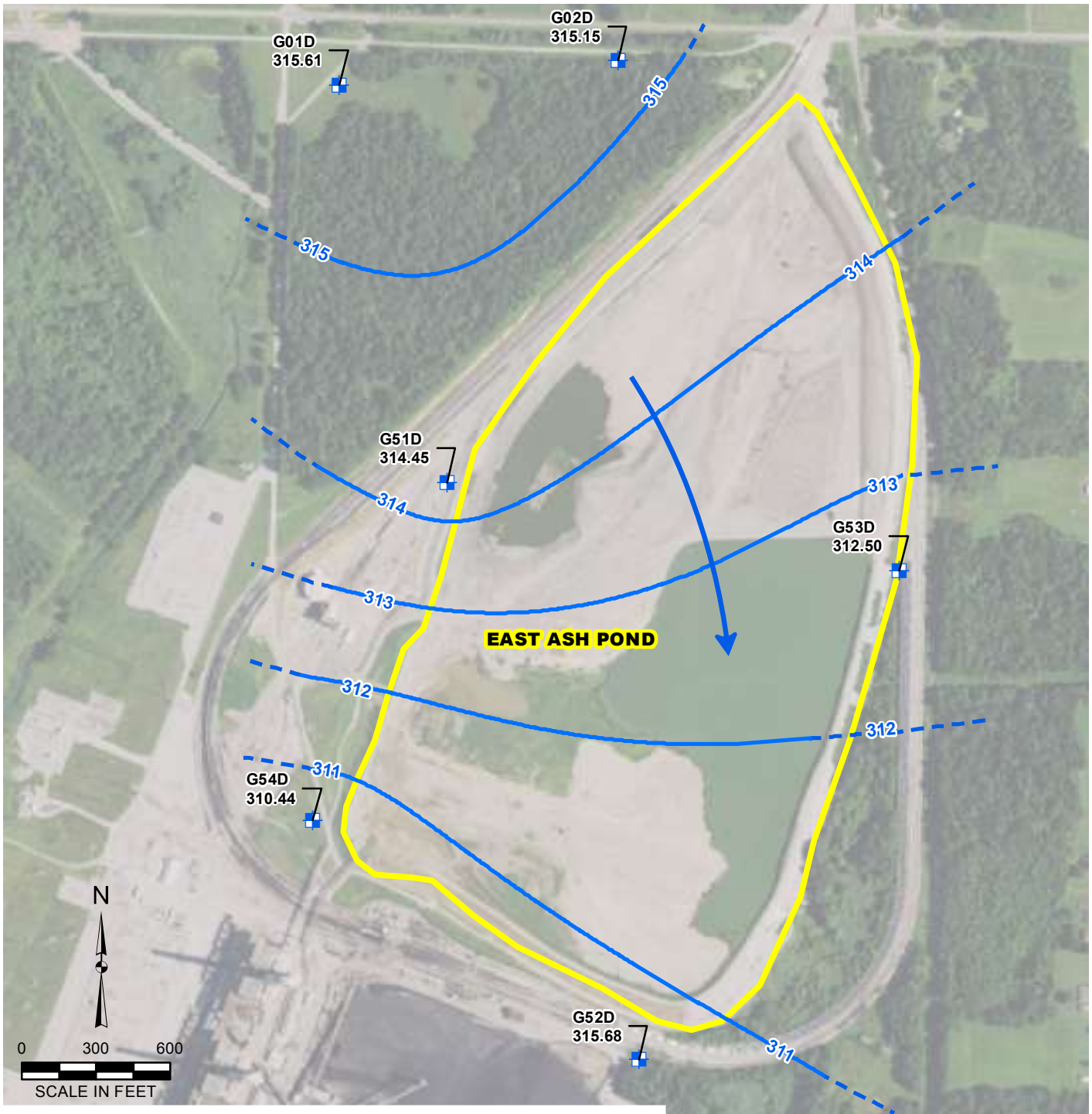
LATITUDE 37.220051 **LONGITUDE** -88.842823



COUNTY **Massac** **API 121272106100** **14 - 15S - 3E**

APPENDIX E
GROUNDWATER CONTOUR MAPS AND ELEVATIONS

GROUNDWATER CONTOUR MAPS



CCR RULE MONITORING WELL LOCATION
GROUNDWATER ELEVATION CONTOUR (1-FT CONTOUR INTERVAL, NAVD88)
INFERRED GROUNDWATER ELEVATION CONTOUR
GROUNDWATER FLOW DIRECTION
CCR MONITORED UNIT

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

NOTE: G52D GROUNDWATER ELEVATION IS NOT INCLUDED IN POTENTIOMETRIC SURFACE CONTOURS

DRAWN BY/DATE:
SDS 1/23/17
REVIEWED BY/DATE:
ANS 1/25/17
APPROVED BY/DATE:
JJW 2/7/17

JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 1: DECEMBER 2, 2015

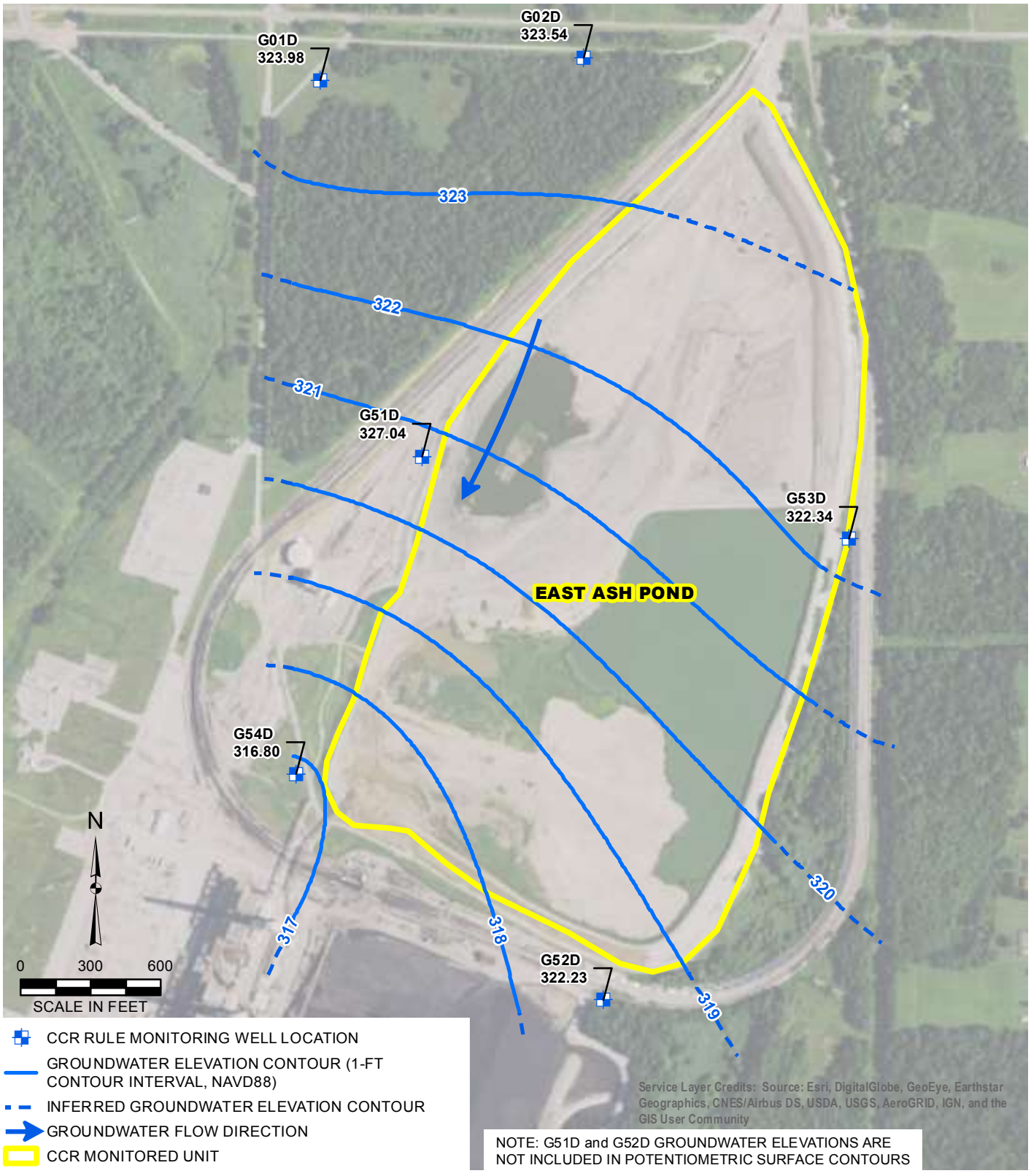
DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285/1.6

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_01\R1_JoppaEAP_GW_Contours.mxd Author: sstolz Date/Time: 2/15/2017, 4:16:52 PM



DRAWN BY/DATE:
SDS 1/23/17
REVIEWED BY/DATE:
ANS 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 2: MARCH 15, 2016

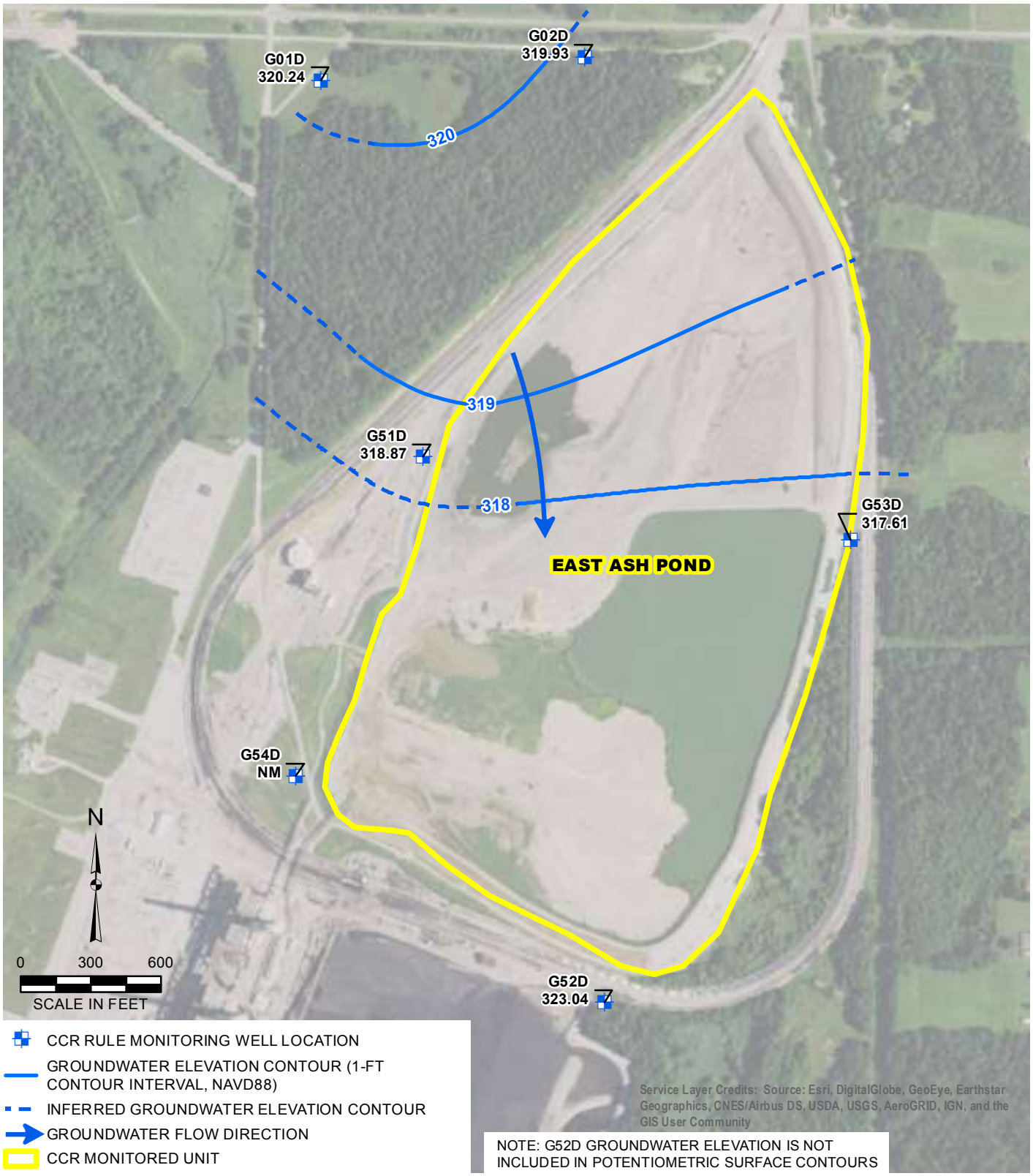
DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_02\R2_JoppaEAP_GW_Contours.mxd Author: sstolz Date/Time: 3/2/2017 4:17:21 PM



Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_03\R3_JoppaEAP_GW_Contours.mxd Author: stolzsd DateTime: 5/2/2017, 6:25:27 PM

DRAWN BY/DATE:
SDS 1/23/17
REVIEWED BY/DATE:
ANS 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

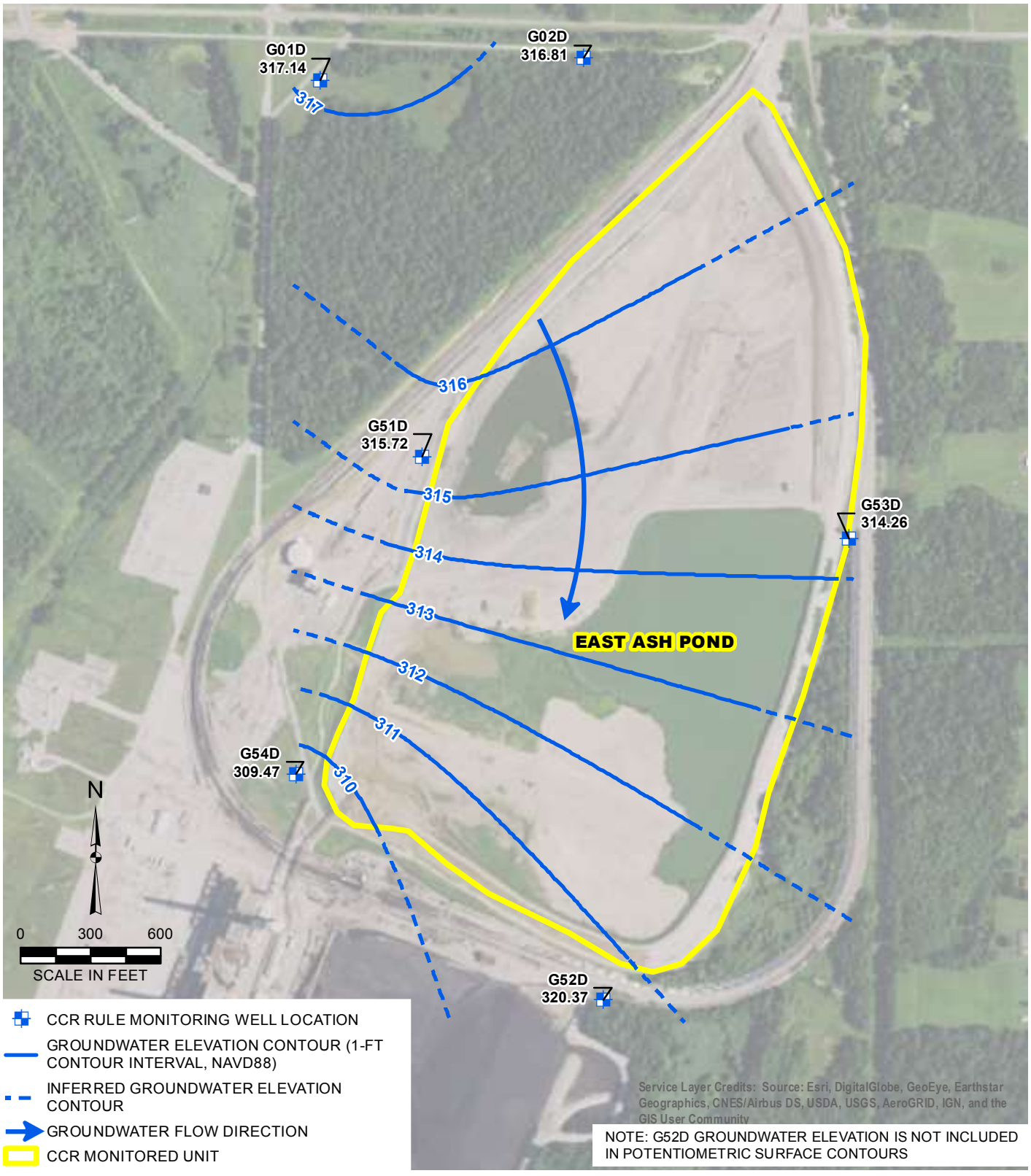
JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 3: JUNE 14, 2016

DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



DRAWN BY/DATE:
SDS 1/23/17
REVIEWED BY/DATE:
ANS 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 4: SEPTEMBER 13, 2016

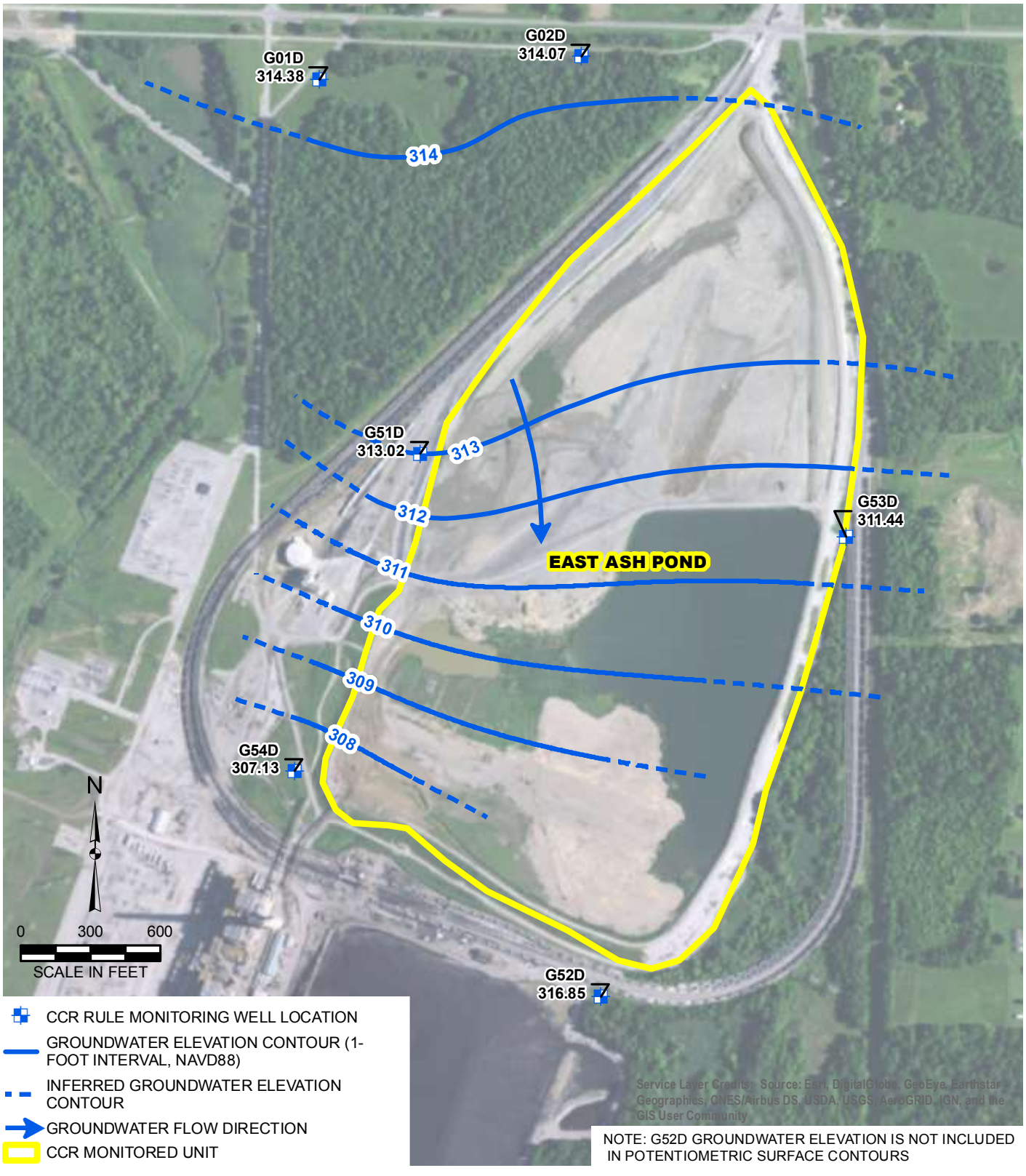
DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_04\R4_JoppaEAP_GW_Contours.mxd Author: sstolz Date/Time: 3/3/2017 2:28:06 PM



NOTE: G52D GROUNDWATER ELEVATION IS NOT INCLUDED IN POTENTIOMETRIC SURFACE CONTOURS

Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_05\R5_JoppaEAP_GW_Contours.mxd Author: stolzsd Date/Time: 9/1/2017, 5:09:29 PM

DRAWN BY/DATE:
SDS 3/6/17
REVIEWED BY/DATE:
ANS 3/6/17
APPROVED BY/DATE:
JJW 8/30/17

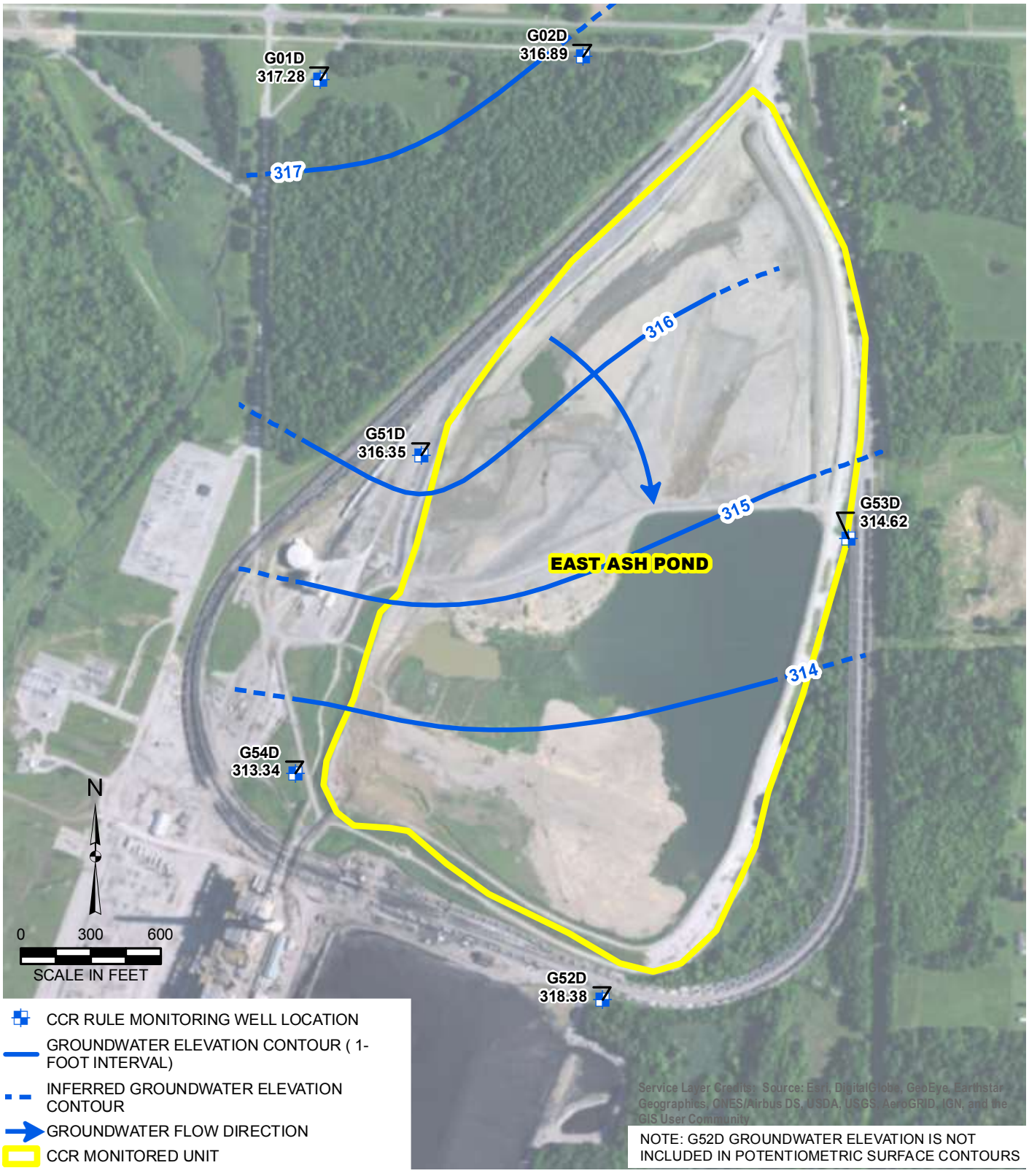
JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 5: DECEMBER 14, 2016

DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_06\R6_JoppaEAP_GW_Contours.mxd Author: stolzsd; Date/Time: 9/1/2017, 5:11:01 PM

DRAWN BY/DATE:
SDS 7/12/17
REVIEWED BY/DATE:
ANS 7/12/17
APPROVED BY/DATE:
JJW 8/30/17

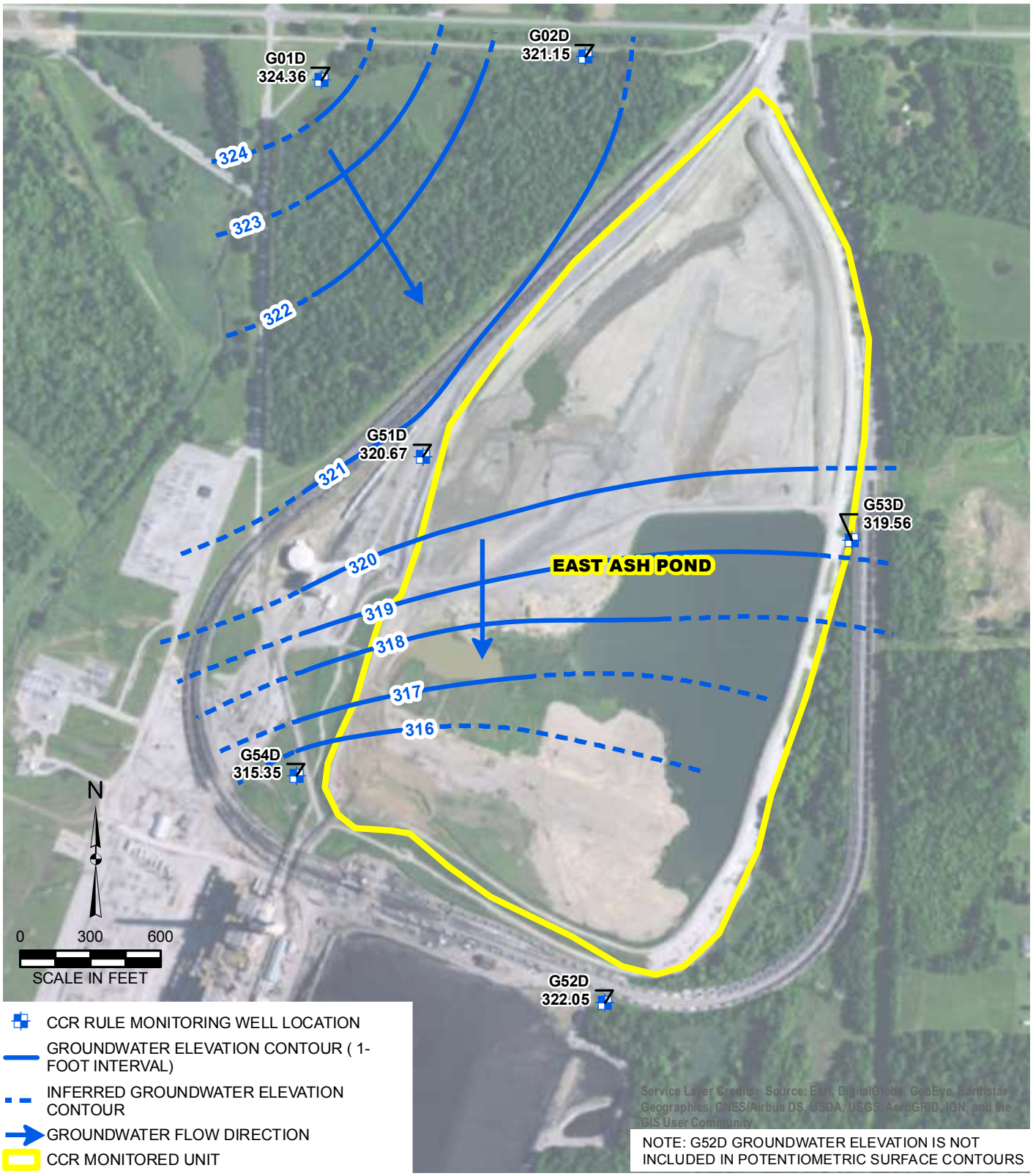
JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 6: MARCH 7, 2017

DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_07\R7_JoppaEAP_GW_Contours.mxd Author: stolzsd; Date/Time: 9/1/2017, 5:11:57 PM

DRAWN BY/DATE:
SDS 7/10/17
REVIEWED BY/DATE:
ANS 7/10/17
APPROVED BY/DATE:
JJW 8/30/17

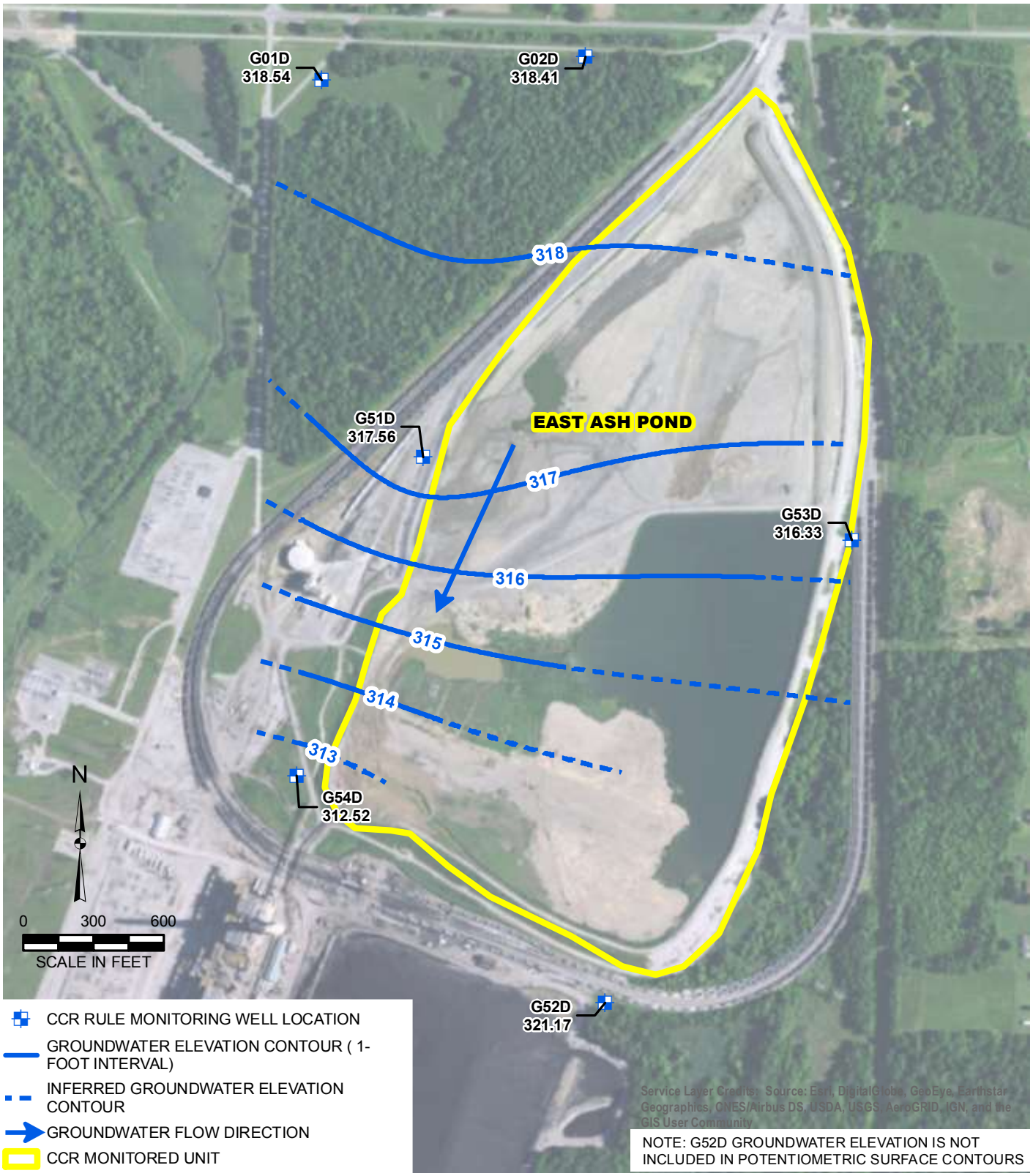
JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 7: JUNE 14, 2017

DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



Y:\Mapping\Projects\2212285\MXD\GW_Contours\Round_08\R8_JoppaEAP_GW_Contours.mxd Author: stolzsd; Date/Time: 9/1/2017, 5:14:13 PM

DRAWN BY/DATE:
SDS 8/10/17
REVIEWED BY/DATE:
ANS 8/10/17
APPROVED BY/DATE:
JJW 8/30/17

JOPPA EAST ASH POND (UNIT ID: 401)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 8: JULY 19, 2017

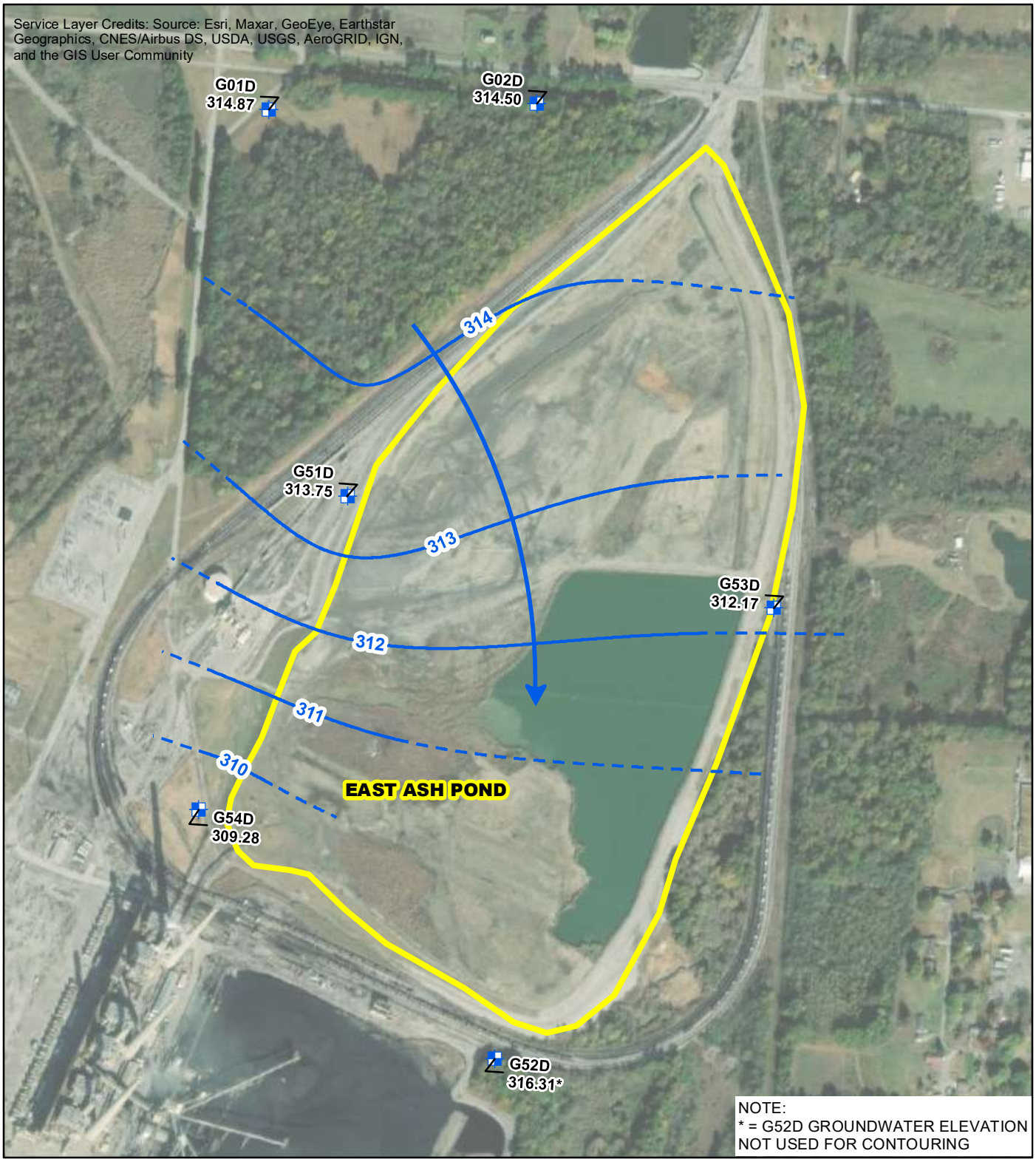
DYNEGY CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

8/13/2020 11:49:24 PM



CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

JOPPA EAST ASH POND (UNIT ID: 401)
GROUNDWATER ELEVATION CONTOUR MAP
NOVEMBER 30, 2017

CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

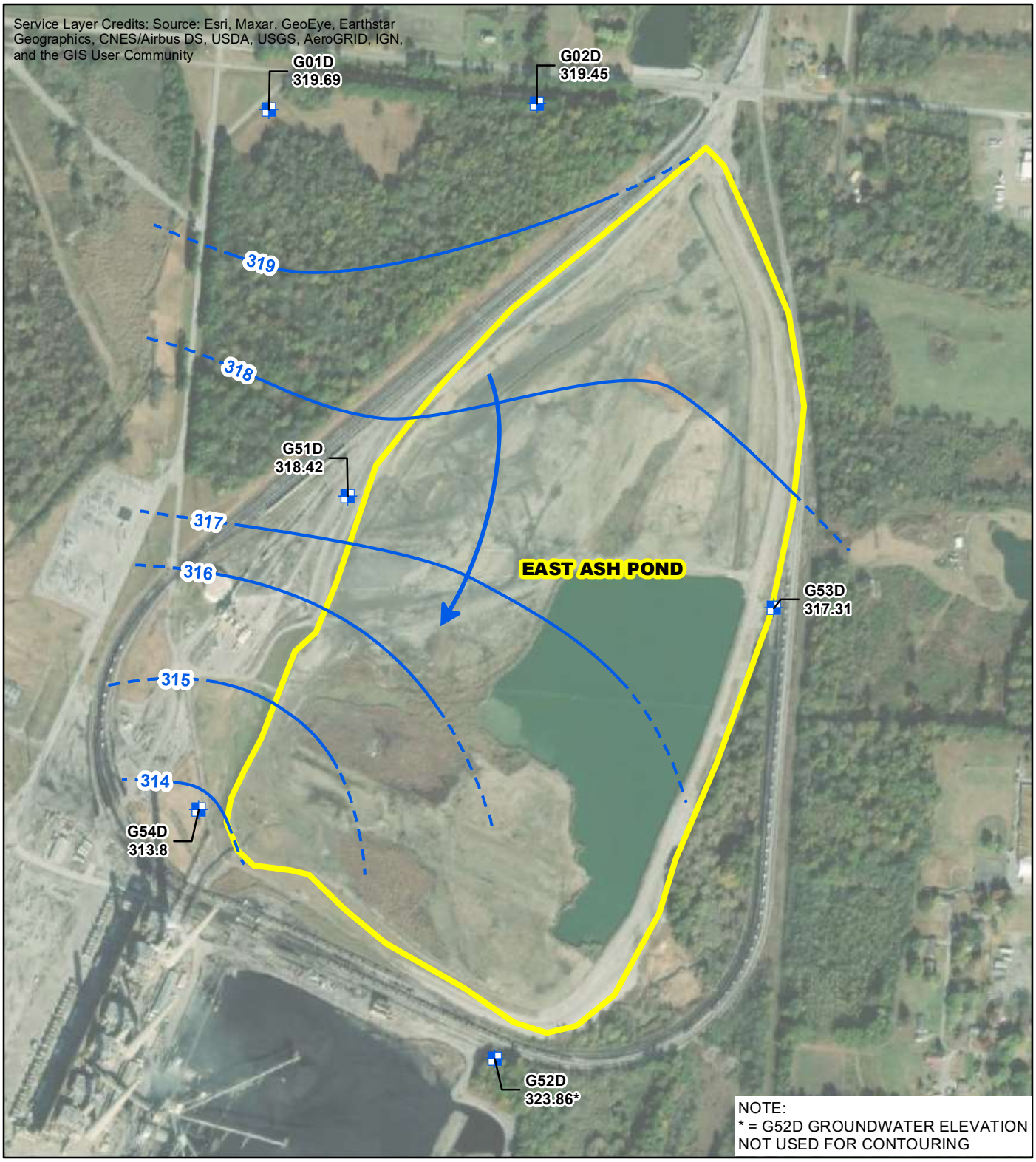
0 150 300 600
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\22\2285\MXD\GW_Contours\Round_09\R9_JoppaEAP_GW_Contours_OBG.mxd

8/13/2020 11:42:31 PM



CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

JOPPA EAST ASH POND (UNIT ID: 401)
GROUNDWATER ELEVATION CONTOUR MAP
JUNE 9, 2018

CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

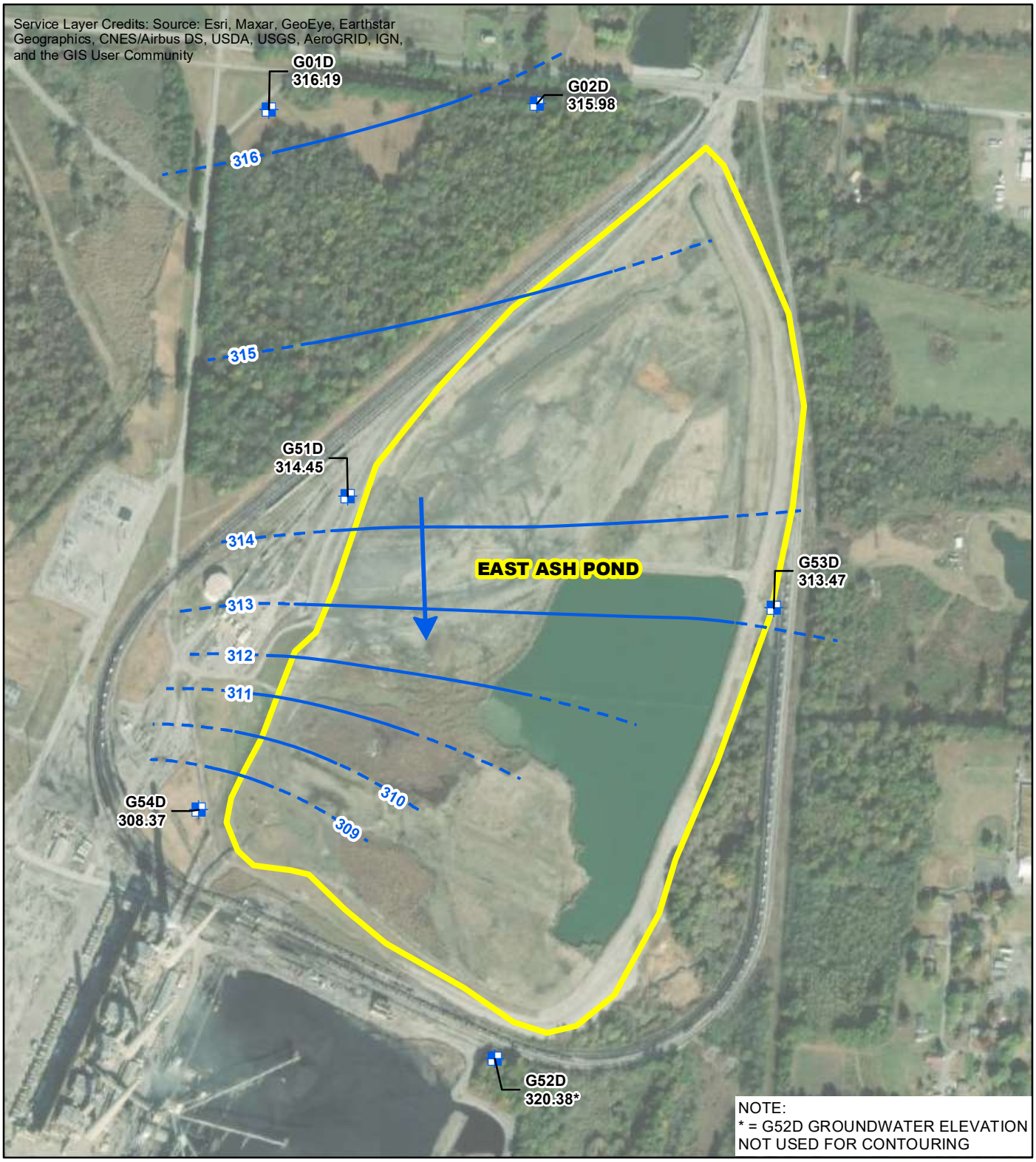
0 150 300 600
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\22\2285\MXD\GW_Contours\Round_2018_2Q\R2018_2Q_JoppaEAP_GW_Contours_OBG.mxd

8/13/2020 11:44:33 PM



CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD 88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

JOPPA EAST ASH POND (UNIT ID: 401)
GROUNDWATER ELEVATION CONTOUR MAP
SEPTEMBER 5, 2018

CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

0 150 300 600
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\22\2285\MXD\GW_Contours\Round_2018_3Q\R2018_3Q_JoppaEAP_GW_Contours.mxd

8/13/2020 11:46:36 PM

CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD 88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

JOPPA EAST ASH POND (UNIT ID: 401)
GROUNDWATER ELEVATION CONTOUR MAP
MARCH 27, 2019

CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

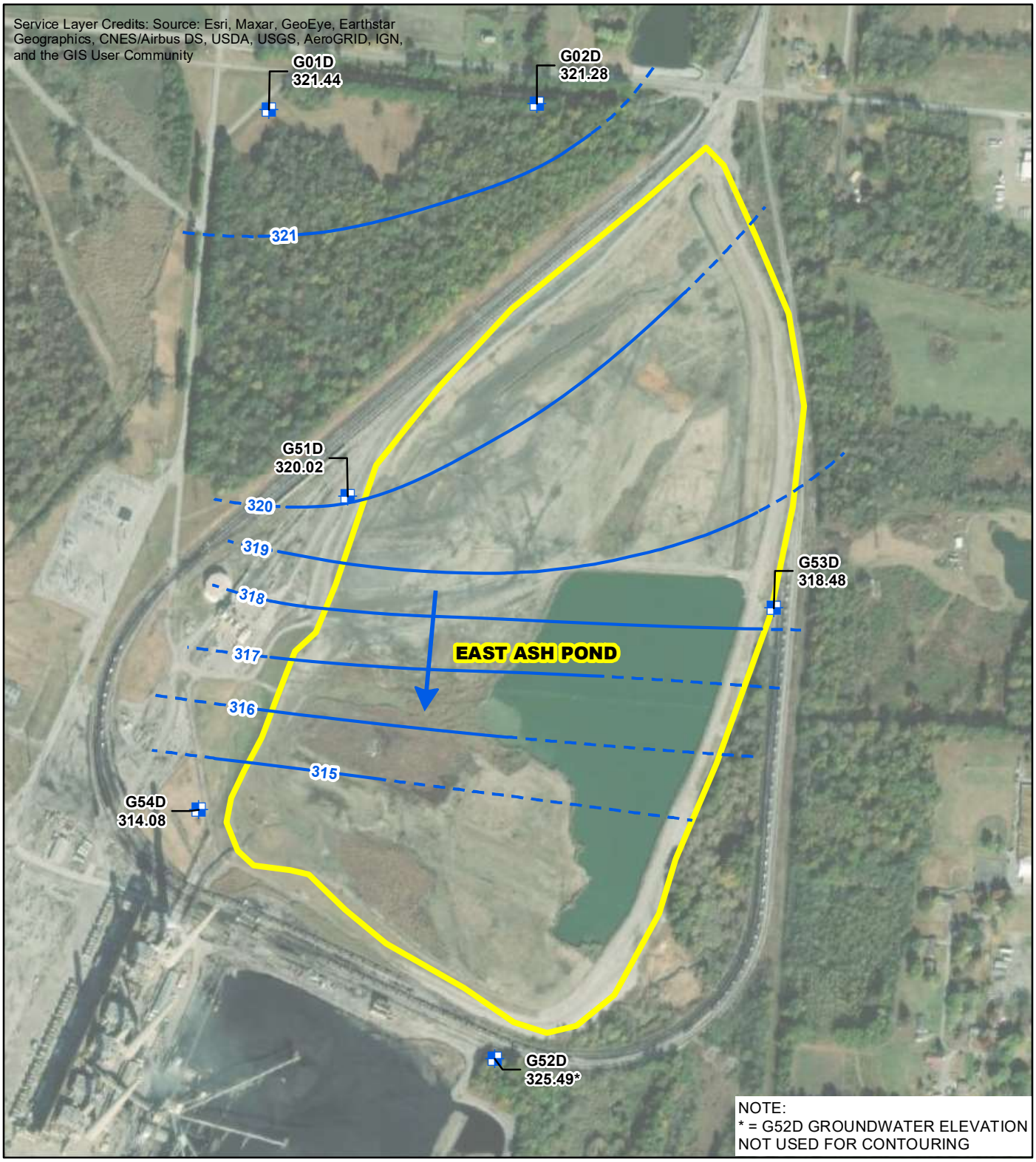
0 150 300 600
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\222285\MXD\GW_Contours\Round_2019_1Q\R2019_1Q_JoppaEAP_GW_Contours.mxd

8/13/2020 11:48:06 PM



CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD 88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

JOPPA EAST ASH POND (UNIT ID: 401)
GROUNDWATER ELEVATION CONTOUR MAP
SEPTEMBER 9, 2019

CCR RULE GROUNDWATER MONITORING
JOPPA POWER STATION
JOPPA, ILLINOIS

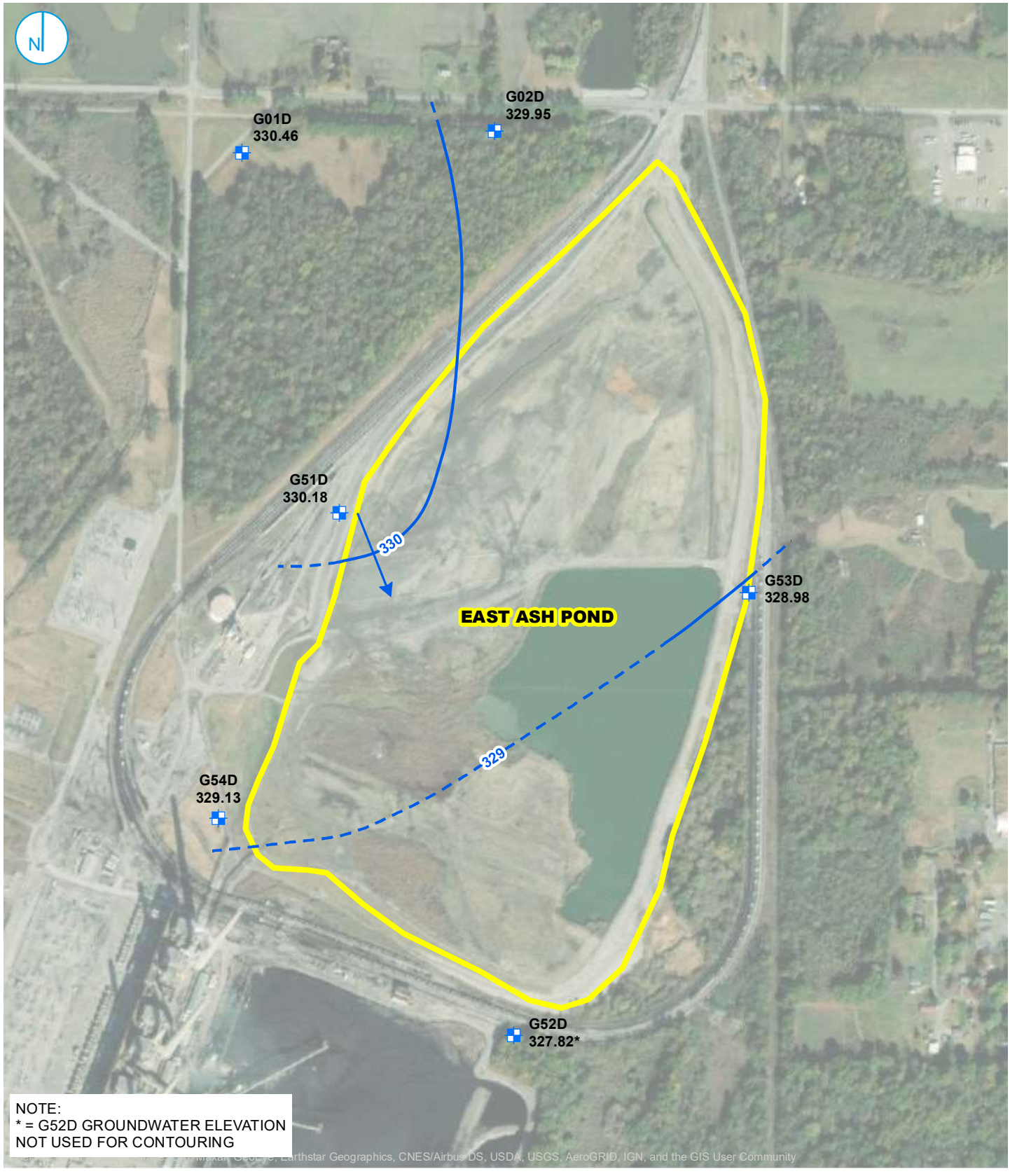
0 150 300 600
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\222285\MXD\GW_Contours\Round_2019_3Q\R2019_3Q_JoppaEAP_GW_Contours.mxd

Y:\Mapping\Projects\22\2285\MXD\GW_Contours\Round_2020_1Q\R2020_1Q_JoppaEAP_GW_Contours.mxd
PROJECT: 169000XXXX | DATED: 8/13/2020 | DESIGNER: STOLZSD



CCR MONITORING WELL
GROUNDWATER ELEVATION CONTOUR (1-FOOT CONTOUR INTERVAL, NAVD 88)
INFERRED GROUNDWATER ELEVATION CONTOUR
GROUNDWATER FLOW DIRECTION
CCR UNIT BOUNDARY, SUBJECT SITE

0 275 550 Feet

GROUNDWATER ELEVATION CONTOUR MAP
MARCH 30, 2020

JOPPA EAST ASH POND (UNIT ID: 401)
VISTRA ENERGY
JOPPA POWER STATION
JOPPA, ILLINOIS

RAMBOLL US CORPORATION
A RAMBOLL COMPANY

RAMBOLL

TABLE E-1
GROUNDWATER ELEVATION RESULTS (2015-2021)

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G01D	12/02/2015	315.61
G01D	03/15/2016	323.98
G01D	06/14/2016	320.24
G01D	06/15/2016	320.24
G01D	09/13/2016	317.14
G01D	09/14/2016	317.14
G01D	12/14/2016	314.38
G01D	03/07/2017	317.28
G01D	06/14/2017	324.36
G01D	07/19/2017	318.54
G01D	11/30/2017	314.87
G01D	06/09/2018	319.69
G01D	09/05/2018	316.19
G01D	03/27/2019	329.69
G01D	09/09/2019	321.44
G01D	03/30/2020	330.46
G01D	09/23/2020	320.32
G01D	09/24/2020	320.32
G01D	03/03/2021	305.27
G01D	03/24/2021	327.02
G01D	04/14/2021	325.92
G01D	05/12/2021	324.12
G01D	06/01/2021	320.46
G01D	06/14/2021	322.10
G01D	07/06/2021	321.38
G01D	07/21/2021	320.89
G01D	09/20/2021	320.05
G02D	12/02/2015	315.15
G02D	03/15/2016	323.54
G02D	06/14/2016	319.93
G02D	06/15/2016	319.93
G02D	09/13/2016	316.81
G02D	09/14/2016	316.81
G02D	12/14/2016	314.07
G02D	03/07/2017	316.89
G02D	06/14/2017	321.15
G02D	07/19/2017	318.41
G02D	11/30/2017	314.50
G02D	06/09/2018	319.45
G02D	09/05/2018	315.98
G02D	03/27/2019	329.22
G02D	09/09/2019	321.28
G02D	03/30/2020	329.95
G02D	09/23/2020	320.14
G02D	09/24/2020	320.14
G02D	03/03/2021	321.77

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G02D	03/24/2021	325.91
G02D	04/14/2021	324.71
G02D	05/12/2021	323.72
G02D	06/01/2021	321.23
G02D	06/14/2021	321.86
G02D	07/06/2021	319.74
G02D	07/21/2021	320.62
G02D	09/20/2021	318.86
G03	03/05/2021	321.37
G03	03/24/2021	325.29
G03	04/14/2021	325.26
G03	05/12/2021	323.15
G03	06/01/2021	318.88
G03	06/15/2021	321.29
G03	07/06/2021	320.43
G03	07/21/2021	320.21
G04	03/04/2021	320.41
G04	03/24/2021	324.92
G04	04/13/2021	325.06
G04	05/11/2021	322.21
G04	06/01/2021	320.79
G04	06/14/2021	320.28
G04	07/06/2021	319.28
G04	07/20/2021	319.12
G05	03/04/2021	316.86
G05	03/24/2021	324.65
G05	04/13/2021	324.43
G05	05/11/2021	321.06
G05	06/01/2021	319.28
G05	06/15/2021	318.66
G05	07/06/2021	318.71
G05	07/20/2021	318.61
G06	03/04/2021	317.63
G06	03/24/2021	323.74
G06	04/13/2021	323.14
G06	05/11/2021	319.12
G06	06/01/2021	317.08
G06	06/15/2021	316.38
G06	07/06/2021	315.44
G06	07/20/2021	315.42
G06S	03/04/2021	317.76
G06S	03/24/2021	324.85
G06S	04/13/2021	323.95
G06S	05/11/2021	319.60
G06S	06/01/2021	317.66
G06S	06/14/2021	317.01

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G06S	07/06/2021	315.88
G06S	07/20/2021	315.80
G07	03/04/2021	316.17
G07	03/24/2021	322.71
G07	04/13/2021	321.96
G07	05/11/2021	317.48
G07	06/01/2021	315.22
G07	06/15/2021	314.48
G07	07/06/2021	313.63
G07	07/20/2021	313.63
G08	03/04/2021	316.89
G08	03/24/2021	322.52
G08	04/13/2021	320.77
G08	05/11/2021	315.82
G08	06/01/2021	313.42
G08	06/15/2021	312.94
G08	07/06/2021	312.52
G08	07/20/2021	312.49
G09	03/04/2021	318.48
G09	03/25/2021	322.65
G09	04/14/2021	319.59
G09	05/11/2021	316.57
G09	05/12/2021	316.57
G09	06/01/2021	311.02
G09	06/15/2021	311.68
G09	07/06/2021	313.60
G09	07/21/2021	312.34
G09M	03/04/2021	321.48
G09M	03/25/2021	324.08
G09M	04/14/2021	322.19
G09M	05/11/2021	321.42
G09M	05/12/2021	321.42
G09M	06/01/2021	317.47
G09M	06/14/2021	318.47
G09M	07/06/2021	316.93
G09M	07/21/2021	317.29
G10	03/04/2021	319.43
G10	03/24/2021	323.30
G10	04/13/2021	320.85
G10	05/11/2021	330.45
G10	06/01/2021	313.37
G10	06/15/2021	313.34
G10	07/06/2021	313.38
G10	07/20/2021	313.54
G11	03/04/2021	319.77
G11	03/24/2021	326.09

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G11	04/14/2021	325.15
G11	05/12/2021	322.77
G11	06/01/2021	323.49
G11	06/14/2021	320.25
G11	07/06/2021	319.25
G11	07/20/2021	319.20
G51D	12/02/2015	314.45
G51D	03/15/2016	327.04
G51D	06/14/2016	318.87
G51D	06/15/2016	318.87
G51D	09/13/2016	315.72
G51D	09/14/2016	315.72
G51D	12/14/2016	313.02
G51D	03/07/2017	316.35
G51D	06/14/2017	320.67
G51D	07/19/2017	317.56
G51D	11/30/2017	313.75
G51D	06/09/2018	318.42
G51D	09/05/2018	314.45
G51D	03/27/2019	329.28
G51D	09/09/2019	320.02
G51D	03/30/2020	330.18
G51D	09/23/2020	318.91
G51D	09/24/2020	318.91
G51D	03/03/2021	321.47
G51D	03/24/2021	326.10
G51D	04/14/2021	325.45
G51D	05/11/2021	323.14
G51D	06/01/2021	321.10
G51D	06/14/2021	320.84
G51D	07/06/2021	322.67
G51D	07/20/2021	319.59
G51D	09/20/2021	317.85
G52D	12/02/2015	315.68
G52D	03/15/2016	322.23
G52D	06/14/2016	323.04
G52D	06/15/2016	323.04
G52D	09/13/2016	320.37
G52D	09/14/2016	320.37
G52D	12/14/2016	316.85
G52D	03/07/2017	318.38
G52D	06/14/2017	322.05
G52D	07/19/2017	321.17
G52D	11/30/2017	316.31
G52D	06/09/2018	323.86
G52D	09/05/2018	320.38

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G52D	03/27/2019	328.73
G52D	09/09/2019	325.49
G52D	03/30/2020	327.82
G52D	09/23/2020	322.71
G52D	09/24/2020	322.71
G52D	03/03/2021	327.46
G52D	03/24/2021	323.36
G52D	03/25/2021	323.36
G52D	04/14/2021	321.87
G52D	05/12/2021	309.79
G52D	06/01/2021	324.23
G52D	06/15/2021	323.91
G52D	07/06/2021	323.36
G52D	07/20/2021	322.91
G52D	09/20/2021	321.10
G53D	12/02/2015	312.50
G53D	03/15/2016	322.34
G53D	06/14/2016	317.61
G53D	06/15/2016	317.61
G53D	09/13/2016	314.26
G53D	09/14/2016	314.26
G53D	12/14/2016	311.44
G53D	03/07/2017	314.62
G53D	06/14/2017	319.56
G53D	07/19/2017	316.33
G53D	11/30/2017	312.17
G53D	06/09/2018	317.31
G53D	09/05/2018	313.47
G53D	03/27/2019	328.27
G53D	09/09/2019	318.48
G53D	03/30/2020	328.98
G53D	09/23/2020	317.41
G53D	09/24/2020	317.41
G53D	03/03/2021	319.40
G53D	03/24/2021	325.15
G53D	03/25/2021	325.15
G53D	04/14/2021	324.23
G53D	05/11/2021	320.99
G53D	06/01/2021	319.65
G53D	06/14/2021	320.17
G53D	07/06/2021	318.02
G53D	07/20/2021	317.83
G53D	09/20/2021	316.26
G54S	03/03/2021	310.25
G54S	03/24/2021	311.48
G54S	04/14/2021	312.84

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G54S	05/12/2021	315.44
G54S	06/01/2021	312.65
G54S	06/14/2021	314.30
G54S	07/06/2021	316.75
G54S	07/20/2021	318.87
G54D	12/02/2015	310.44
G54D	03/15/2016	316.80
G54D	06/15/2016	312.24
G54D	09/13/2016	309.47
G54D	09/14/2016	309.47
G54D	12/14/2016	307.13
G54D	03/07/2017	313.34
G54D	06/14/2017	315.35
G54D	07/19/2017	312.52
G54D	11/30/2017	309.28
G54D	06/09/2018	313.80
G54D	09/05/2018	308.37
G54D	03/27/2019	326.30
G54D	09/09/2019	314.08
G54D	03/30/2020	329.13
G54D	09/23/2020	313.18
G54D	09/24/2020	313.18
G54D	03/03/2021	317.69
G54D	03/24/2021	324.08
G54D	04/14/2021	322.45
G54D	05/12/2021	319.02
G54D	06/01/2021	314.79
G54D	06/14/2021	314.93
G54D	07/06/2021	314.73
G54D	07/20/2021	314.77
G54D	09/20/2021	312.54
G151	03/03/2021	326.64
G151	03/24/2021	330.47
G151	04/14/2021	329.35
G151	05/11/2021	329.35
G151	06/01/2021	325.68
G151	06/14/2021	326.03
G151	07/06/2021	324.48
G151	07/20/2021	324.77
G152B	03/03/2021	338.25
G152B	03/25/2021	338.38
G152B	04/14/2021	336.25
G152B	05/12/2021	338.96
G152B	06/01/2021	334.71
G152B	06/15/2021	335.06
G152B	07/06/2021	332.91

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G152B	07/20/2021	332.91
G153	03/03/2021	319.04
G153	03/25/2021	324.74
G153	04/13/2021	324.60
G153	05/11/2021	320.59
G153	06/01/2021	319.71
G153	06/14/2021	320.19
G153	07/06/2021	318.17
G153	07/20/2021	317.91
XPW01	03/05/2021	369.84
XPW01	03/24/2021	370.64
XPW01	04/14/2021	367.84
XPW01	05/12/2021	369.71
XPW01	06/01/2021	367.76
XPW01	06/14/2021	368.67
XPW01	07/06/2021	367.83
XPW01	07/21/2021	368.46
XPW02	03/04/2021	372.79
XPW02	03/24/2021	373.89
XPW02	04/14/2021	371.64
XPW02	05/12/2021	372.53
XPW02	06/01/2021	370.79
XPW02	06/14/2021	371.54
XPW02	07/06/2021	370.52
XPW02	07/21/2021	371.15
XPW03	03/04/2021	373.84
XPW03	03/24/2021	374.54
XPW03	04/14/2021	372.77
XPW03	05/12/2021	373.31
XPW03	06/01/2021	372.07
XPW03	06/14/2021	372.40
XPW03	07/06/2021	372.06
XPW03	07/21/2021	372.27
XSG01	03/05/2021	357.48
XSG01	03/25/2021	367.78
XSG01	04/14/2021	368.78
XSG01	05/12/2021	369.28
XSG01	06/01/2021	368.86
XSG01	06/14/2021	367.28
XSG01	07/06/2021	367.18
XSG01	07/20/2021	367.03
SG02	03/03/2021	323.28
SG02	03/04/2021	324.48
SG02	03/05/2021	324.83
SG02	03/24/2021	320.66
SG02	04/13/2021	312.19

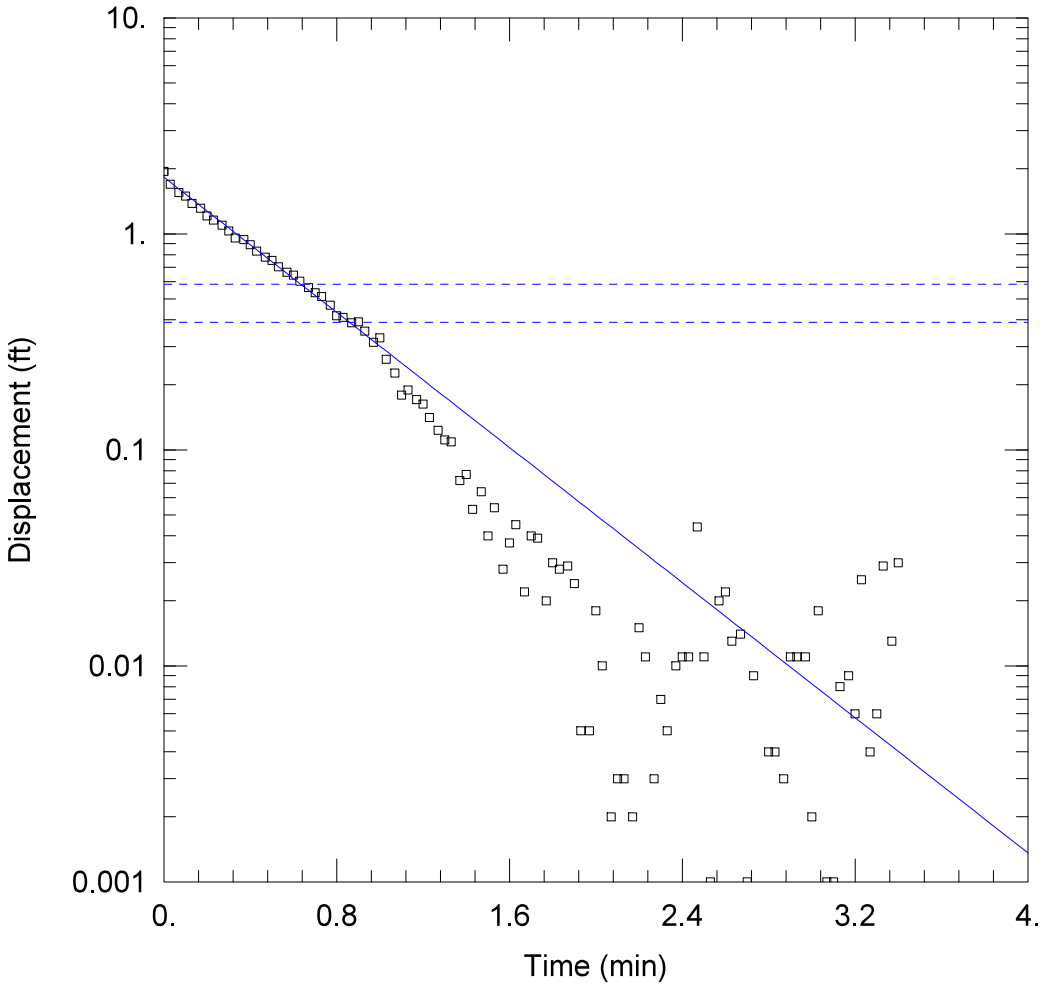
TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
SG02	04/14/2021	312.01
SG02	05/11/2021	312.39
SG02	05/12/2021	310.73
SG02	06/01/2021	301.18
SG02	06/14/2021	303.62
SG02	06/15/2021	302.69
SG02	07/06/2021	306.26
SG02	07/20/2021	309.37
SG02	07/21/2021	309.33

Notes:
ft NAVD88 = feet relative to the North American Vertical Datum 1988, GEOID 12A

generated 10/11/2021, 12:35:23 PM CDT

APPENDIX F
HYDRAULIC CONDUCTIVITY TEST DATA



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:36:29

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

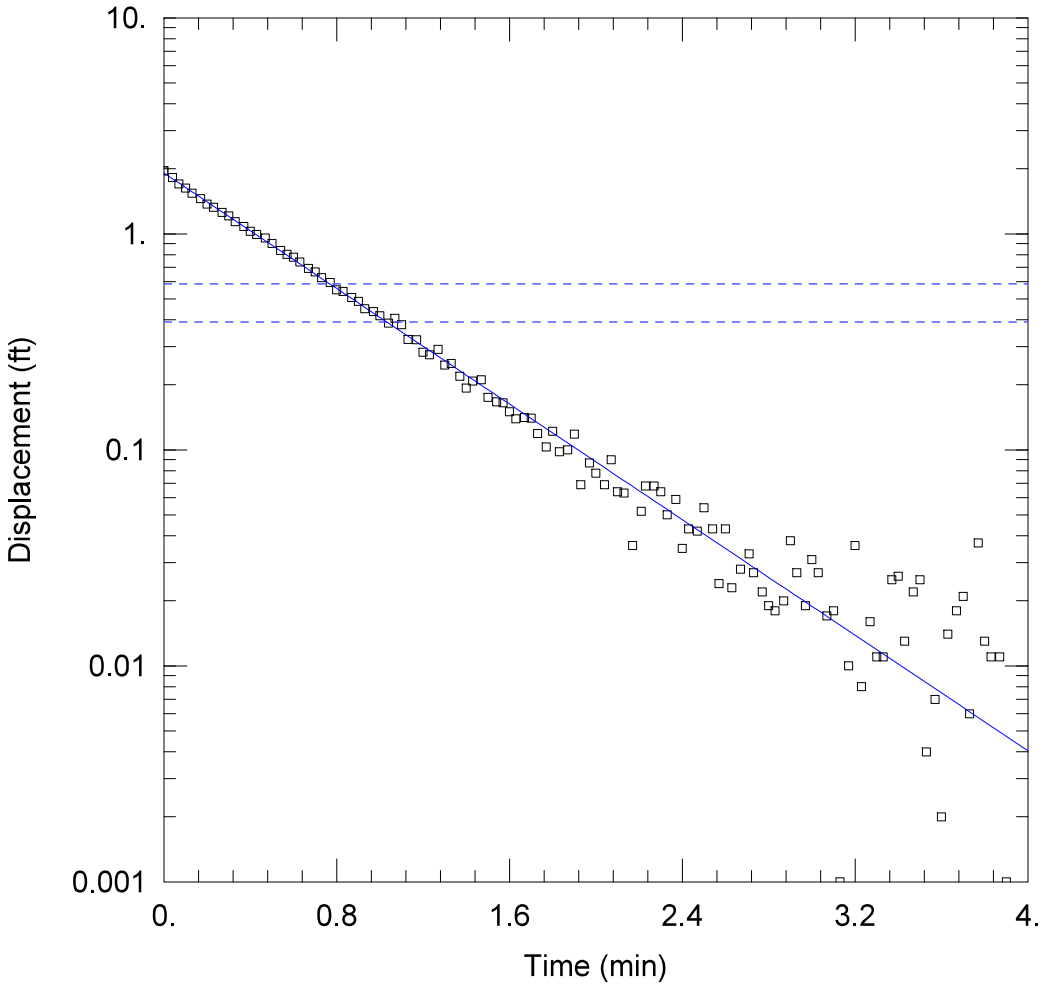
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 1 slug in))

Initial Displacement: 1.945 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001199 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.829 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:37:34

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

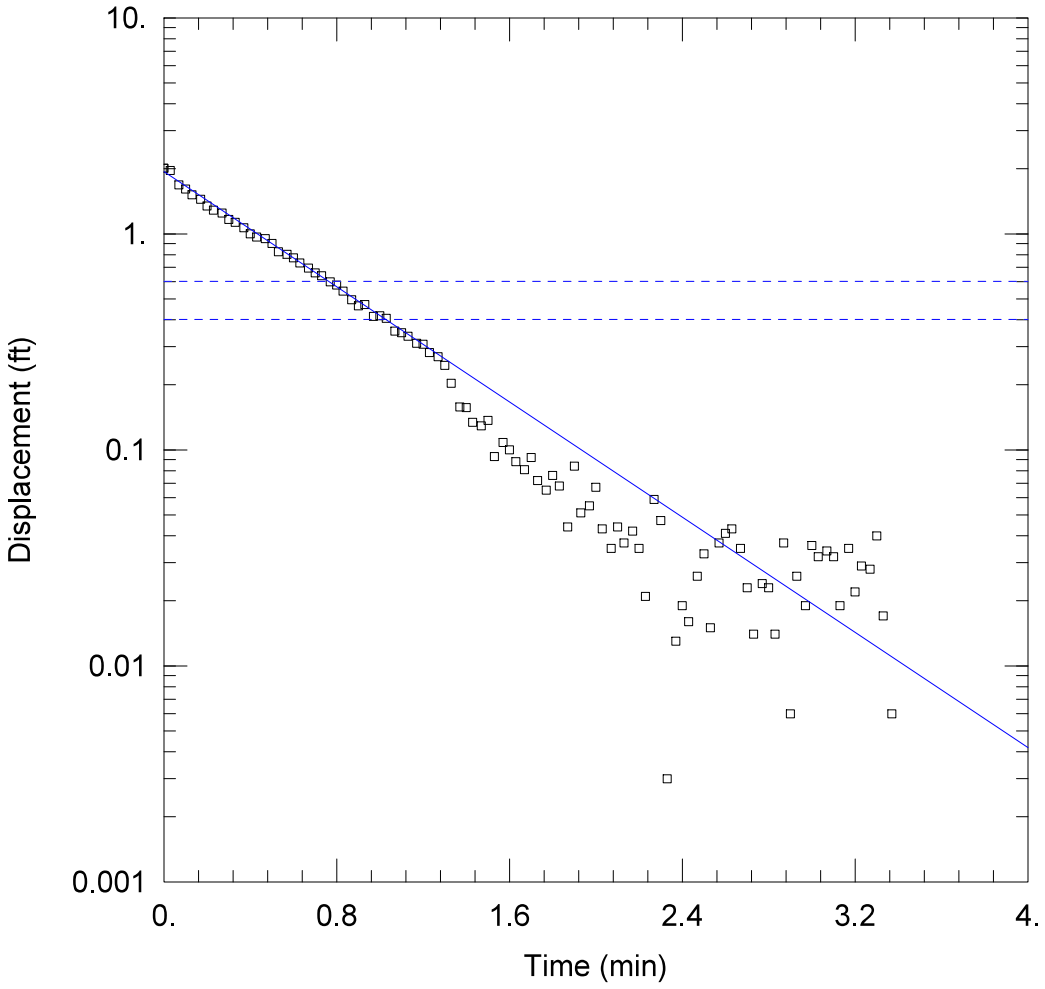
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 2 slug out))

Initial Displacement: 1.956 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001025 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.915 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:38:16

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

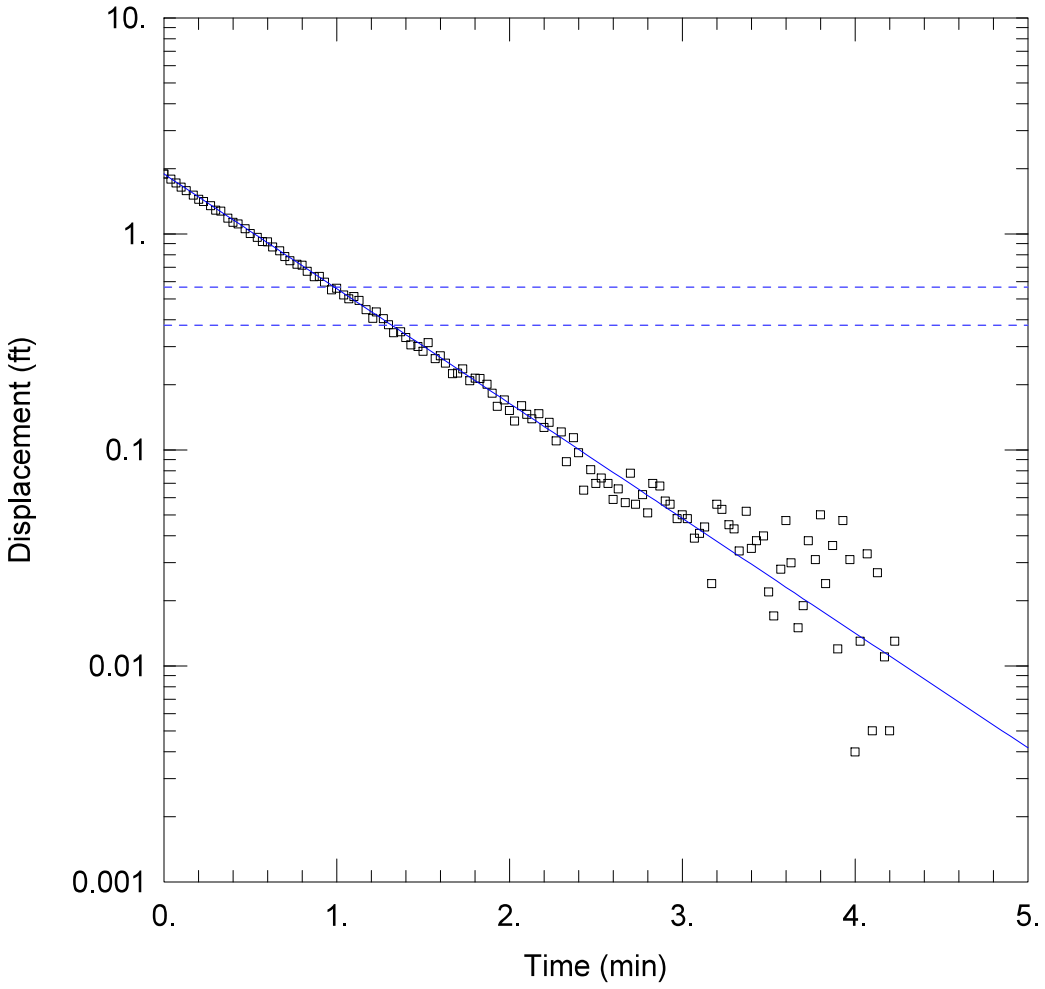
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 3 slug in))

Initial Displacement: 2.01 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001022 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.941 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:38:53

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

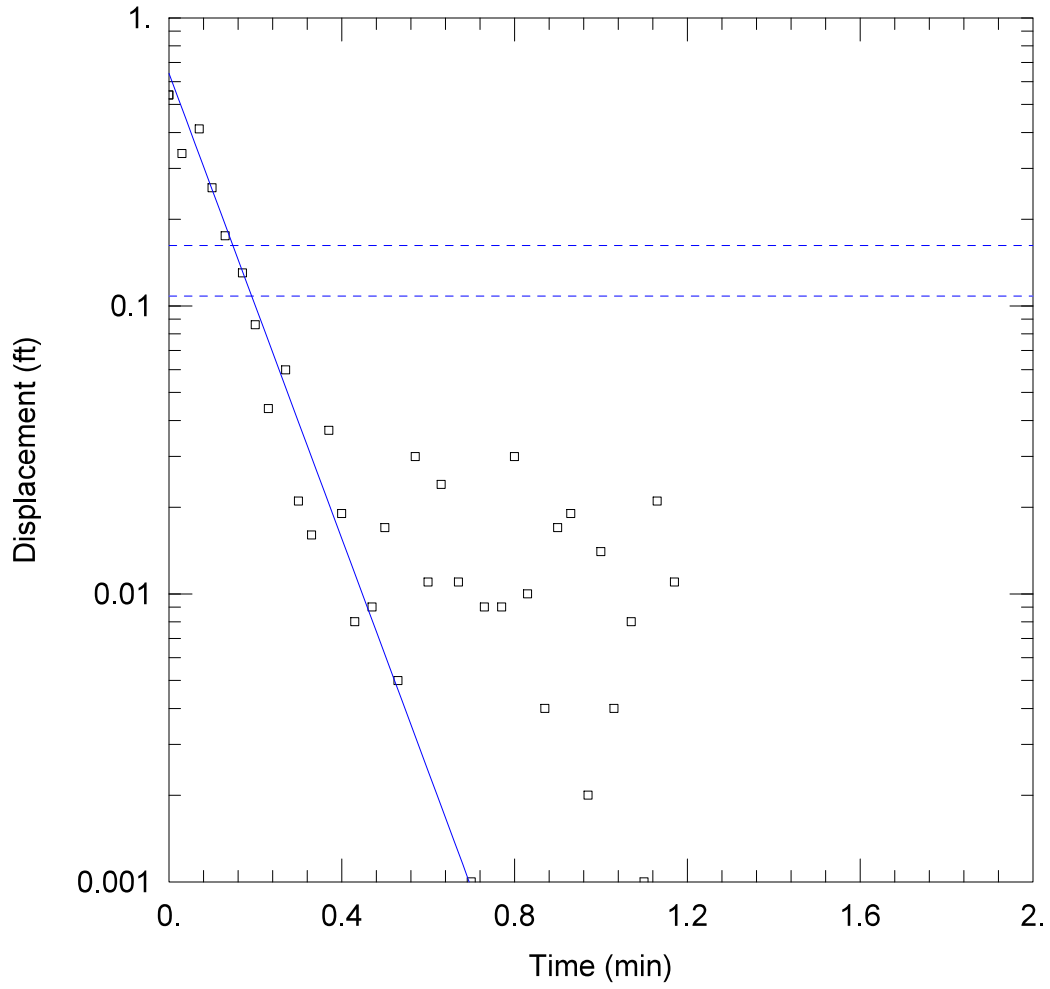
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 4 slug out))

Initial Displacement: 1.89 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.0008143 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.895 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:41:12

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

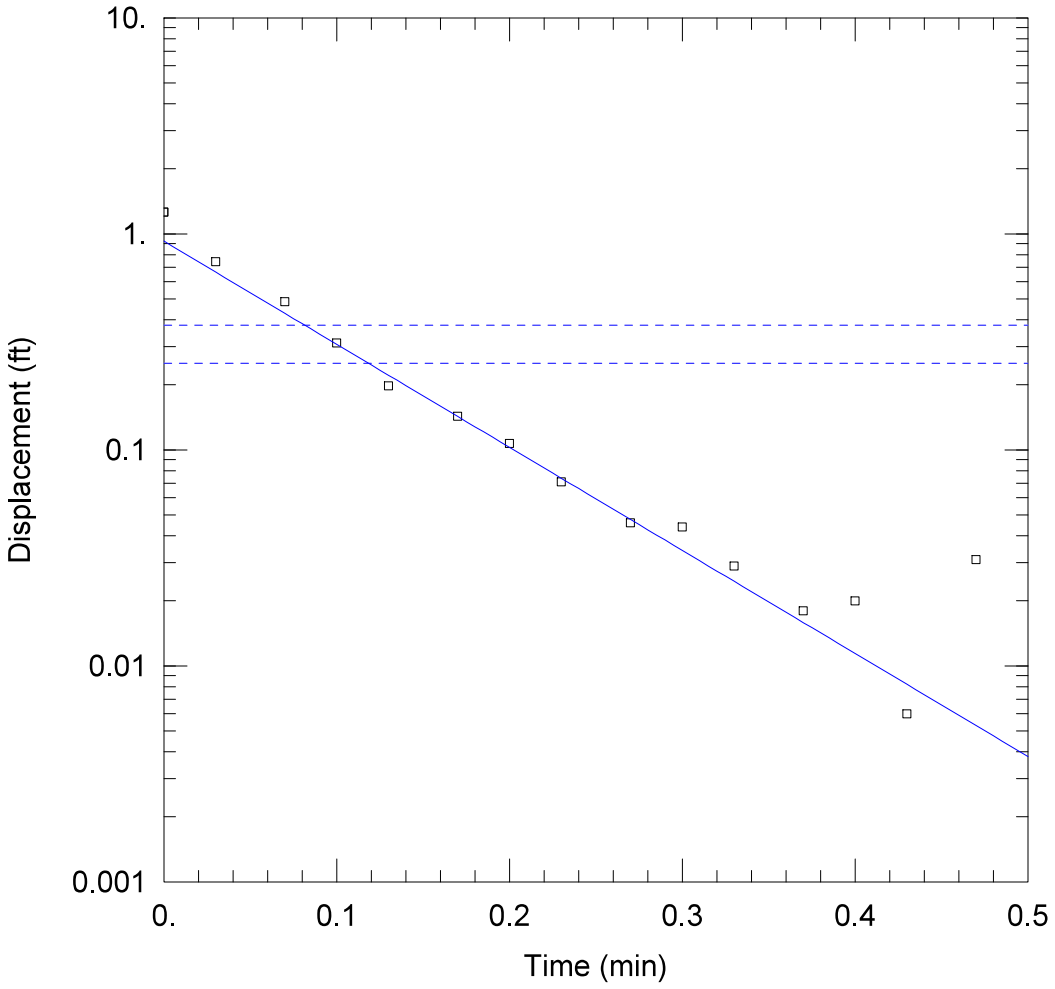
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 1 slug in))

Initial Displacement: 0.54 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006959 cm/sec
y0 = 0.6416 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:41:51

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: G-07

AQUIFER DATA

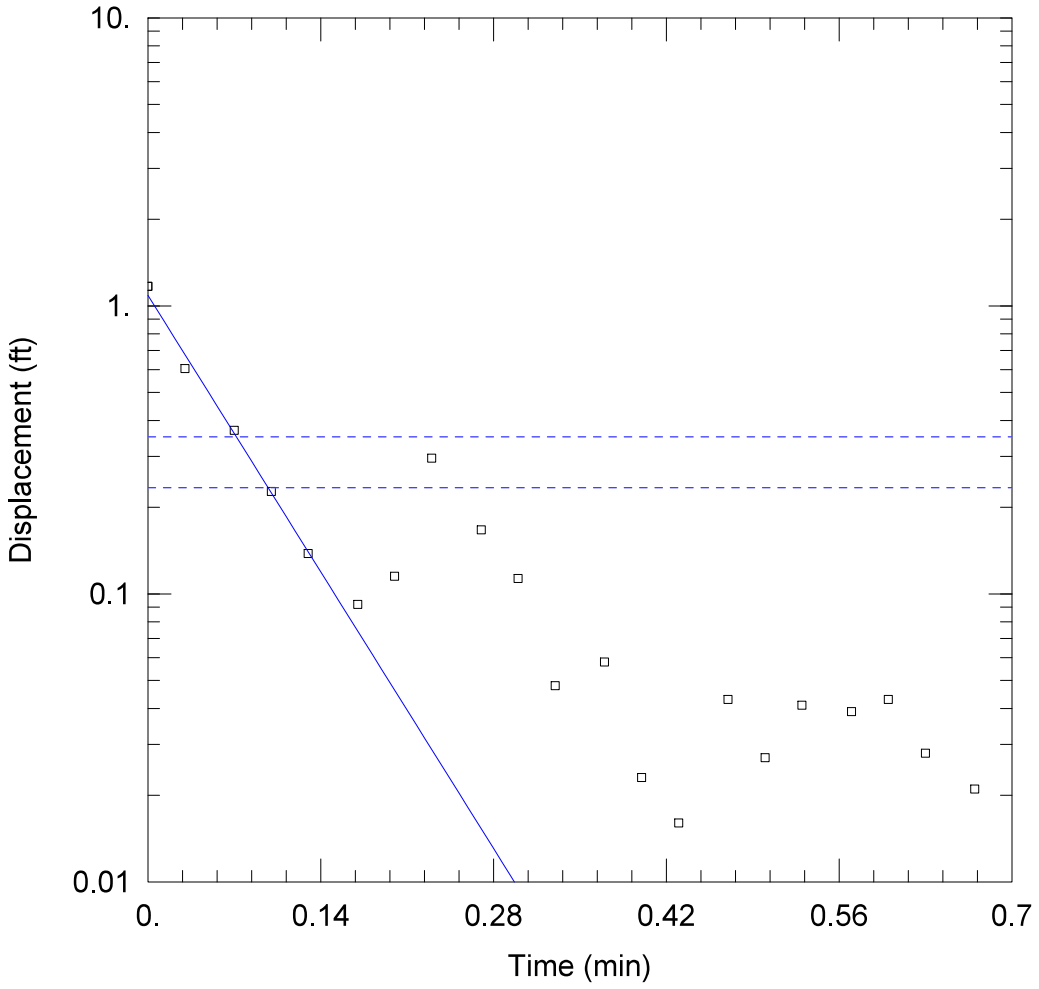
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 2 slug-out))

Initial Displacement: 1.26 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.008223 cm/sec
y0 = 0.9246 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:42:56

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: G-07

AQUIFER DATA

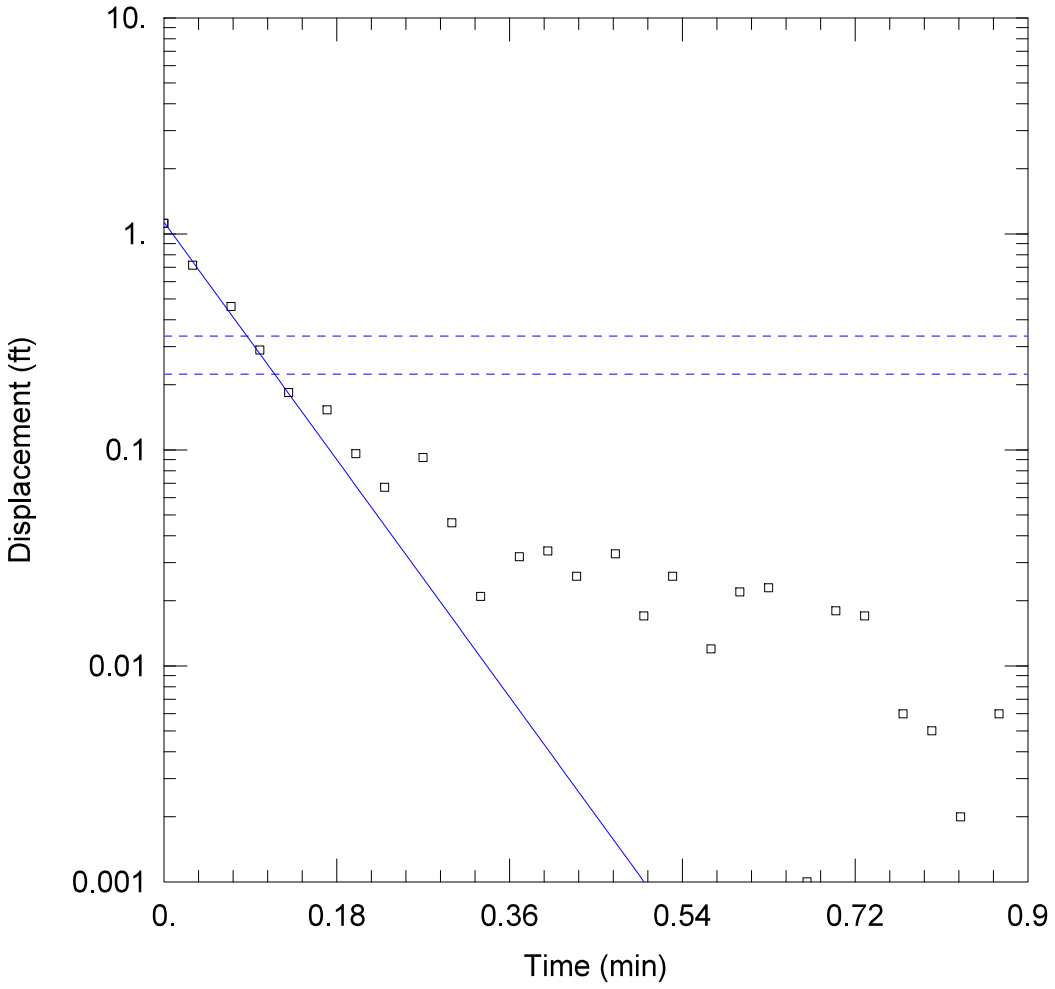
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 3 slug-in))

Initial Displacement: 1.168 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01182 cm/sec
y0 = 1.087 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:43:39

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

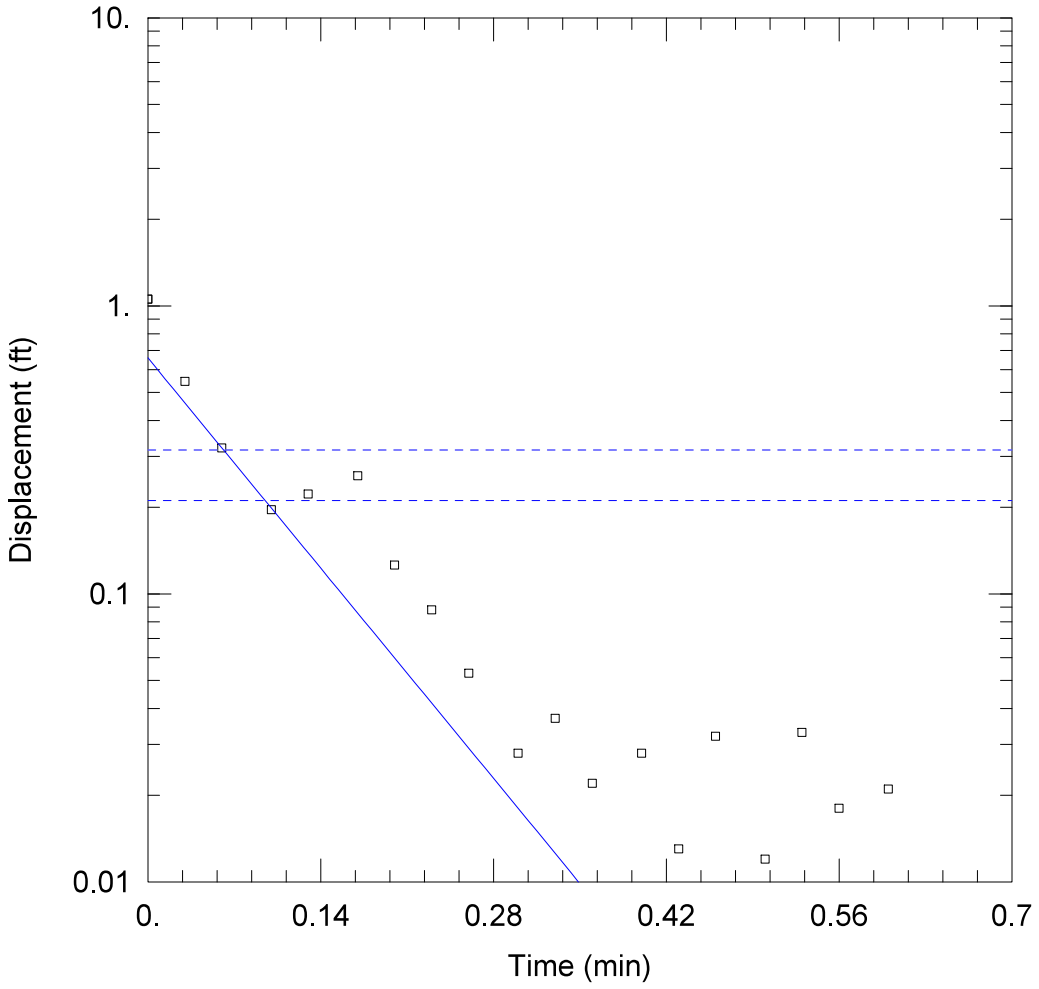
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 4 slug-out))

Initial Displacement: 1.119 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01052 cm/sec
y0 = 1.132 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 5 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:44:38

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

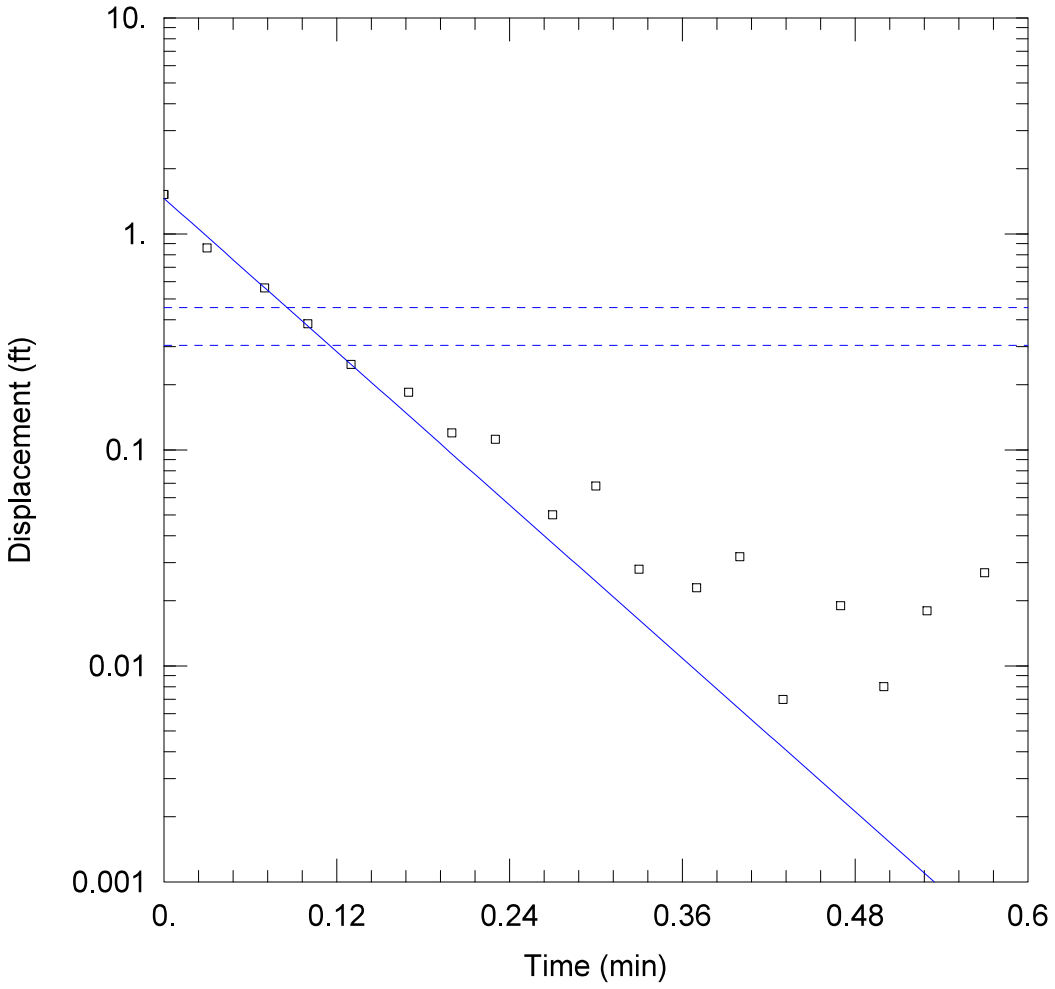
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 5 slug-out))

Initial Displacement: 1.054 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.008984 cm/sec
Solution Method: Bouwer-Rice
y0 = 0.6591 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 6 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:45:44

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

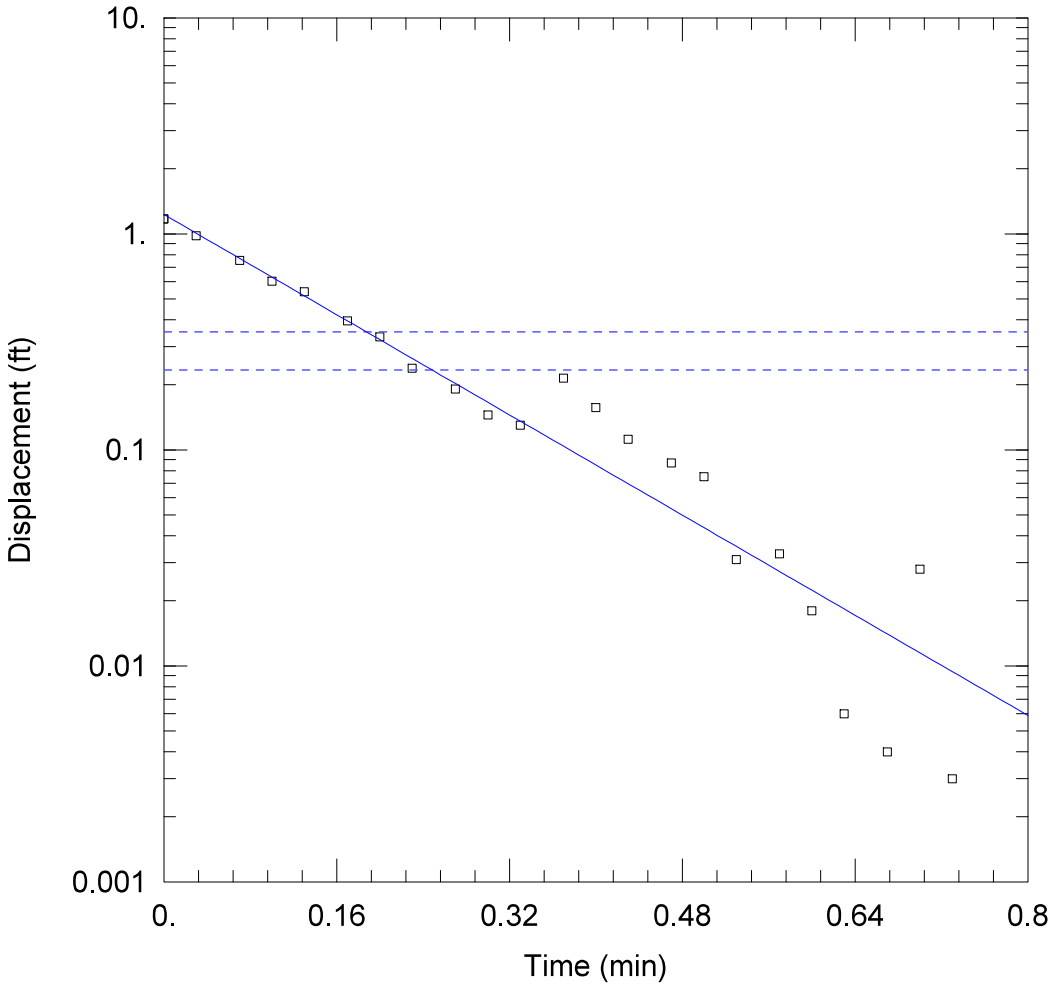
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 6 slug-out))

Initial Displacement: 1.521 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.01019 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.46 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 16:26:39

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

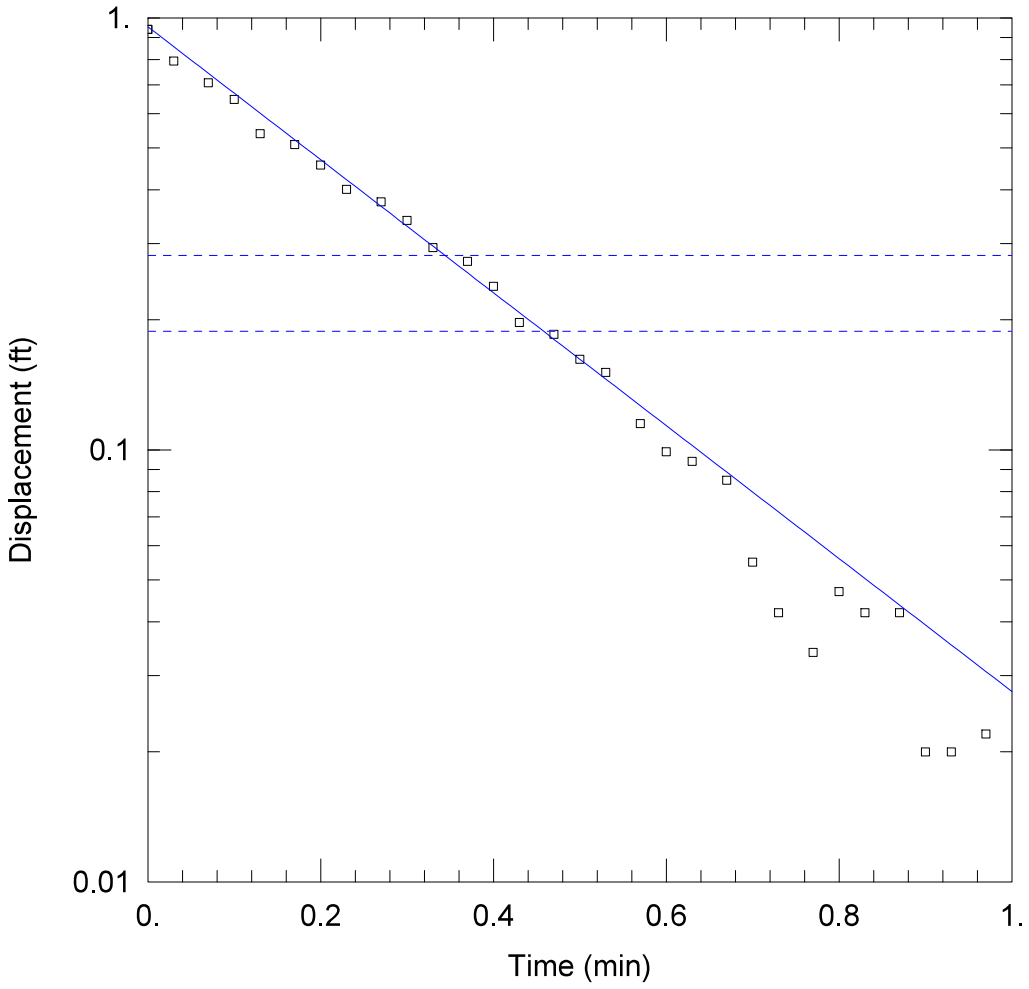
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 1 slug-in))

Initial Displacement: 1.17 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.005507 cm/sec
y0 = 1.229 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 16:29:24

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

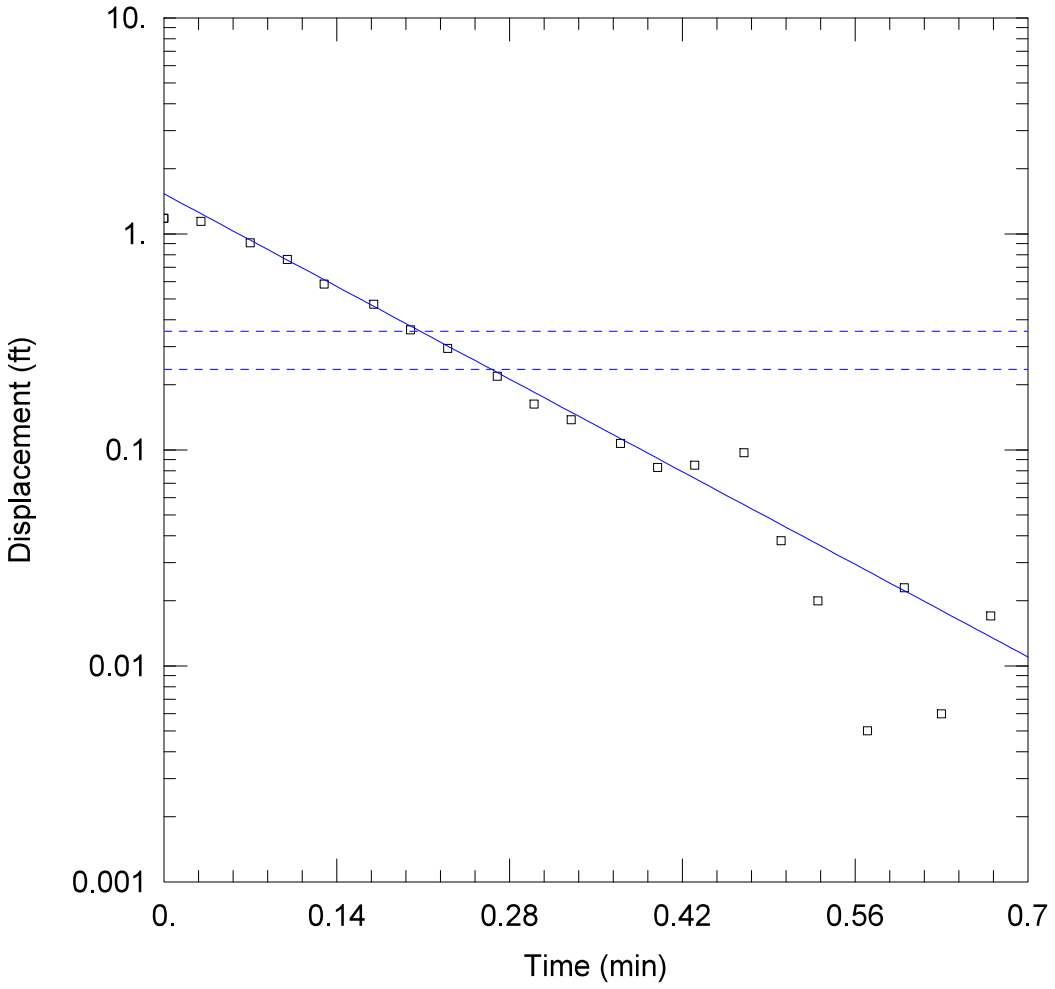
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 2 slug-out))

Initial Displacement: 0.94 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.002923 cm/sec
y0 = 0.953 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 16:31:33

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

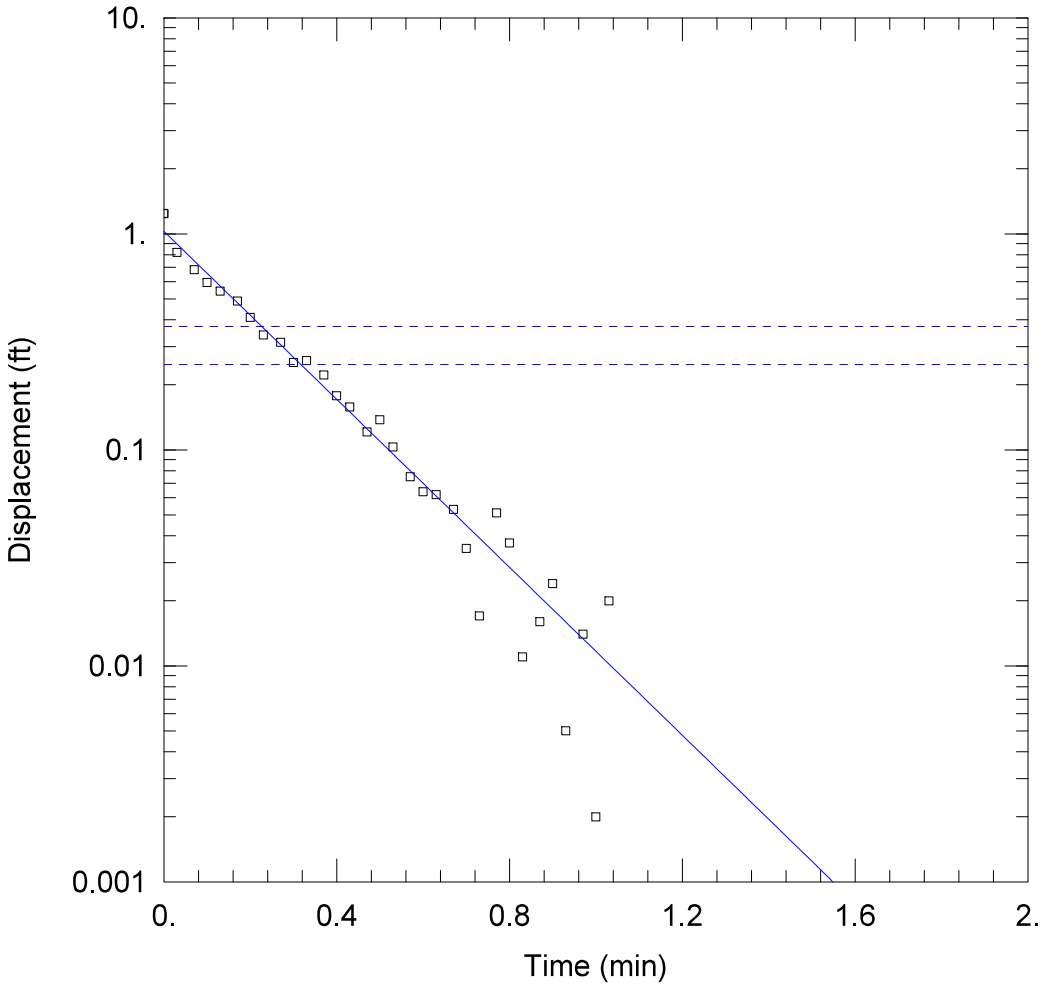
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 2 slug-out))

Initial Displacement: 1.18 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.005818 cm/sec
y0 = 1.532 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 16:33:50

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

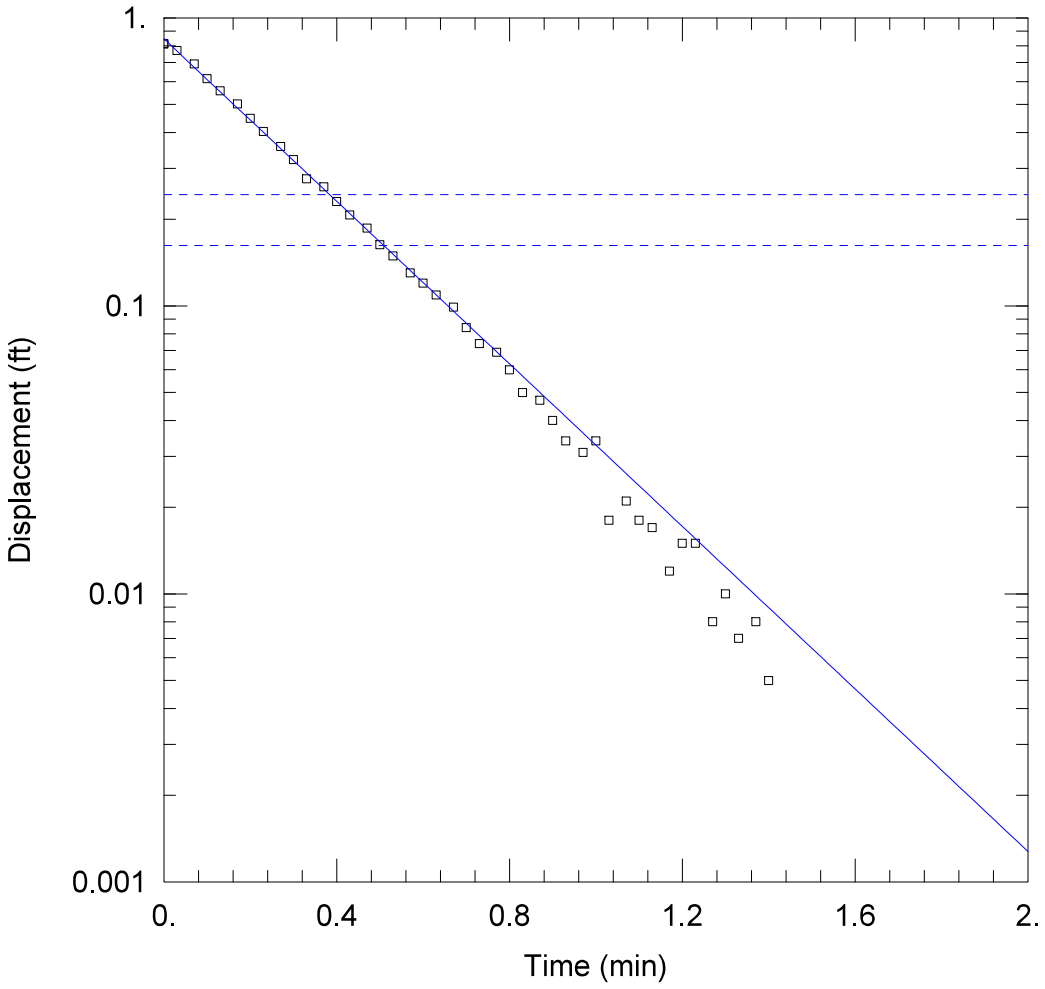
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 4 slug-out))

Initial Displacement: 1.24 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.003693 cm/sec
y0 = 1.026 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-9 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:43:53

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-9

AQUIFER DATA

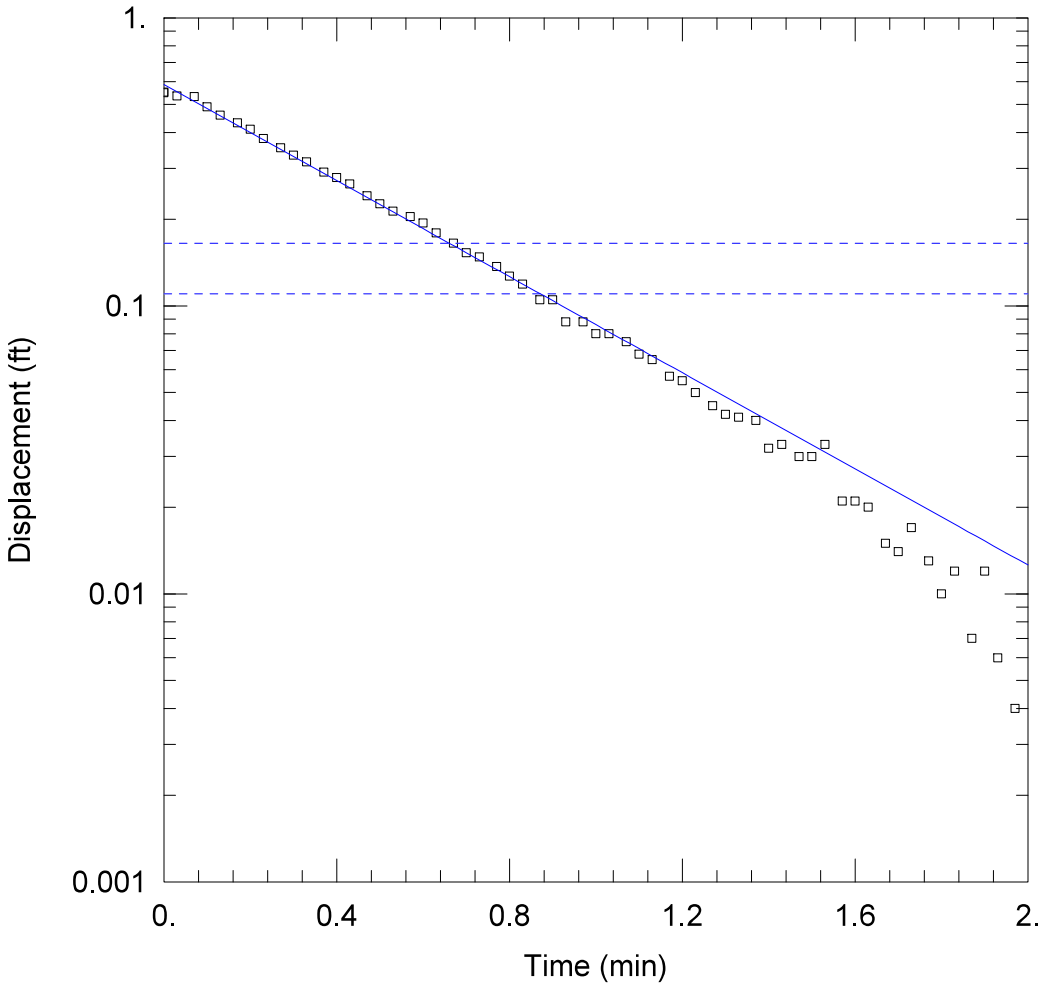
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-9 (test 1 slug-in))

Initial Displacement: 0.81 ft
Total Well Penetration Depth: 40.03 ft
Casing Radius: 0.083 ft
Static Water Column Height: 40.03 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.002618 cm/sec
y0 = 0.8457 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-9 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:46:36

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-9

AQUIFER DATA

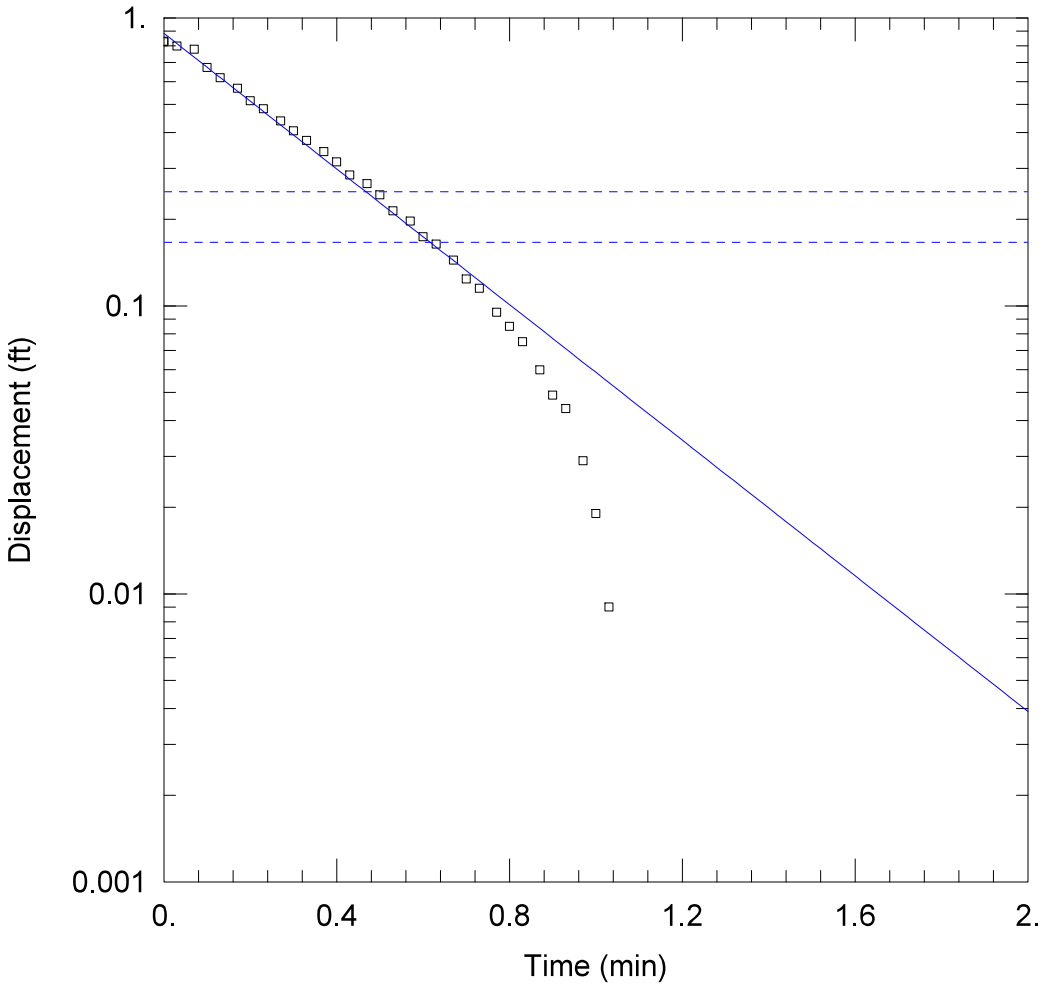
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-9 (test 2 slug-out))

Initial Displacement: 0.55 ft
Total Well Penetration Depth: 40.03 ft
Casing Radius: 0.083 ft
Static Water Column Height: 40.03 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.001548 cm/sec
y0 = 0.5873 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:40:34

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

Saturated Thickness: 10. ft Anisotropy Ratio (Kz/Kr): 0.1

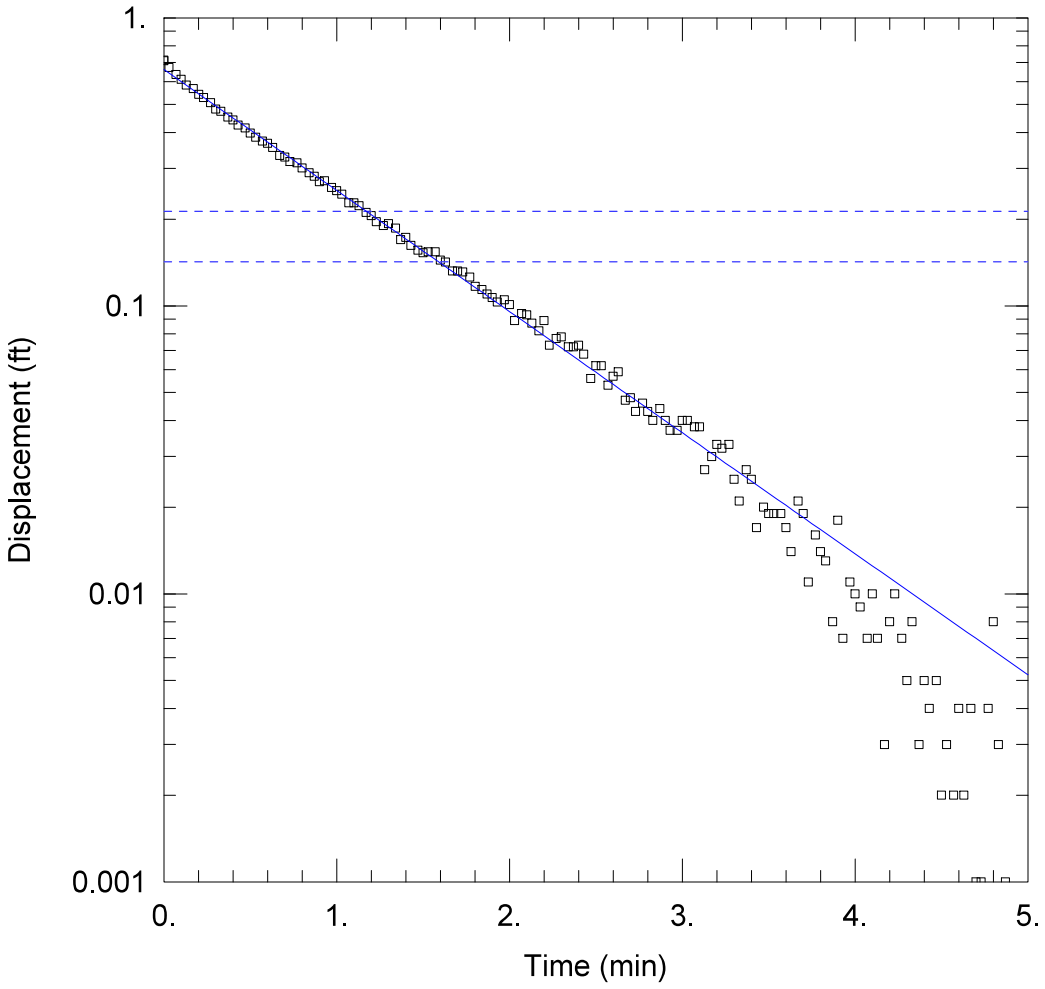
WELL DATA (G-10 (test 1 slug-in))

Initial Displacement: 0.83 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 0.001355 cm/sec y0 = 0.8835 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:42:40

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

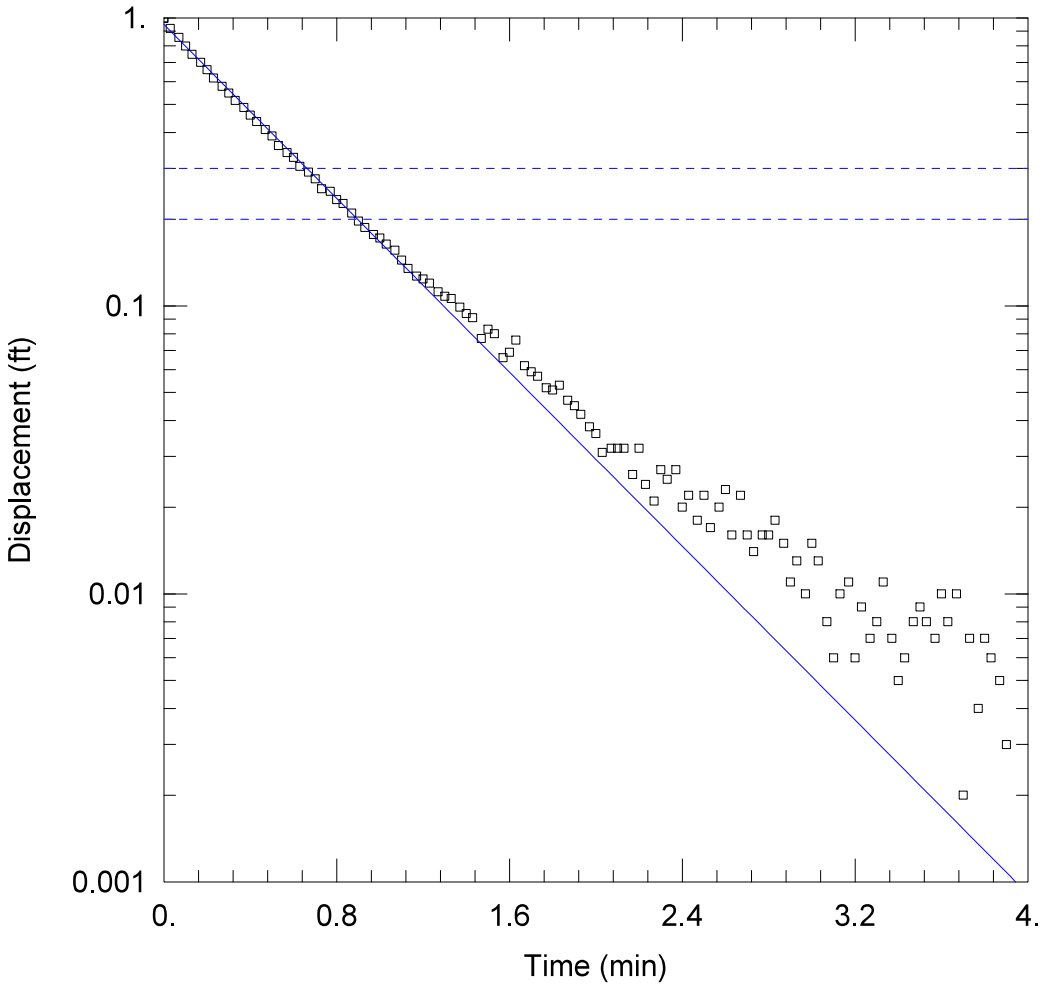
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 2 slug-out))

Initial Displacement: 0.71 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004838 cm/sec
y0 = 0.662 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:44:50

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

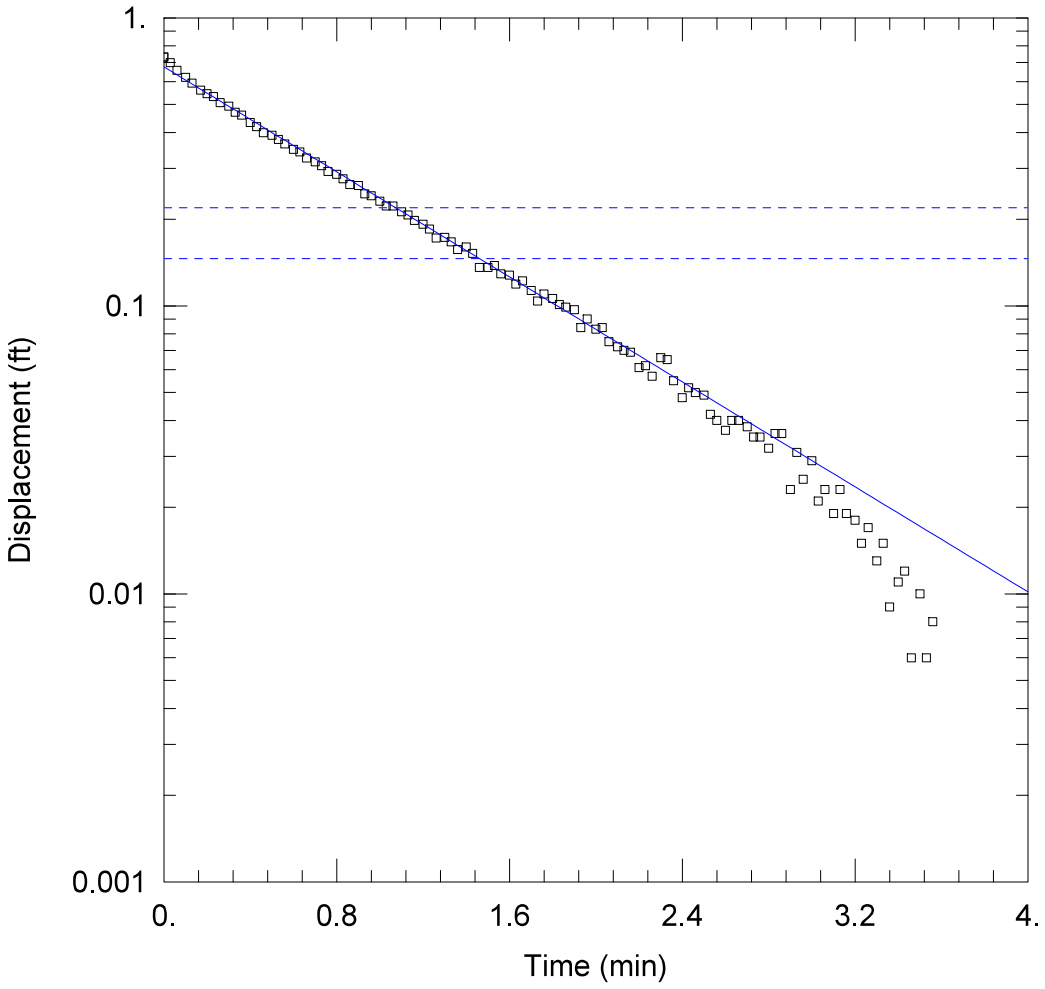
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 3 slug-in))

Initial Displacement: 1. ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0008689 cm/sec
y0 = 0.9483 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:46:31

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

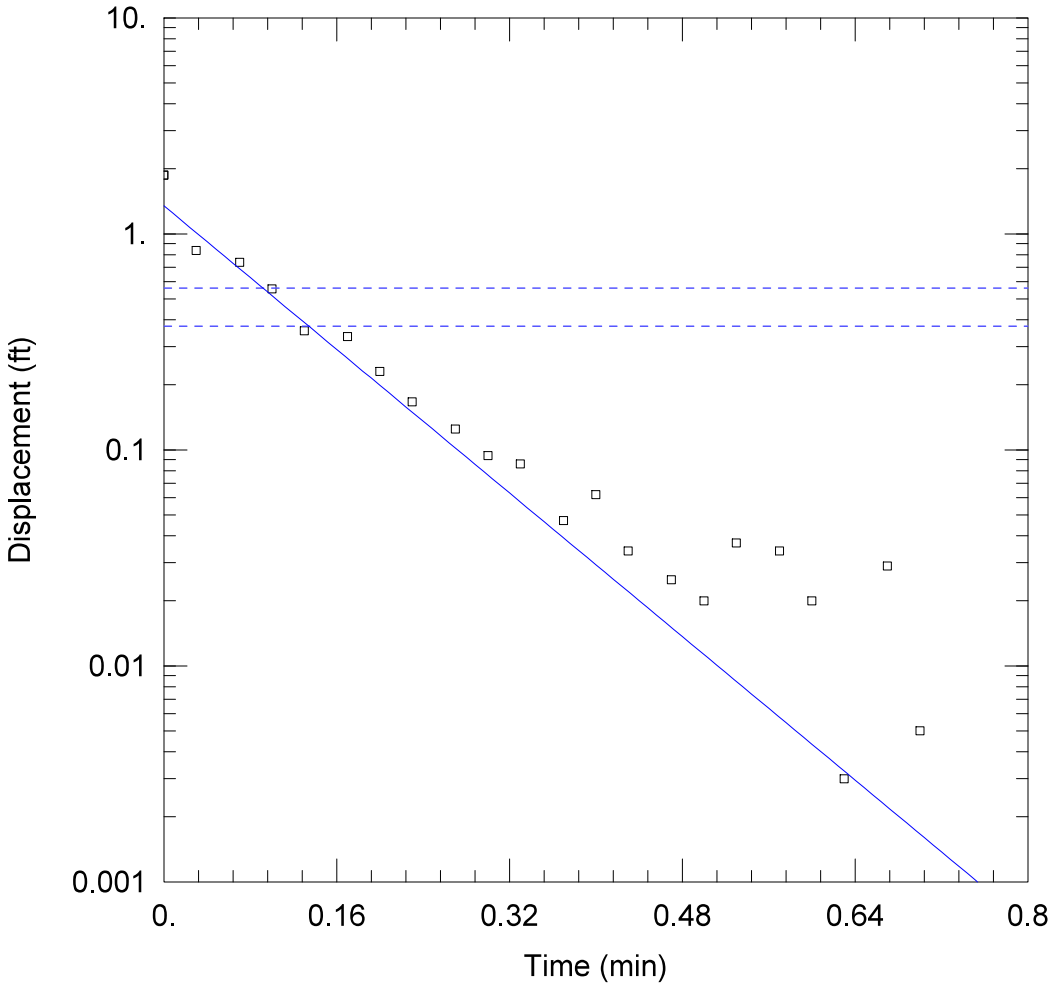
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 4 slug-out))

Initial Displacement: 0.73 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0005246 cm/sec
y0 = 0.6756 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:09:34

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

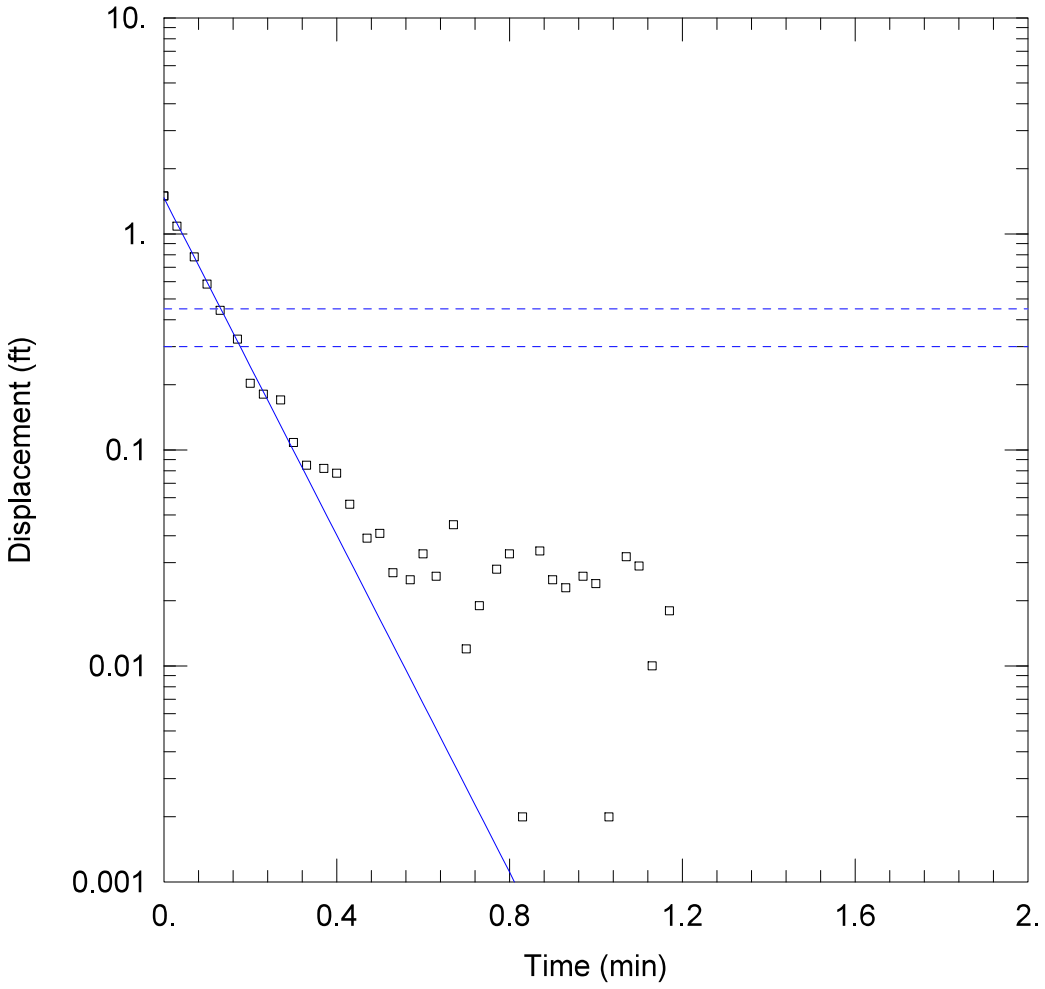
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 1 slug-in))

Initial Displacement: 1.87 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.007151 cm/sec
y0 = 1.348 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:11:32

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

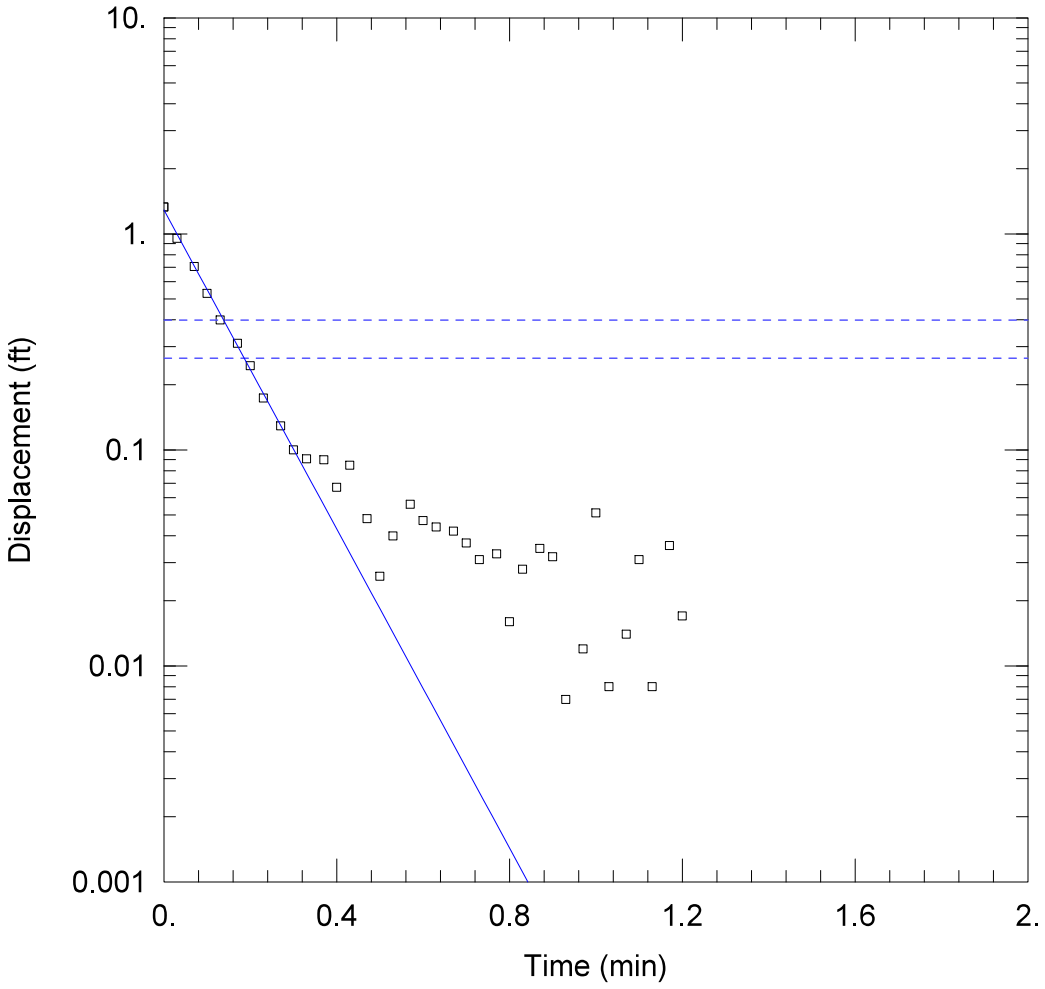
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 2 slug-out))

Initial Displacement: 1.5 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006716 cm/sec
y0 = 1.466 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:15:17

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

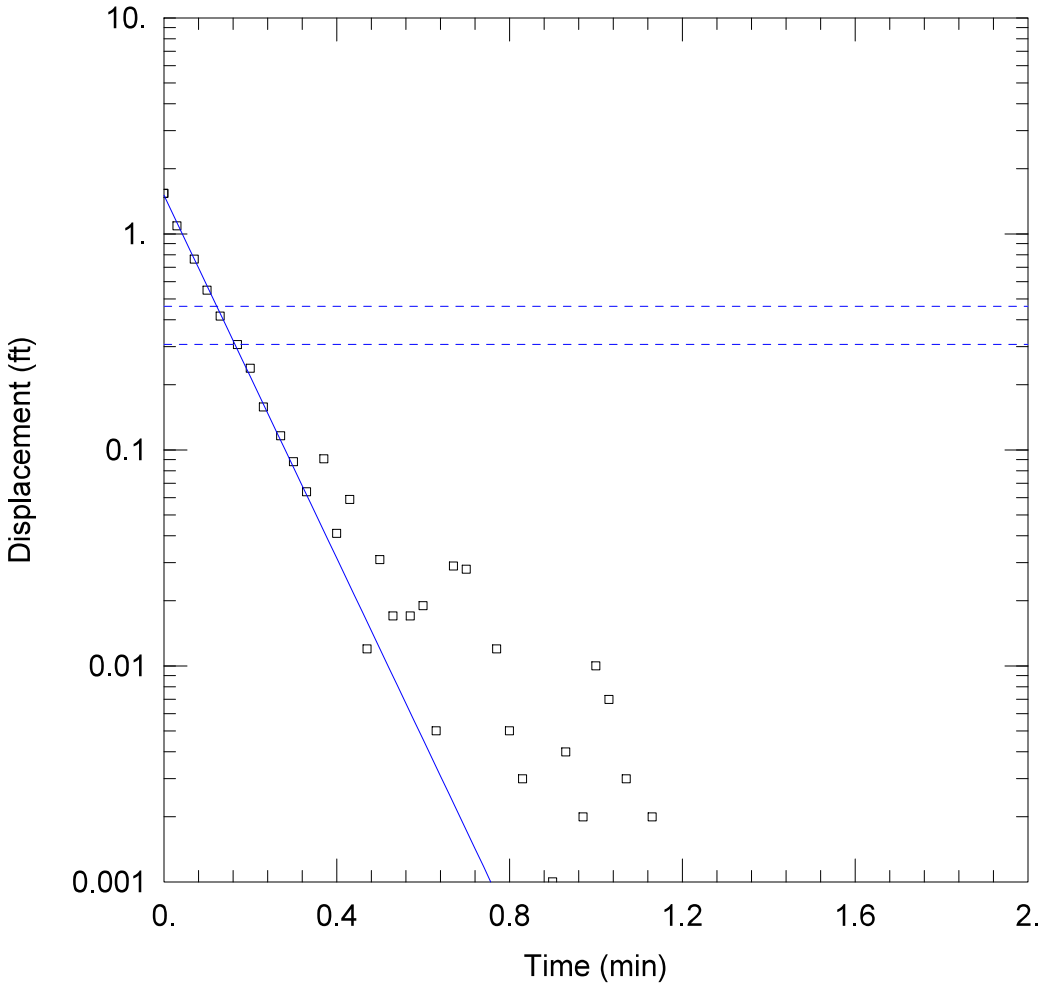
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 3 slug-in))

Initial Displacement: 1.33 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006355 cm/sec
y0 = 1.288 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:19:03

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

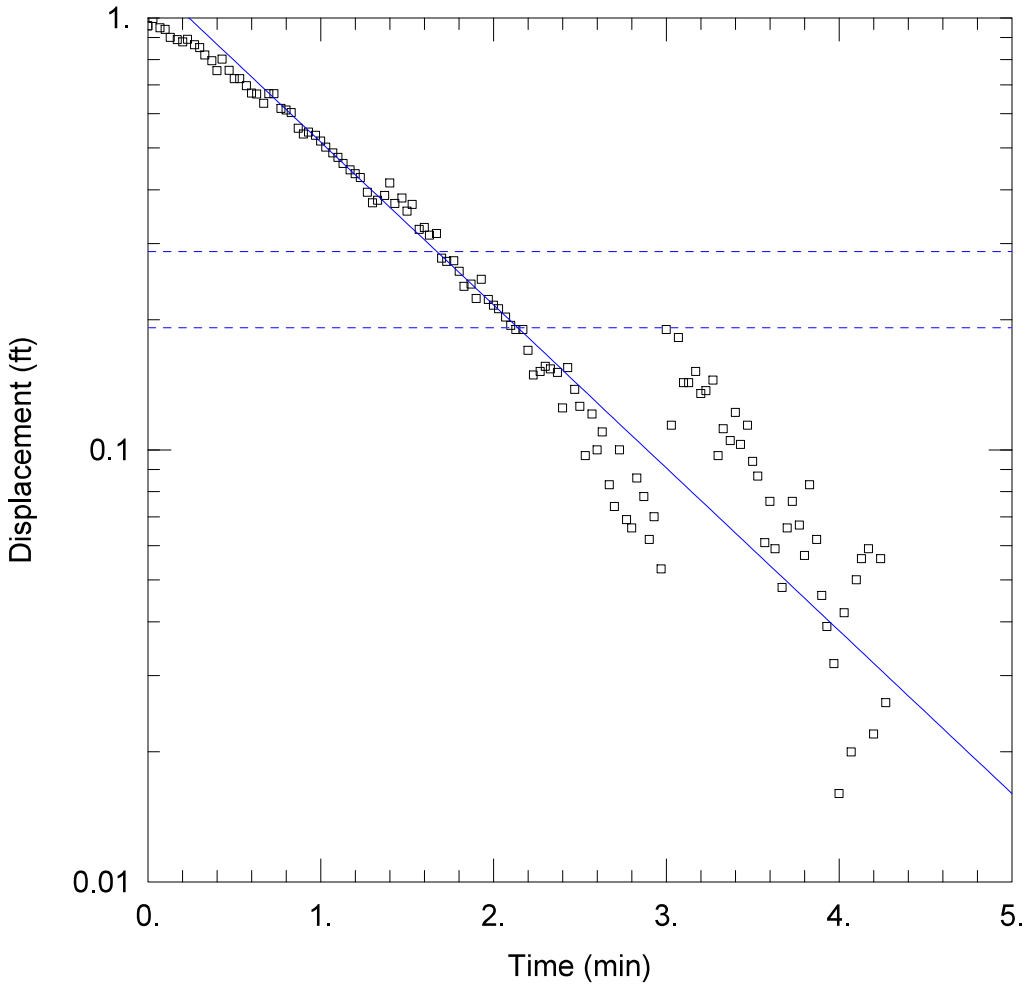
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 4 slug-out))

Initial Displacement: 1.54 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.007229 cm/sec
y0 = 1.506 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 1 (Slug-in).aqt
Date: 03/31/21 Time: 08:32:59

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

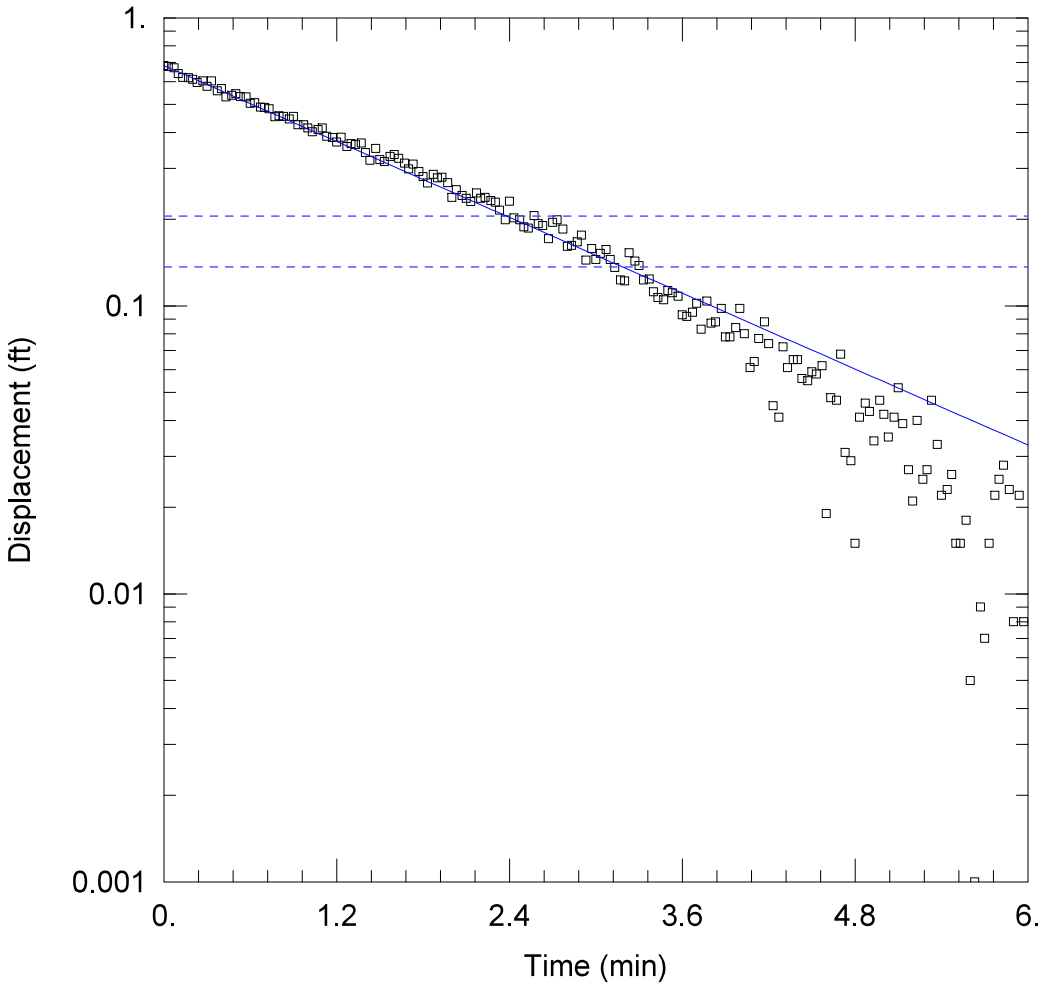
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 1 (Slug in))

Initial Displacement: 0.959 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 1. ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0002725 cm/sec
y0 = 1.228 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 2 (Slug-out).aqt
Date: 03/31/21 Time: 08:41:16

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

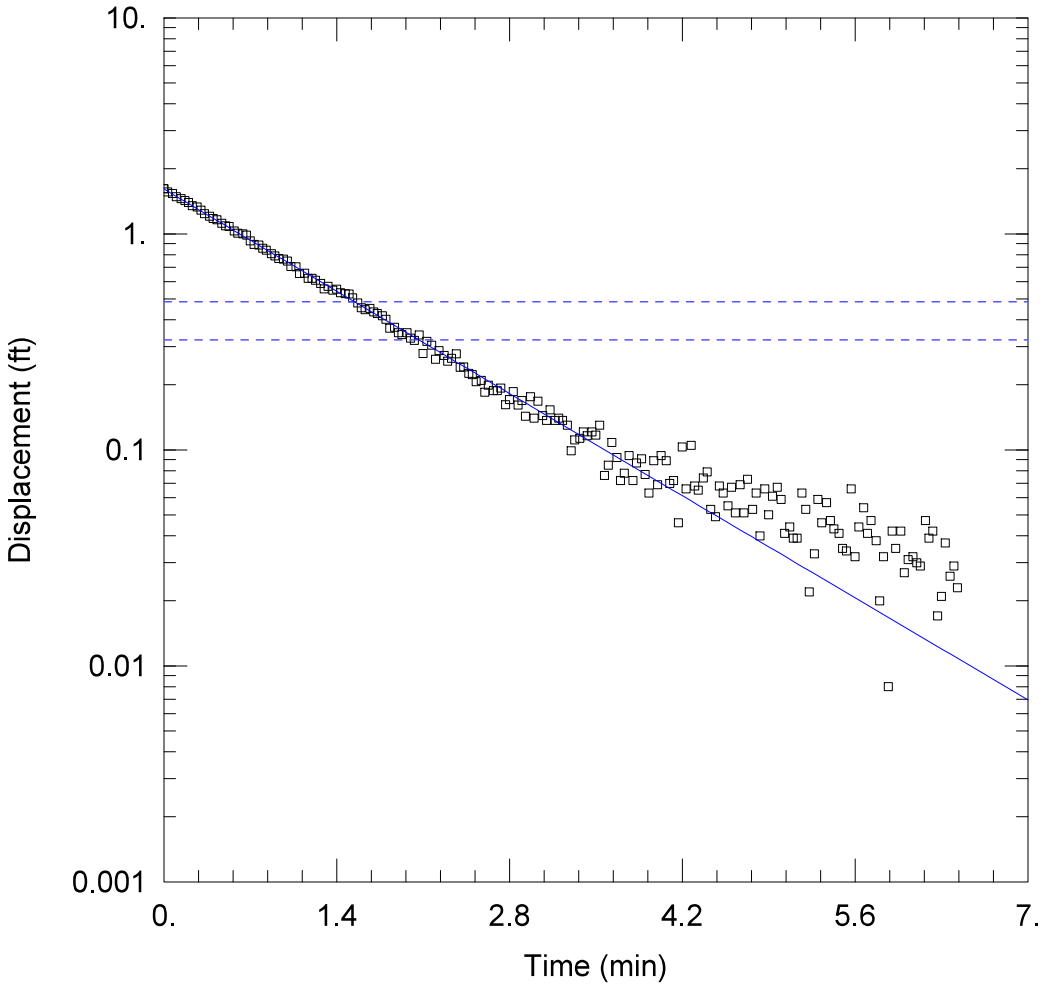
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 2 (Slug out))

Initial Displacement: 0.683 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0003783 cm/sec
y0 = 0.6827 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 3 (Slug-in).aqt
Date: 03/31/21 Time: 08:44:06

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

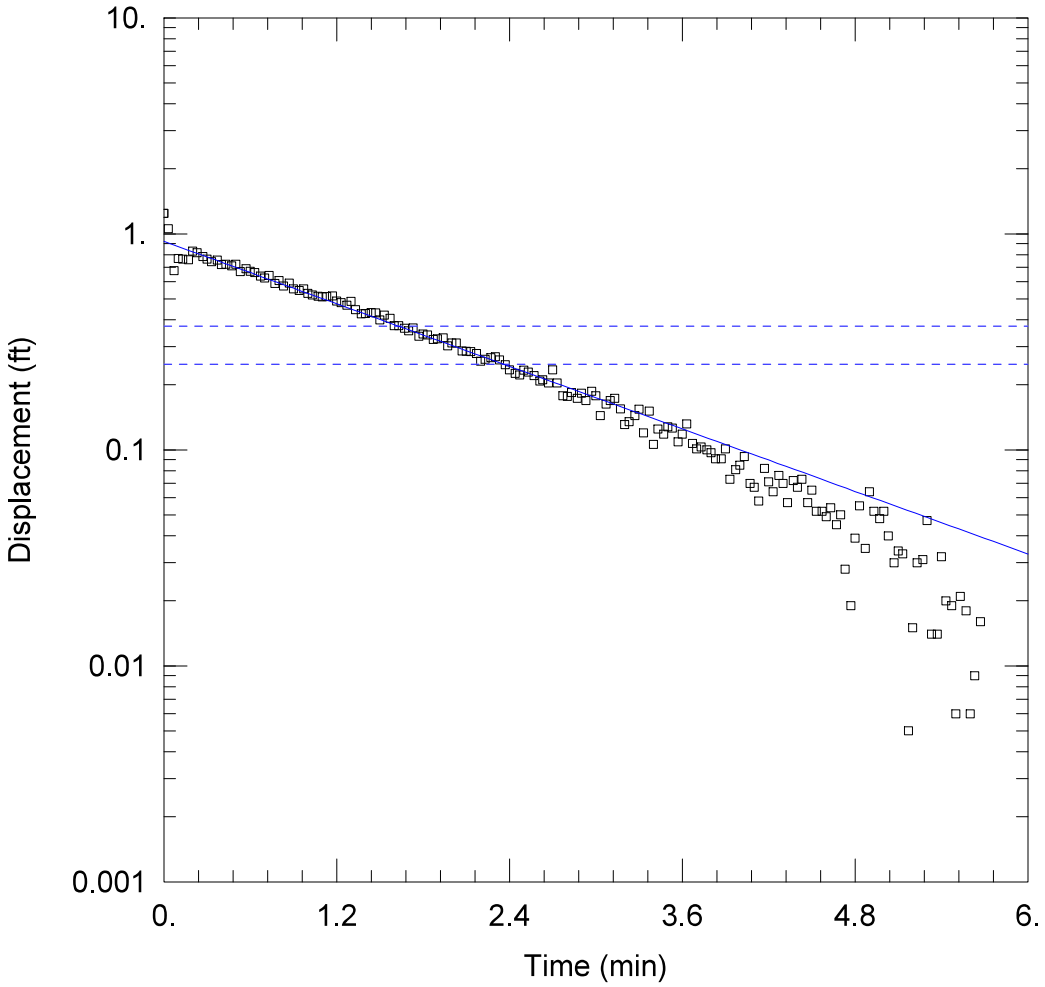
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 3 (Slug in))

Initial Displacement: 1.615 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0005824 cm/sec
y0 = 1.613 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 4 (Slug-out).aqt
Date: 03/31/21 Time: 08:48:06

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

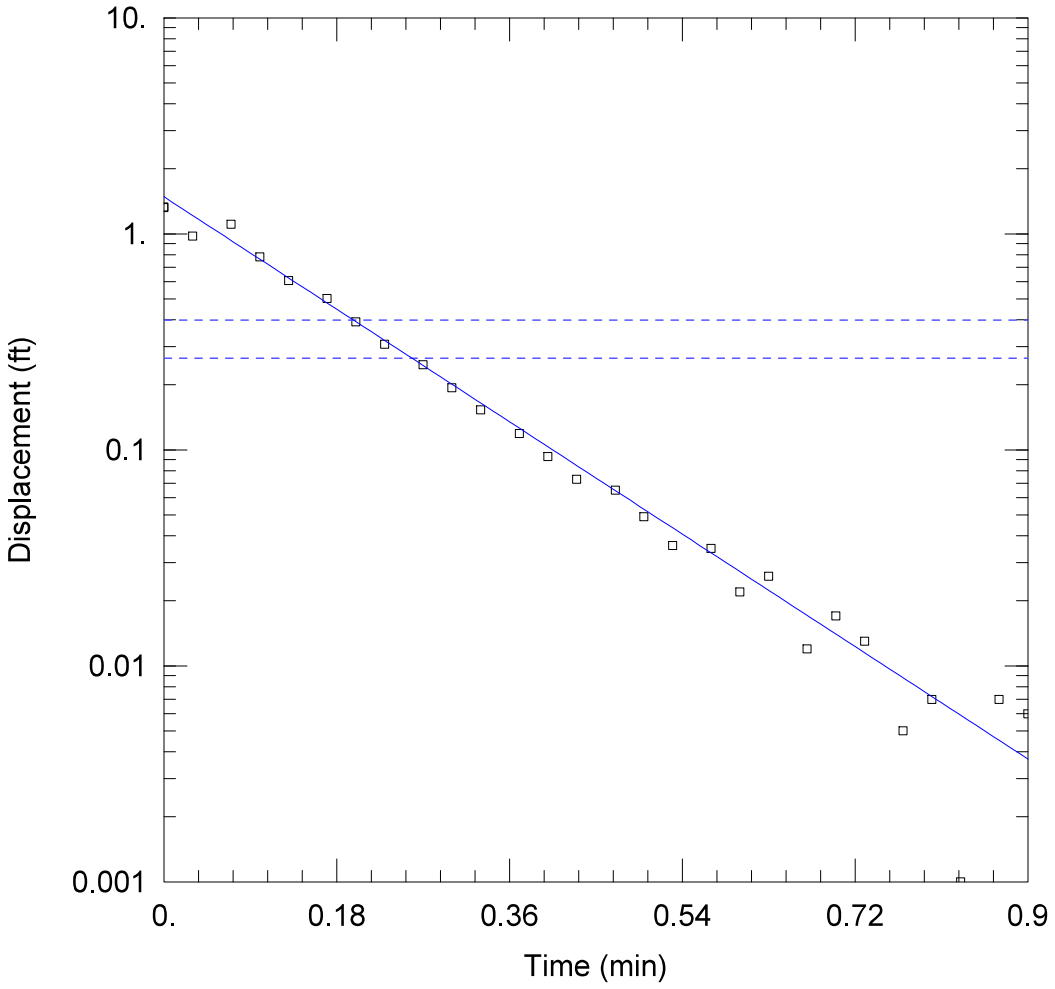
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 4 (Slug out))

Initial Displacement: 1.244 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004155 cm/sec
y0 = 0.9235 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:03:08

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

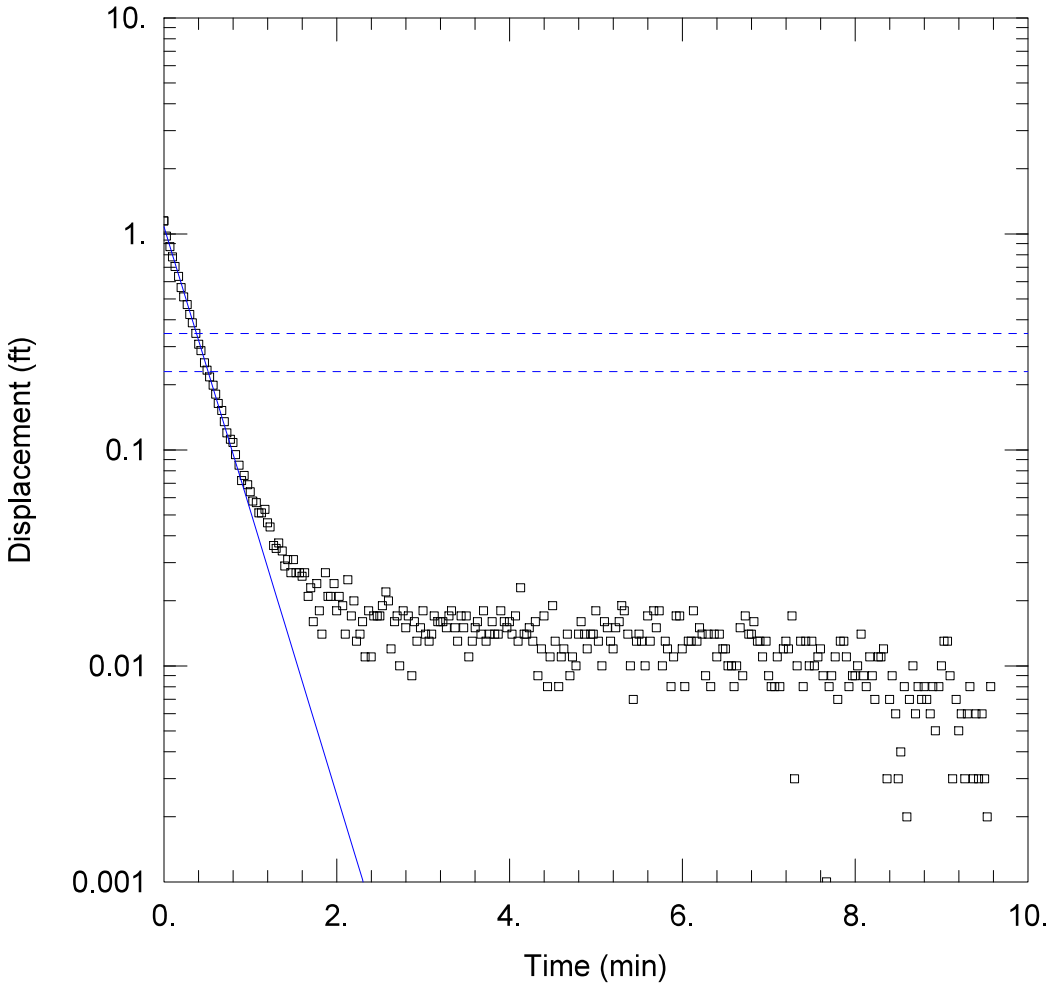
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 1 slug-in))

Initial Displacement: 1.33 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.009817 cm/sec
y0 = 1.486 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:19:01

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

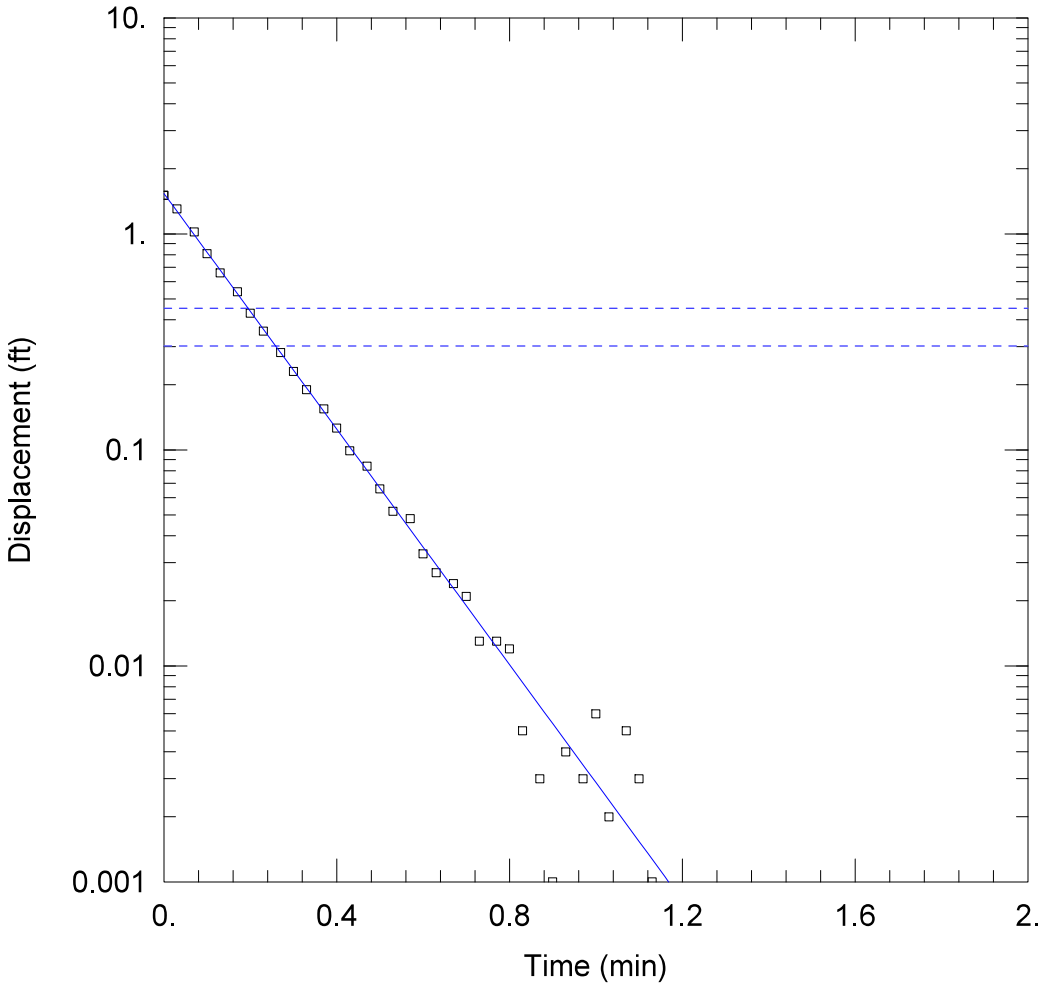
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 2 slug-out))

Initial Displacement: 1.15 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.004464 cm/sec
y0 = 1.079 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:22:08

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

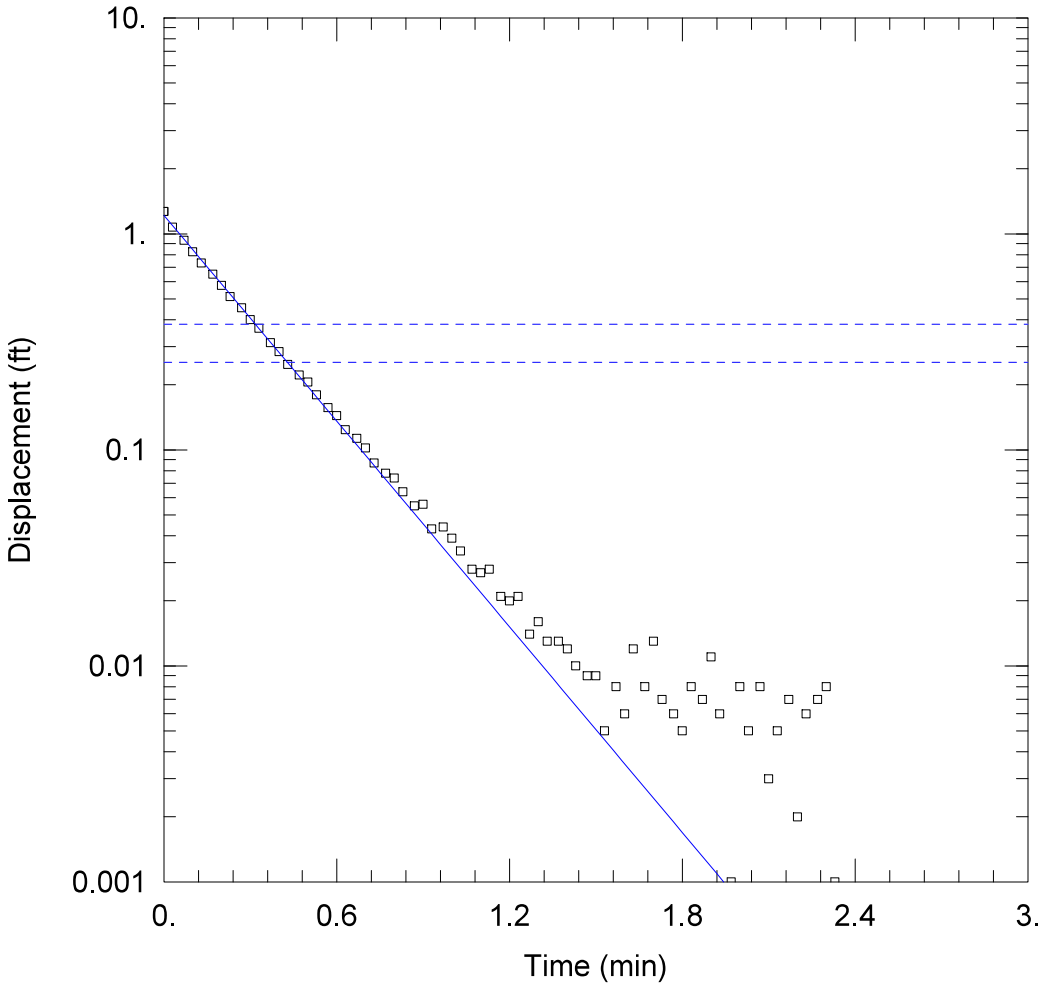
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 3 slug-in))

Initial Displacement: 1.51 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.009254 cm/sec
y0 = 1.537 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:24:39

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

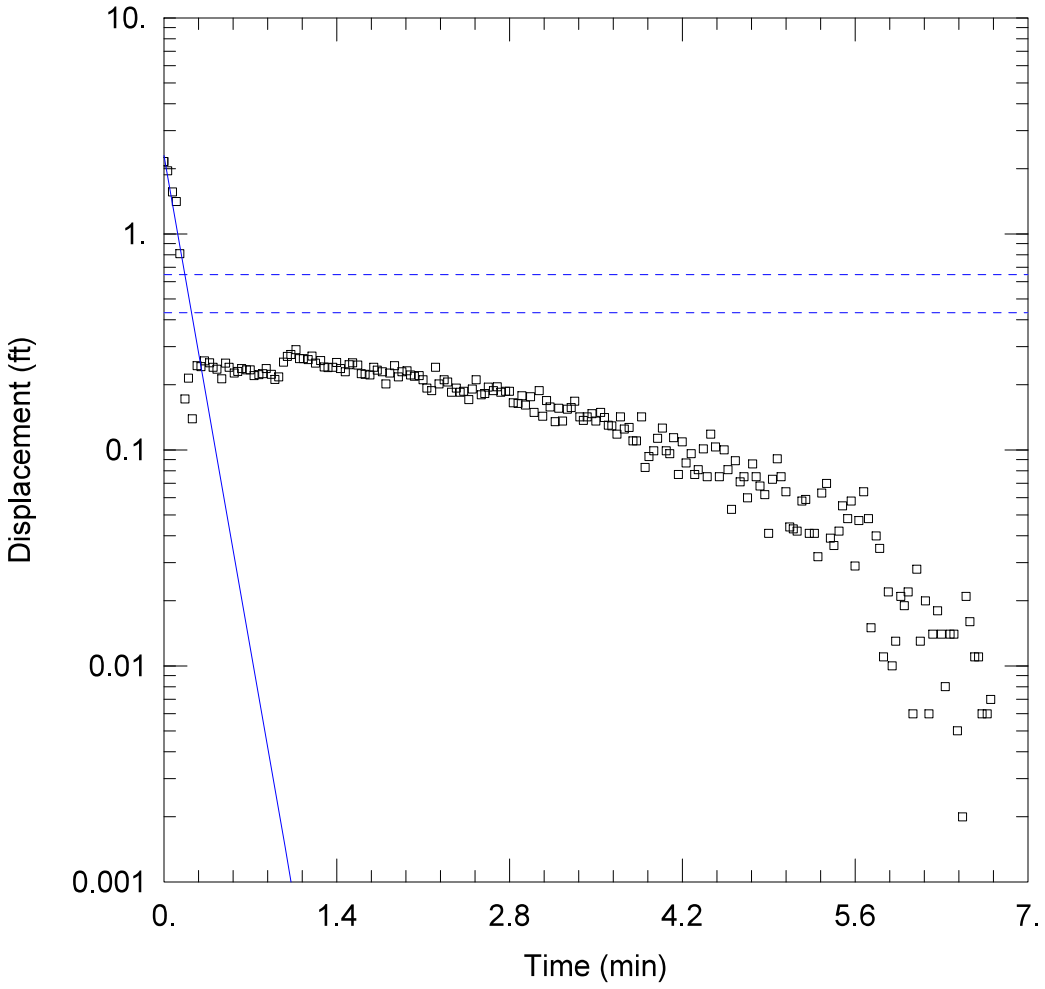
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 4 slug-out))

Initial Displacement: 1.27 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.005386 cm/sec
y0 = 1.217 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 13:57:26

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

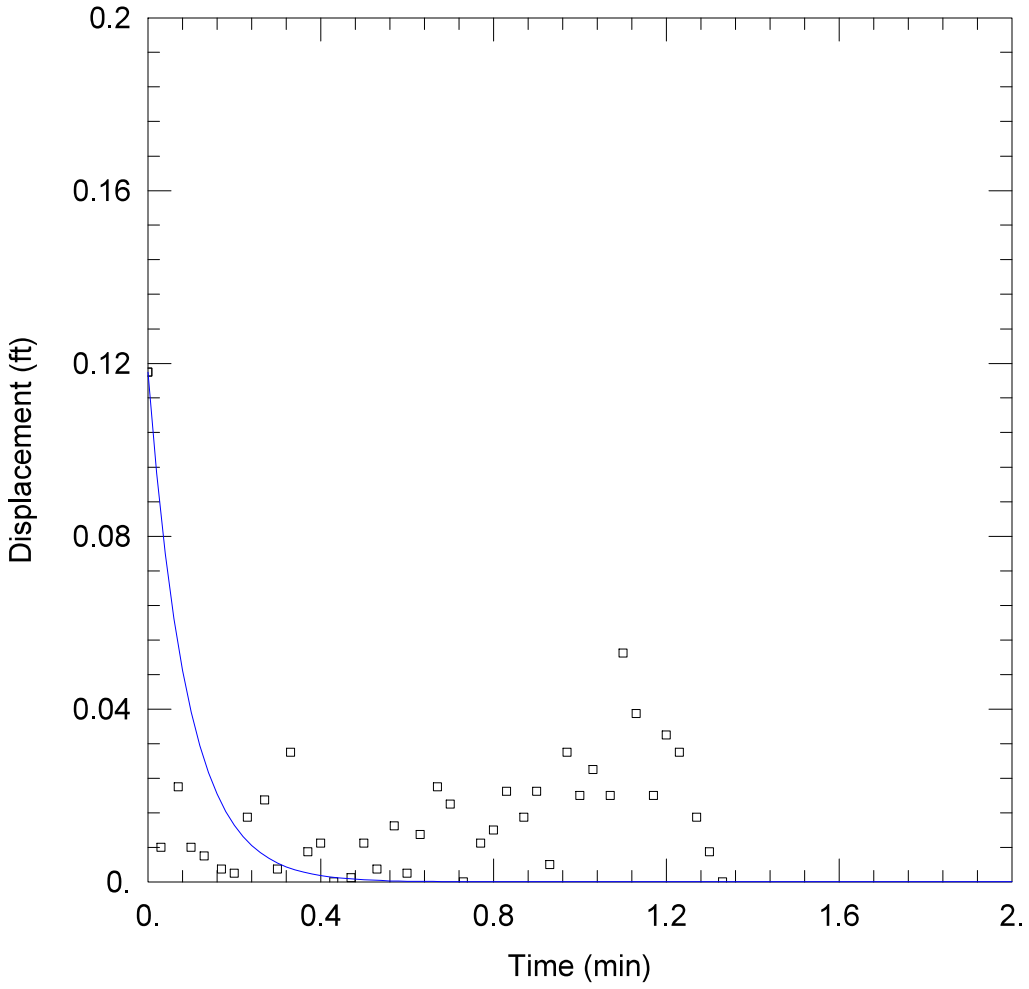
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 1 slug-in))

Initial Displacement: 2.159 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.01129 cm/sec
y0 = 2.303 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:00:35

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

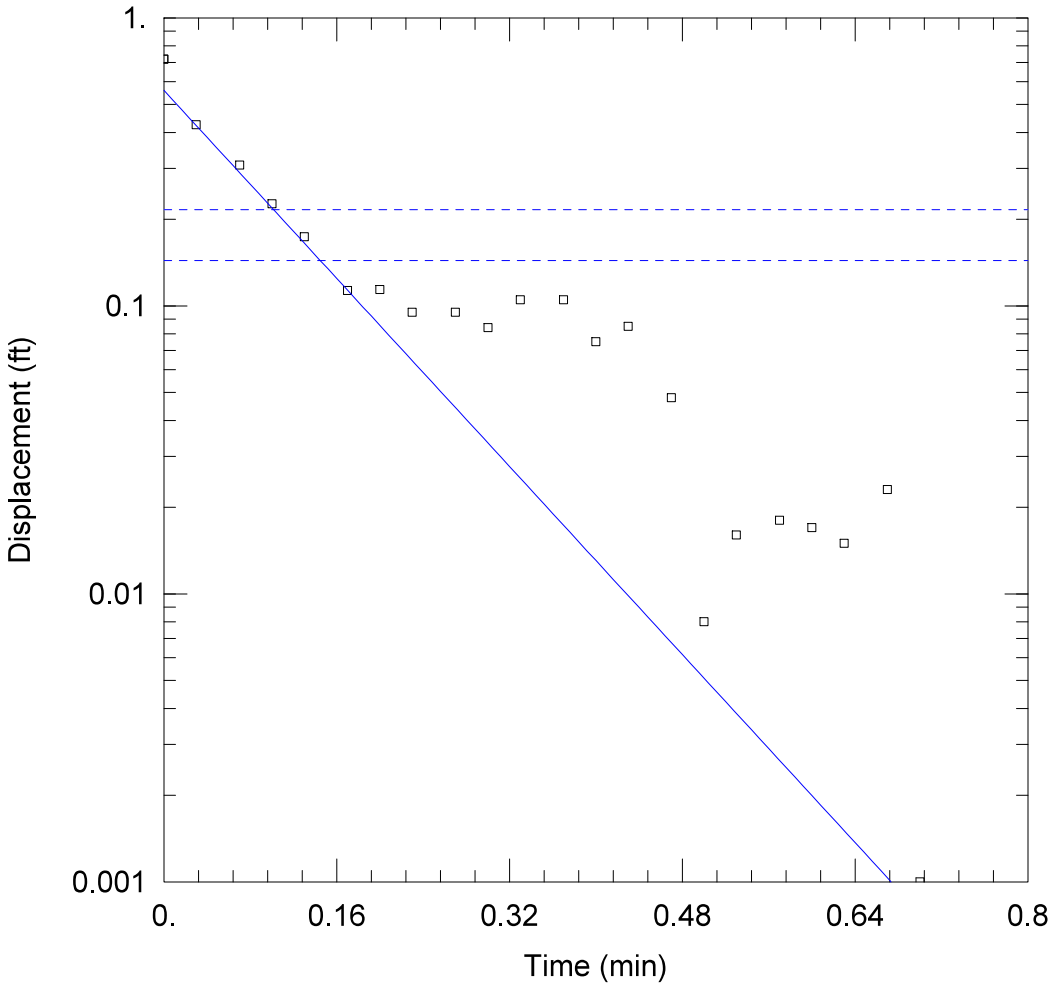
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 1 slug-in))

Initial Displacement: 0.118 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.01653 cm/sec
Le = 0.1 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:04:42

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

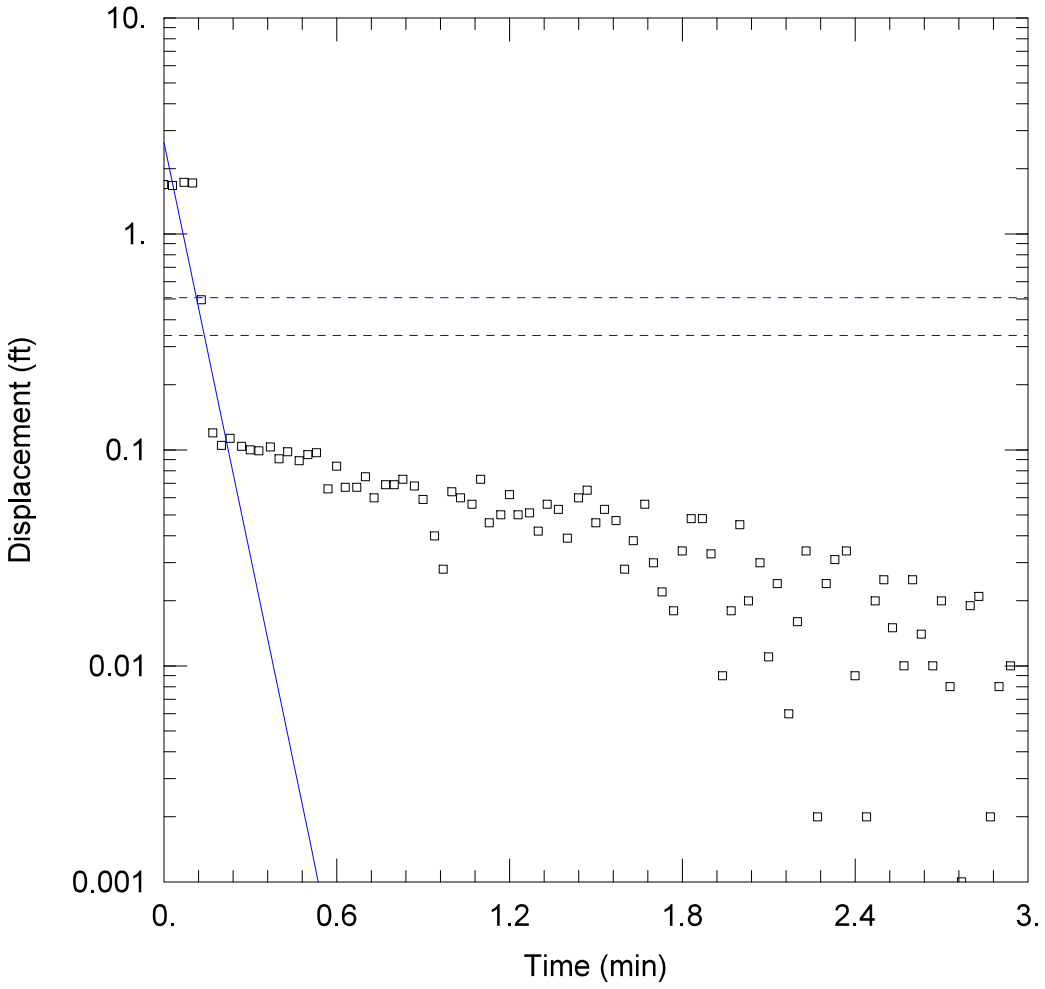
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 3 slug-out))

Initial Displacement: 0.719 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.01413 cm/sec
y0 = 0.5601 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:07:51

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

Saturated Thickness: 31. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 4 slug-out))

Initial Displacement: 1.69 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

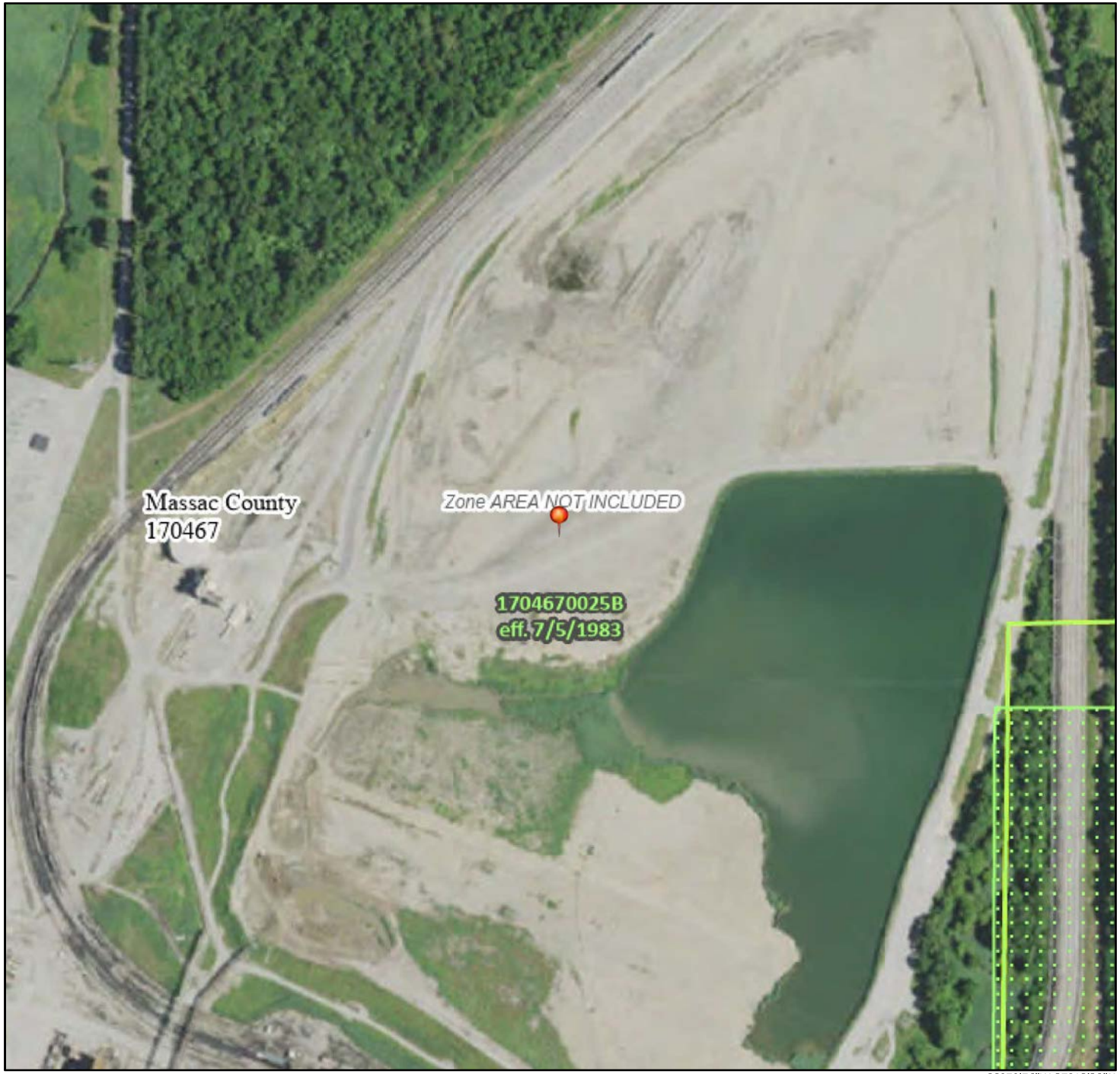
K = 0.02209 cm/sec y0 = 2.648 ft

APPENDIX G
FEMA FLOOD HAZARD MAP

National Flood Hazard Layer FIRMette

FEMA

88°51'33"W 37°13'8"N



88°50'56"W 37°12'39"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 Cross Sections with 1% Annual Chance
- 17.5 Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 8/31/2021 at 10:52 AM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

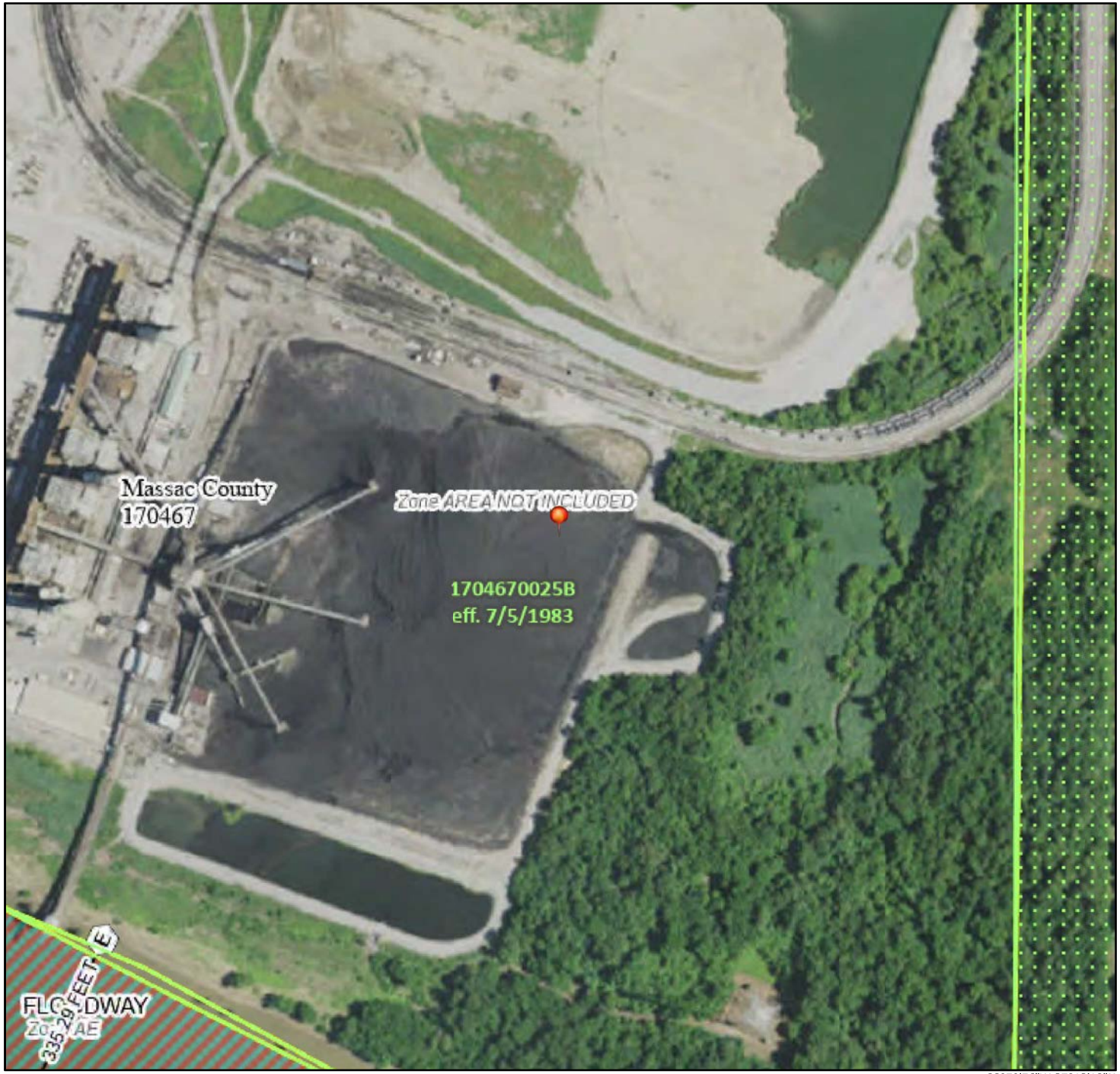
This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

R001019

National Flood Hazard Layer FIRMette

FEMA

88°51'34"W 37°12'47"N



88°50'56"W 37°12'18"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 / 17.5 Cross Sections with 1% Annual Chance / Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 8/31/2021 at 10:48 AM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

R001020

ATTACHMENT I

October 2021

Intended for
Electric Energy, Inc.

Date
October 25, 2021

Project No.
1940100806-006

GROUNDWATER MONITORING PLAN
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

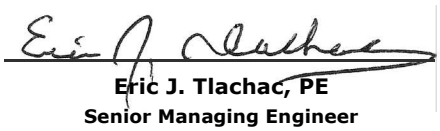
GROUNDWATER MONITORING PLAN
JOPPA POWER PLANT EAST ASH POND

Project Name	**Joppa Power Plant East Ash Pond**
Project No.	**1940100806-006**
Recipient	**Electric Energy, Inc.**
Document Type	**Groundwater Monitoring Plan**
Revision	**FINAL**
Date	**October 25, 2021**

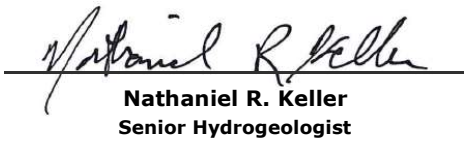
Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com

Brian G. Hennings, PG
Senior Managing Hydrogeologist



Eric J. Tlachac, PE
Senior Managing Engineer



Nathaniel R. Keller
Senior Hydrogeologist

Chase J. Christenson, PG
Hydrogeologist

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 (Groundwater Monitoring Plan, Joppa Power Plant East Ash Pond), has been designed and constructed to meet the requirements of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the Hydrogeologic Site Characterization Report (Ramboll 2021; included in the Operating Permit to which this Groundwater Monitoring Plan is attached).

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 (Groundwater Monitoring Plan, Joppa Power Plant East Ash Pond), has been designed and constructed to meet the requirements of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the Hydrogeologic Site Characterization Report (Ramboll 2021; included in the Operating Permit to which this Groundwater Monitoring Plan is attached).

Brian G. Hennings
Professional Geologist
196.001482
Illinois
Date: October 25, 2021

CONTENTS

Licensed Professional Certifications		**2**
1.	**Introduction**	**6**
1.1	Overview	6
1.2	Site Location and Background	6
1.3	Conceptual Model	7
2.	**Groundwater Monitoring Systems**	**9**
2.1	Existing Monitoring Well Network and Analysis	9
2.1.1	40 C.F.R. § 257 Monitoring Program	9
2.1.2	Part 845 Well Installation and Monitoring	10
2.2	Proposed Part 845 Monitoring Well Network	10
2.3	Well Abandonment	11
3.	**Applicable Groundwater Quality Standards**	**12**
3.1	Groundwater Classification	12
3.2	Statistical Evaluation of Background Groundwater Data	12
3.3	Applicable Groundwater Protection Standards	12
4.	**Groundwater Monitoring Plan**	**14**
4.1	Monitoring Networks and Parameters	14
4.1.1	40 C.F.R. § 257 Groundwater Monitoring	14
4.1.2	Part 845 Groundwater Monitoring	14
4.2	Sampling Schedule	15
4.3	Groundwater Sample Collection	16
4.4	Laboratory Analysis	16
4.5	Quality Assurance Program	16
4.6	Groundwater Monitoring System Maintenance Plan	17
4.7	Statistical Analysis	17
4.8	Data Reporting	17
4.9	Compliance with Applicable On-site Groundwater Protection Standards	17
4.10	Alternate Source Demonstrations	18
4.11	Assessment of Corrective Measures and Corrective Action	18
5.	**References**	**20**

TABLES (IN TEXT)

Table A 40 C.F.R. § 257 Groundwater Monitoring Program Parameters
Table B Part 845 Groundwater Monitoring Program Parameters
Table C Proposed Part 845 Monitoring Well Network
Table D Part 845 Groundwater Monitoring Program Parameters
Table E Part 845 Sampling Schedule

TABLES (ATTACHED)

Table 1-1 Part 845 Requirements Checklist
Table 2-1 Monitoring Well Locations and Construction Details
Table 3-1 Background Groundwater Quality and Standards
Table 4-1 Sampling and Analysis Summary
Table 4-2 Detection and Reporting Limits for Part 845 Parameters

FIGURES (ATTACHED)

Figure 1-1 Site Location Map
Figure 1-2 Site Map
Figure 1-3 Uppermost Aquifer Groundwater Elevation Contours, March 3 and 4, 2021
Figure 2-1 Proposed Part 845 Groundwater Monitoring Well Network

APPENDICES

Appendix A Statistical Analysis Plan

ACRONYMS AND ABBREVIATIONS

§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
40 C.F.R.	Title 40 of the Code of Federal Regulations
ASD	Alternate Source Demonstration
bgs	below ground surface
CCR	coal combustion residuals
cm/s	centimeters per second
CSM	conceptual site model
EAP	East Ash Pond
GMP	Groundwater Monitoring Plan
GWPS	groundwater protection standard
HCR	Hydrogeologic Site Characterization Report
ID	identification
IEPA	Illinois Environmental Protection Agency
JPP	Joppa Power Plant
LAU	lower aquifer unit
LCU	lower confining unit
NA	not applicable
NAVD88	North American Vertical Datum of 1988
NID	National Inventory of Dams
No.	number
NRT/OBG	Natural Resource Technology, an OBG Company
OBG	O'Brien & Gere Engineers, Inc.
Part 845	Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
PMP	potential migration pathway
QA/QC	quality assurance/quality control
Ramboll	Ramboll Americas Engineering Solutions, Inc.
RL	reporting limit
SI	surface impoundment
TDS	total dissolved solids
UA	uppermost aquifer
UCU	upper confining unit
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 Groundwater Monitoring Plan (GMP) on behalf of Joppa Power Plant (JPP), operated by Electric Energy, Inc. This report will apply specifically to the CCR Unit referred to as the East Ash Pond (EAP), Vistra identification (ID) number (No.) 401, IEPA ID No. W1270100004-02, and National Inventory of Dams (NID) No. IL50714. The EAP is a 111-acre active unlined CCR SI used to manage CCR and non-CCR waste streams at the JPP. This GMP includes Part 845 content requirements specific to 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 the EAP at the JPP.

A checklist which identifies the specific requirements of 35 I.A.C. § 845.630, 35 I.A.C. § 845.640, and 35 I.A.C. § 845.650 is included in **Table 1-1**. The table provides references to sections, tables, and figures included in this document to locate the information that meets specific requirements of 35 I.A.C. § 845.630, 35 I.A.C. § 845.640, and 35 I.A.C. § 845.650.

1.2 Site Location and Background

The JPP is west of the Village of Joppa in Massac County, Illinois, northeast of the Ohio River in Section 14, Township 15 South, Range 3 East (**Figure 1-1**). The JPP property is bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north and west, the Village of Joppa to the east, and the Ohio River to the south. The EAP is located in the west half of Section 14 directly north of the JPP and is bounded immediately to the east by the railway right-of-way which is adjacent to forested portions of residential property in the Village of Joppa.

The JPP currently operates the EAP for management of CCR waste streams. A permit exempt CCR landfill is present in the northwestern portion of the JPP property. In addition, there is a former CCR disposal area, Joppa West, located in the western portion of the JPP property (**Figure 1-2**). The landfill and Joppa West are not the subject of this GMP.

The EAP is classified as an existing unlined CCR SI which is used to manage both fly ash and bottom ash. The EAP was built in two phases. The northern portion (Phase I) was placed into service in late 1973, while the southern portion (Phase II) was permitted in May 1985 with completion of construction occurring in late 1985. These two sections are separated by a dividing dike (*i.e.,* Central Dike) and are referred to as the Northern and Southern Ponds. The pond embankment has not been raised since its construction in 1973, but material has been added in some areas to increase the width. The Northern Pond is diked over the length of its perimeter and the height of the dike varies from approximately 15 to 45 feet above the outboard toe of slope. The crest is at an approximate elevation of 380 feet North American Vertical Datum of 1988 (NAVD88). The Southern Pond is also a diked earthen embankment structure with a height that varies from approximately 15 to 45 feet above its outboard toe. As with the Northern Pond,

the crest is at an approximate elevation of 380 feet NAVD88 (O'Brien & Gere Engineers, Inc. [OBG], 2010).

1.3 Conceptual Model

Significant site investigation has been completed at the JPP to characterize the geology, hydrogeology, and groundwater quality. Based on extensive investigation and monitoring, the EAP has been well characterized and detailed in the Hydrogeologic Site Characterization Report (HCR [Ramboll, 2021]; included in the Operating Permit to which this Plan is attached). A conceptual site model (CSM) has been developed and is discussed below.

In addition to the CCR present at the Joppa EAP, there are four distinct hydrostratigraphic units summarized below that have been identified based on stratigraphic relationships and common hydrogeologic characteristics:

- **Upper Confining Unit (UCU)**: Includes low permeability silt and clay of the Equality Formation, silts of the Peoria/Roxana/Loveland, and clay and silt of the Metropolis Formation. This unit was encountered in all borings advanced at the EAP in 2021 and limits the vertical migration of CCR impacts into the uppermost aquifer.
- **Uppermost Aquifer**: Includes high permeability sands with gravel, silt, and clay lenses of the Upper McNairy Formation. The uppermost aquifer at the EAP was encountered at elevations ranging from 222.6 to 318.6 feet NAVD88.
- **Lower Confining Unit (LCU)**: Includes clay and silt of the Lower McNairy Formation that was encountered in all borings advanced to bedrock. Based on material description, continuous lateral extent, and observed vertical gradients this unit is identified as an LCU.
- **Lower Aquifer Unit (LAU)**: The lowermost unit identified at the EAP which underlies all unlithified deposits and is considered a potential migration pathway (PMP). This unit is comprised of the Salem Limestone, which is the uppermost lithified unit identified at the EAP and used as a potable and non-potable water supply in the vicinity of the JPP.

Groundwater flow direction and gradients have not changed significantly since the first hydrogeologic study of the EAP was completed in 2009, and recent data support the existing CSM, which has been refined to incorporate additional data as follows:

- Groundwater migrates downward through the UCU which is composed of the Equality Formation, Silt Unit, and Metropolis Formation into the uppermost aquifer.
- Groundwater migrates within high permeability sands and gravels of the McNairy Formation which comprises the uppermost aquifer generally south towards the Ohio River.
- Vertical gradients measured between the LAU and the uppermost aquifer indicate upward migration of groundwater from the LAU to the uppermost aquifer and into the Ohio River.

Groundwater elevations and contours for March 3 and 4, 2021 are presented in **Figure 1-3**.

Part 845 parameters were monitored in the uppermost aquifer and LAU monitoring wells at the EAP as part of the Title 40 of the Code of Federal Regulations (40 C.F.R.) § 257 monitoring program beginning in 2015. These data were supplemented with sampling of additional locations in 2021. The results indicate that the following parameters were detected at concentrations greater than the applicable 35 I.A.C. § 845.600 groundwater protection standards (GWPSs) and are considered potential exceedances:

- Boron - at five uppermost aquifer wells (G06, G07, G08, G09, and G10).
- Cobalt - at thirteen uppermost aquifer wells (G01D, G03, G05, G06S, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D), and at LAU well G09M.
- pH – at two UCU wells (G54S and G151), and at thirteen uppermost aquifer wells (G01D, G02D, G03, G05, G06S, G07, G09, G10, G11, G51D, G52D, G53D, and G54D).
- Radium 226 and 228 combined – at upgradient uppermost aquifer well G02D.
- Sulfate - at uppermost aquifer wells G10 and G11.
- Thallium – at uppermost aquifer wells G05 and G11.

Concentration results for the above parameters were compared directly to 35 I.A.C. § 845.600 GWPS, without an evaluation of background concentrations. Evaluation of background groundwater quality has been completed as part of this GMP, and compliance with Part 845 will be determined following the first round of groundwater sampling. The first round of groundwater sampling for compliance will be completed the quarter following issuance of the Operating Permit and in accordance with this GMP.

2. GROUNDWATER MONITORING SYSTEMS

2.1 Existing Monitoring Well Network and Analysis

This GMP is being provided to propose a groundwater monitoring network and monitoring program specific to the EAP that will comply with Part 845. Monitoring networks and programs that apply to other units are not discussed in this GMP. Those programs will continue to be performed as specified in IEPA approvals. Any future modifications will be proposed and submitted to IEPA for approval in a separate document. The remaining discussion in this document will include only these networks and monitoring programs that are applicable and specific to the EAP, specifically the 40 C.F.R. § 257 network and the proposed Part 845 monitoring network.

2.1.1 40 C.F.R. § 257 Monitoring Program

The 40 C.F.R. § 257 well network for the EAP consists of six monitoring wells installed nearby or adjacent to the EAP within the unlithified uppermost aquifer. The EAP 40 C.F.R. § 257 well network consists of two background monitoring wells (G01D and G02D) and four compliance monitoring wells (G51D, G52D, G53D, and G54D). The boring logs, well construction forms, and other related monitoring well forms are available in the Operating Records as required by 40 C.F.R. § 257.91 for each monitored CCR Unit or CCR Multi-Unit, and are included in Appendix B of the HCR (included in the Operating Permit to which this Plan is attached).

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 the EAP (Natural Resource Technology, an OBG Company [NRT/OBG], 2017).

Groundwater samples are collected semiannually and analyzed for the laboratory and field parameters from Appendix III and Appendix IV of 40 C.F.R. § 257, summarized in **Table A** below.

Table A. 40 C.F.R. § 257 Groundwater Monitoring Program Parameters

Field Parameters[1]			
Groundwater Elevation	pH		
Appendix III Parameters (Total, except total dissolved solids [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.

Results and analysis of groundwater sampling are reported annually by January 31 of the following year and made available on the CCR public website as required by 40 C.F.R. § 257.

2.1.2 Part 845 Well Installation and Monitoring

In 2021, 12 additional monitoring wells (G03, G04, G05, G06, G06S, G07, G08, G09, G09M, G10, G11, and G54S) were installed along the perimeter of the EAP to assess the vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet below ground surface (bgs) as specified in 35 I.A.C. § 845.620(b). Additionally, three leachate monitoring wells (XPW01, XPW02, and XPW03) were installed within the EAP unit to characterize the CCR materials.

Prospective Part 845 monitoring wells were sampled for eight rounds from February to August 2021 and the results were assessed for selection of the EAP Part 845 monitoring well network. Groundwater samples were collected and analyzed for 35 I.A.C. § 845.600 parameters as summarized in **Table B** below.

Table B. 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)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1] Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential were recorded during sample collection.

Data and results from the Part 845 background monitoring were included in the water quality discussion included in the HCR (included in the Operating Permit to which this Plan is attached). The data collected from background locations during the Part 845 monitoring were used to evaluate and calculate background concentrations for the EAP. The evaluation and discussion are included in **Section 3.2** of this report.

Data collected from the 40 C.F.R. § 257 monitoring network from 2015 to 2021, and from the Part 845 background monitoring were used for selection of the Part 845 monitoring well network proposed in **Section 2.2**.

2.2 Proposed Part 845 Monitoring Well Network

The groundwater monitoring network proposed in this plan will include 14 wells screened in the uppermost aquifer (G01D, G02D, G03, G05, G06, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D) and two temporary water level only surface water staff gages (XSG01 and SG02). The proposed network is summarized in **Table C** below and displayed on **Figure 2-1.**

Fourteen wells (two background and 12 compliance) will be used to monitor groundwater concentrations within the uppermost aquifer.

The groundwater samples collected from the 14 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 C** below.

Table C. Proposed Part 845 Monitoring Well Network

Well ID	Monitored Unit	Well Screen Interval (feet bgs)	Well Type [1]
G01D	UA	54.2 – 63.9	Background
G02D	UA	62.2 – 71.8	Background
G03	UA	55.0 – 65.0	Compliance
G05	UA	50.0 – 60.0	Compliance
G06	UA	75.0 – 85.0	Compliance
G07	UA	50.0 – 60.0	Compliance
G08	UA	75.0 – 85.0	Compliance
G09	UA	59.5 – 69.5	Compliance
G10	UA	60.3 – 70.3	Compliance
G11	UA	55.7 – 65.7	Compliance
G51D	UA	49.6 – 53.0	Compliance
G52D	UA	69.9 – 79.6	Compliance
G53D	UA	47.3 – 56.9	Compliance
G54D	UA	70.0 – 79.7	Compliance
XSG01[2,3]	CCR	NA	WLO
SG02[2,3]	Surface Water	NA	WLO

[1] Well type refers to the role of the well in the monitoring network.

[2] Surface water level measuring points.

[3] Location is temporary pending implementation of impoundment closure per an approved Construction Permit Application.

NA = Not Applicable

UA = uppermost aquifer

WLO = water level only

2.3 Well Abandonment

No wells are currently proposed for abandonment.

3. APPLICABLE GROUNDWATER QUALITY STANDARDS

3.1 Groundwater Classification

Groundwater at the EAP meets the definition of Class I - Potable Resource Groundwater (35 I.A.C. § 620.210), based on the following criteria:

- The groundwater is located more than 10 feet bgs and within an unconsolidated silty sand and gravel unit which is five feet or more in thickness and contains less than 12 percent of fines.
- Slug testing results identified a mean hydraulic conductivity of 3.1×10^{-3} centimeters per second (cm/s), which exceeds the 1×10^{-4} cm/s criterion.
- The groundwater does not underlie a previously mined area or a coal mine refuse disposal area.

3.2 Statistical Evaluation of Background Groundwater Data

A Statistical Analysis Plan (**Appendix A**) 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 United States Environmental Protection Agency's (USEPA) *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 most background concentrations in the uppermost aquifer are less than the groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1). 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 exception is for pH lower limit, where the background lower limit for pH is less than the 35 I.A.C. § 845.600 standard. Therefore, the GWPS for pH lower limit will be the background measurement.

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 A**.

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)(1). The groundwater monitoring program will include sampling and analysis procedures that are consistent and that provide an accurate representation of groundwater quality at the background and compliance wells as required by 35 I.A.C. § 845.630. As discussed in **Section 2**, two monitoring programs specific to the EAP exist: the 40 C.F.R. § 257 monitoring program and the proposed Part 845 monitoring program. These networks will continue to be monitored until USEPA approves Part 845. It is expected that upon USEPA approval of Part 845, the 40 C.F.R. § 257 monitoring program and reporting will be eliminated, and the proposed Part 845 monitoring and reporting included in this Plan will continue until requirements of Part 845 have been achieved.

4.1 Monitoring Networks and Parameters

4.1.1 40 C.F.R. § 257 Groundwater Monitoring

The existing 40 C.F.R. § 257 monitoring program was discussed in detail in **Section 2.1.1**. Six wells (two background and four compliance) are sampled for Appendix III and Appendix IV parameters on a semi-annual frequency. No changes are proposed to this monitoring network. Well locations and parameters will continue to be monitored and reported as required by 40 C.F.R. § 257 until USEPA approves Part 845.

4.1.2 Part 845 Groundwater Monitoring

The proposed Part 845 monitoring network will consist of two background monitoring wells (G01D and G02D), 12 compliance monitoring wells (G03, G05, G06, G07, G08, G09, G10, G11, G51D, G52D, G53D, G54D), and two temporary water level only surface water staff gages (XSG01 and SG02) to monitor potential impacts from the EAP (**Figure 2-1**). These monitoring wells are screened within the uppermost aquifer (G01D, G02D, G03, G05, G06, G07, G08, G09, G10, G11, G51D, G52D, G53D, and G54D) along the perimeter of the EAP. Groundwater samples will be collected and analyzed for the laboratory and field parameters in **Table D** below.

Table D. 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)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1] Dissolved oxygen, temperature, specific conductivity, and oxidation/reduction potential will be recorded during sample collection.

All parameters listed above were sampled a minimum of eight times by October 18, 2021 to establish background groundwater quality in accordance with 35 I.A.C. § 845.650 (b)(1)(A). Discussion of background groundwater quality is included in **Section 3.2**.

4.2 Sampling Schedule

Groundwater sampling for the Part 845 monitoring well network will initially be performed quarterly according to the following schedule:

Table E. 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).

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 A**, 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 257.107.

Groundwater monitoring and analysis completed in accordance with the Part 845 monitoring under an approved monitoring program will be reported to IEPA within 60 days after completion of sampling and the data placed 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 submitted to IEPA annually by January 31 as required by 35 I.A.C. § 845.550, for data collected the preceding year. The report will include the status of the groundwater monitoring and any required corrective action plan for the EAP in addition to other requirements detailed in 35 I.A.C. § 845.610(e).

4.9 Compliance with Applicable On-site Groundwater Protection 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 the EAP caused the contamination and the EAP 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 4.1.2**.

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.

4.11 Assessment of Corrective Measures and Corrective Action

As described in 35 I.A.C. § 845.660, if the ASD summarized in **Section 4.10** has not been approved by IEPA, an assessment of corrective measures will be initiated within 90 days of the detection of a result exceeding 35 I.A.C. § 845.600 standards (*i.e.,* receipt of laboratory data). The assessment of corrective measures will include at least the following (35 I.A.C. § 845.660 (c)):

- 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;
- The time required to begin and complete the corrective action plan; and
- 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.

Within one year of completing the assessment of corrective measures, a corrective action plan will be developed to identify the selected remedy in accordance with 35 I.A.C. § 845.670. If

closure of the CCR Unit is required, a closure alternatives analysis will be completed as specified in 35 I.A.C. § 845.710. The analysis and selected alternative will be submitted to IEPA in a Closure Plan as specified by 35 I.A.C. § 845.720. Groundwater monitoring proposed in this Addendum will continue as specified until the post closure care period has expired and IEPA has approved termination of post-closure care.

5. REFERENCES

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, an OBG Company (NRT/OBG), 2017. *Sampling and Analysis Plan. Joppa East Ash Pond, Joppa Power Station, Joppa Illinois, Project No. 2285, Revision 0,* October 17, 2017.

O'Brien & Gere Engineers, Inc. (OBG), 2010. *Dam Safety Assessment of CCW Impoundments. Joppa Plant, Prepared for: US Environmental Protection Agency, Washington, DC*, September 24, 2010.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. *Hydrogeologic Site Characterization Report. East Ash Pond. Joppa Power Plant*. Joppa, Illinois.

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

TABLE 1-1. PART 845 REQUIREMENTS CHECKLIST
GROUNDWATER MONITORING PLAN
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in GMP
845.630	**Groundwater Monitoring Systems**	
845.630(a)(2)	Potential contaminant pathways must be monitored.	NA
845.630(a) 845.630(b) 845.630(c)	At least two upgradient wells and four downgradient wells (min. 1 and 3, but requires additional documentation)	Sections 2.2 & 4.1.2 Table 2-1 Figure 2-1
845.630(a) 845.630(b) 845.630(c)	Downgradient Well Density	Figure 2-1
845.630(a)(2)	Downgradient wells at waste boundary	Figure 2-1
845.640	**Groundwater Sampling and Analysis Requirements**	
845.640(a)	Consistent sampling and analysis procedures	Section 4 Tables 4-1 & 4-2
845.640(b)	Methods are appropriate	Section 4 Tables 4-1 & 4-2
845.640(c)	Groundwater elevations must be measured in each well prior to purging, each time groundwater is sampled.	Section 4.3
845.640 (d)(e)(f)(g)(h)	Establishment of background and application of statistical methods	Sections 3.2 & 4.7 Appendix A
845.640(i)	Analyze total recoverable metals	Section 4.1.2
845.640(j)	Analyze groundwater samples using a certified laboratory	Section 4.4

TABLE 1-1. PART 845 REQUIREMENTS CHECKLIST

GROUNDWATER MONITORING PLAN

JOPPA POWER PLANT

EAST ASH POND

JOPPA, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in GMP
845.650	**Groundwater Monitoring Program**	
845.650(a)	Must include monitoring for all constituents with a groundwater protection standard in Section 845.600(a), calcium, and turbidity	Section 4.1.2
845.650(b)(c)	Groundwater Monitoring Frequency	Sections 4.1.2 & 4.2
845.650(d)(e)	Exceedances of the groundwater protection standard	Sections 4.9, 4.10 & 4.11
845.650(b)(2) and (3)	Staff gauge/ piezometer to monitor head in impoundment	Sections 2.2 & 4.1.2 Figure 2-1 (XSG01)
NA	Staff gauge/ piezometer to monitor head of neighboring surface water body	Sections 2.2 & 4.1.2 Figure 2-1 (SG02)

[O: CJC 08/17/21; C: LDC 08/30/21]

Notes:

GMP = Groundwater Monitoring Plan

NA = Not Applicable

RAMBOLL

R001045

TABLE 2-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
GROUNDWATER MONITORING PLAN
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Well Number	Type	HSU	Date Constructed	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)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
G01D	B	UA	08/14/2015	364.19	364.19	Top of Disk	361.50	54.19	63.85	307.31	297.65	64.40	297.10	9.7	2	37.220429	-88.857179
G02D	B	UA	08/13/2015	363.65	363.65	Top of Disk	360.82	62.21	71.84	298.61	288.98	72.40	288.50	9.6	2	37.220715	-88.853311
G03	C	UA	02/02/2021	357.87	357.87	Top of PVC	354.84	55.00	65.00	302.90	292.90	65.00	289.80	10	2	37.220682	-88.850376
G05	C	UA	02/01/2021	361.21	361.21	Top of PVC	358.45	50.00	60.00	311.20	301.20	60.00	298.50	10	2	37.21719	-88.849014
G06	C	UA	01/29/2021	355.24	355.24	Top of PVC	352.60	75.00	85.00	280.20	270.20	85.00	267.60	10	2	37.212929	-88.848893
G07	C	UA	01/29/2021	353.53	353.53	Top of PVC	350.34	50.00	60.00	303.50	293.50	60.00	290.30	10	2	37.211001	-88.848969
G08	C	UA	01/28/2021	343.54	343.54	Top of PVC	341.72	75.00	85.00	268.50	258.50	85.00	256.70	10	2	37.210531	-88.851015
G09	C	UA	01/31/2021	351.70	351.70	Top of PVC	348.69	59.50	69.50	292.20	282.20	69.50	279.20	10	2	37.210336	-88.854116
G10	C	UA	02/01/2021	353.49	353.49	Top of PVC	350.75	60.30	70.30	293.20	283.20	70.30	280.50	10	2	37.211272	-88.855841
G11	C	UA	01/19/2021	366.55	366.55	Top of PVC	363.38	55.70	65.70	310.90	300.90	65.70	297.70	10	2	37.214408	-88.85633
G51D	C	UA	08/18/2015	363.85	363.85	Top of PVC	361.10	49.61	59.27	311.49	301.83	59.90	301.20	9.7	2	37.216016	-88.855653
G52D	C	UA	08/19/2015	348.41	348.41	Top of PVC	345.88	69.85	79.55	276.03	266.33	80.01	265.90	9.7	2	37.209626	-88.852943
G53D	C	UA	08/21/2015	355.47	355.47	Top of PVC	352.16	47.29	56.89	304.87	295.27	57.33	294.20	9.6	2	37.215069	-88.849367
G54D	C	UA	08/11/2015	357.03	357.03	Top of PVC	353.71	69.96	79.66	283.75	274.05	80.14	273.60	9.7	2	37.212264	-88.857485
XSG01	WLO	CCR	--	--	371.78	Staff gauge	--	--	--	--	--	--	--	--	--	37.21517	-88.8498
SG02	WLO	SW	--	--	--	Staff gauge	--	--	--	--	--	--	--	--	--	37.207287	-88.860503

Notes:
All elevation data are presented relative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
Type refers to the role of the well in the monitoring network: background (B), compliance (C), or water level measurements only (WLO)
WLO wells are temporary pending implementation of impoundment closure per an approved Construction Permit application
-- = data not available
BGS = below ground surface
CCR = Coal Combustion Residual
ft = foot or feet
HSU = Hydrostratigraphic Unit
PVC = polyvinyl chloride
SW = surface water
UA = uppermost aquifer

generated 10/16/2021, 8:39:41 PM CDT

RAMBOLL

R001046

TABLE 3-1. BACKGROUND GROUNDWATER QUALITY AND STANDARDS
GROUNDWATER MONITORING PLAN
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Parameter	Background Concentration	845 Limit	Groundwater Protection Standard	Unit
Antimony, total	0.001	0.006	0.006	mg/L
Arsenic, total	0.0017	0.010	0.010	mg/L
Barium, total	0.248	2.0	2.0	mg/L
Beryllium, total	0.0011	0.004	0.004	mg/L
Boron, total	0.0511	2	2	mg/L
Cadmium, total	0.001	0.005	0.005	mg/L
Chloride, total	31	200	200	mg/L
Chromium, total	0.0037	0.1	0.1	mg/L
Cobalt, total	0.0015	0.006	0.006	mg/L
Fluoride, total	0.25	4.0	4.0	mg/L
Lead, total	0.0015	0.0075	0.0075	mg/L
Lithium, total	0.003	0.04	0.04	mg/L
Mercury, total	0.0002	0.002	0.002	mg/L
Molybdenum, total	0.0015	0.1	0.1	mg/L
pH (field)	6.8 / 6.0	9.0 / 6.5	9.0 / 6.0	SU
Radium 226 and 228 combined	1.7	5	5	pCi/L
Selenium, total	0.0041	0.05	0.05	mg/L
Sulfate, total	39	400	400	mg/L
Thallium, total	0.002	0.002	0.002	mg/L
Total Dissolved Solids	332	1200	1200	mg/L

Notes:
For pH, the values presented are the upper / lower limits
Groundwater protection standards 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

generated 10/16/2021, 8:52:33 PM CDT

RAMBOLL

TABLE 4-1. SAMPLING AND ANALYSIS SUMMARY
GROUNDWATER MONITORING PLAN
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Parameter	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)	Sample Hold Time from Collection Date
Metals											
Metals [6]	6020, Li - EPA 200.7	14	2	0	0	1	17	plastic	600 mL	HNO_3 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											
Fluoride	9214 or EPA 300	14	2	0	0	1	17	plastic	300 mL	Cool to 4 °C	28 days
Chloride	9251 or EPA 300	14	2	0	0	1	17	plastic	100 mL	Cool to 4 °C	28 days
Sulfate	9036 or EPA 300	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											
Radium 226	9315 or EPA 903	14	0	0	0	0	14	plastic	1000 mL	HNO_3 to pH<2	6 months
Radium 228	9320 or EPA 904	14	0	0	0	0	14	plastic	1000 mL	HNO_3 to pH<2	6 months
Field Parameters											
pH	SM 4500-H+ B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Dissolved Oxygen [8]	SM 4500-O/405.1	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Temperature [8]	SM 2550	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Oxidation/Reduction Potential [8]	SM 2580 B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Specific Conductance [8]	SM 2510 B	14	NA	NA	NA	NA	14	flow-through cell	NA	none	immediately
Turbidity [7]	SM 2130 B	14	NA	NA	NA	NA	14	flow-through cell or hand-held turbidity meter	NA	none	immediately

[O: CJC 08/17/21; C: LDC 08/30/21]

Notes:
[1] Analytical method numbers are from SW-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as appropriate.
[2] Field duplicates will be collected at a frequency of one per group of 10 or fewer investigative water samples. Field duplicates will not be collected for radium analysis.
[3] 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.
[4] 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.
[5] Sample volume is estimated and will be determined by the laboratory.
[6] Metals = antimony, arsenic, barium, beryllium, 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 instrument availability.
[7] 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.
[8] Parameter collected for quality assurance 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.
< = less than
°C = degrees Celsius
HNO_3 = nitric acid
mL = milliliter
NA = not applicable
NTU = nephelometric turbidity unit

RAMBOLL

R001048

TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS

GROUNDWATER MONITORING PLAN

JOPPA POWER PLANT

EAST ASH POND

JOPPA, 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 228 combined	7440-14-4	pCi/L	9315/9320 or EPA 903/904	5	5	-- [6]	-- [7]

RAMBOLL

R001049

TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS

GROUNDWATER MONITORING PLAN

JOPPA POWER PLANT

EAST ASH POND

JOPPA, ILLINOIS

Constituent	CAS	Unit	Analytical Methods [1]	USEPA MCL [2]	35 I.A.C. § 845.600	RL [4, 5]	MDL [5]
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
Turbidity	NA	NTU	SM 2130 B	NS	NS	NA	NA

[O: CJC 08/17/21; C: LDC 08/30/21]

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

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

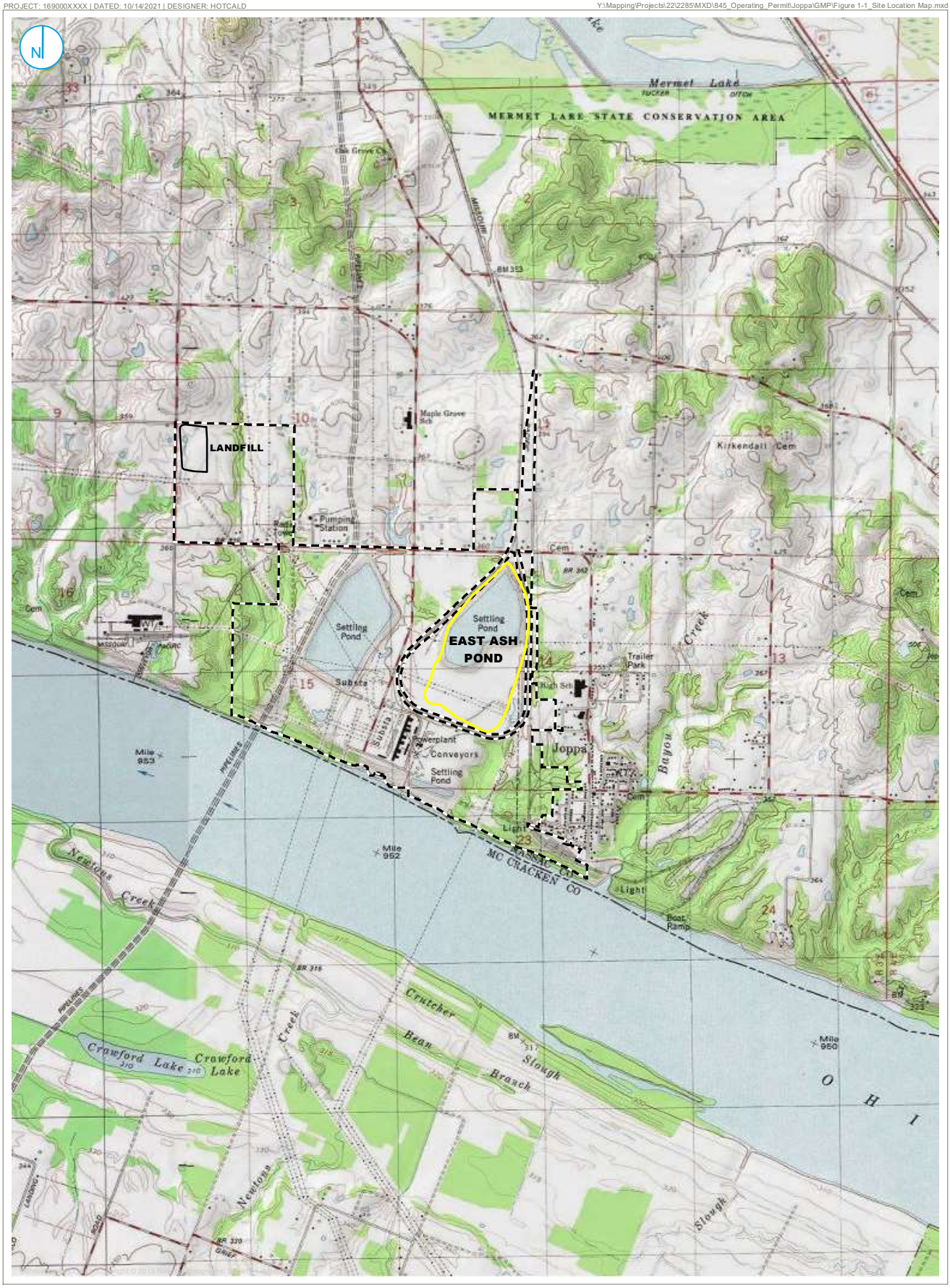
RAMBOLL

R001050

FIGURES

PROJECT: 169000XXXX | DATED: 10/14/2021 | DESIGNER: HOTCALD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\GMP\Figure 1-1_Site Location Map.mxd



PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
PROPERTY BOUNDARY

0 1,000 2,000 Feet

SITE LOCATION MAP

FIGURE 1-1

GROUNDWATER MONITORING PLAN
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Joppa\GMP\Figure 1-2_Site Map.mxd

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: HOTCALD

PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
CENTRAL DIKE
PROPERTY BOUNDARY

0 375 750 Feet

SITE MAP

GROUNDWATER MONITORING PLAN
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 1-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

R001053

PROJECT: 169000XXXX | DATED: 9/3/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\GMP\Figure 1-3_GWE_Contours_Event1_20210304.mxd

- MONITORING WELL
- STAFF GAUGE
- GROUNDWATER ELEVATION CONTOUR (1-FT CONTOUR INTERVAL, NAVD88)
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 200 400 Feet

NOTES:
1.ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.
2. ELEVATIONS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS MARCH 3 AND 4, 2021

GROUNDWATER MONITORING PLAN
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 1-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 10/18/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\GMP\Figure 2-1_Proposed Monitoring Well Network.mxd

- COMPLIANCE WELL
- BACKGROUND WELL
- STAFF GAUGE
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 200 400 Feet

PROPOSED PART 845 GROUNDWATER MONITORING WELL NETWORK

FIGURE 2-1

GROUNDWATER MONITORING PLAN
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

APPENDIX A
STATISTICAL ANALYSIS PLAN

Prepared for
Electric Energy, Inc.

Date
October 25, 2021

Project No.
1940100806-006

STATISTICAL ANALYSIS PLAN

EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

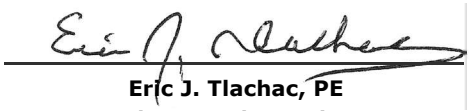
STATISTICAL ANALYSIS PLAN
JOPPA POWER PLANT EAST ASH POND

Project Name	**Joppa Power Plant East Ash Pond**
Project No.	**1940100806-006**
Recipient	**Electric Energy, Inc.**
Document Type	**Statistical Analysis Plan**
Version	**FINAL**
Date	**October 25, 2021**

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com

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; Joppa Power Plant East Ash Pond. 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; Joppa Power Plant East Ash Pond) 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; Joppa Power Plant East Ash Pond) 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; Joppa Power Plant East Ash Pond), 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

CONTENTS

Licensed Professional Certifications		**2**
1.	**Introduction**	**6**
1.1	Statistical Analysis Objectives	6
1.2	Statistical Analysis Plan Approach	6
2.	**Background Monitoring and Data Preparation**	**8**
2.1	Sample Independence	8
2.2	Non-Detect Data Processing	9
2.3	Testing for Normality	9
2.4	Testing for Outliers	9
2.5	Trend Analysis	10
2.6	Spatial Variation	10
2.7	Temporal Variation	10
2.8	Updating Background	11
3.	**Compliance Monitoring**	**13**
3.1	GWPS Establishment and Exceedance Determination	13
3.1.1	The Upper Tolerance Limit	14
3.1.2	Parametric Confidence Intervals around a Mean	16
3.1.3	Non-Parametric Confidence Intervals around a Median	16
3.1.4	The Upper Prediction Limit for a Future Mean	17
3.1.5	The Non-Parametric Upper Prediction Limit for a Future Median	17
3.1.6	Parametric Linear Regression and Confidence Band	18
3.1.7	Non-Parametric Thiel-Sen Trend Line and Confidence Band	20
3.2	Determination of Statistically Significant Increases over Background	21
4.	**References**	**22**

TABLES (IN TEXT)

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:

$$UTL = \exp\left[\overline{y} + \kappa\,(n, \gamma, \alpha - 1) \cdot s_y\right]$$

$\overline{y}$ = 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:

$$\hat{b} = \sum_{i=1}^{n} (t_i - \overline{t}) \cdot x_i / (n-1) \cdot s_t^2$$

x_i = i^{th} concentration value and

t_i = i^{th} sampling date

$\overline{t}$ = sampling mean date

s_t^2 = variance of the sampling dates

This estimate leads to the following regression equation:

$$\hat{x} = \overline{x} + \hat{b} \cdot (\mathrm{t} - \overline{t})$$

$\overline{x}$ = 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:

$$LCL_{1-\alpha} = \hat{x}_0 - \sqrt{2 s_e^2 \cdot F_{1-2\alpha,2,\mathrm{n}-1} \cdot \left[\frac{1}{n} + \frac{(t_0 - \overline{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$$UCL_{1-\alpha} = \hat{x}_0 - \sqrt{2 s_e^2 \cdot F_{1-2\alpha,2,\mathrm{n}-2} \cdot \left[\frac{1}{n} + \frac{(t_0 - \overline{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$\hat{x}_0$ = estimated mean concentration from the regression equation at time t_0

$F_{1-2\alpha,2,\mathrm{n}-2}$ = upper $(1\text{-}2\alpha)^{th}$ 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 J

October 2021

Memorandum

BURNS McDONNELL

Date: 25 October 2021

Subject: IEPA Part 845 – Slope Maintenance Documentation for East Ash Pond at Joppa Power Plant

Electric Energy, Inc. operates the coal-fired Joppa Power Plant (Plant) located in Massac County, Illinois. The East Ash Pond is an inactive surface impoundment storing coal combustion residuals (CCR). The requirements for the East Ash Pond are found in 35 Ill. Admin. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845).

Pursuant to Part 845, Section 845.230(d)(2)(F), the initial operating permit application for existing or inactive CCR surface impoundments that have not 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 Joppa East Ash CCR impoundment, 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 Joppa East Ash Pond Operations and Maintenance Manual

1. 1. 1 Operation and Maintenance Inspection

Inspections of the dam and appurtenant works are to be made by the Plant Engineer. During these inspections, a checklist of items to be maintained and items to be observed should be recorded. Appendix B 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 Electric Energy Shift Supervisor should be notified.**

Frequency: Quarterly and 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 - The water level in the reservoir should be recorded. Maximum reservoir levels as a result of heavy rainfall should be recorded.

2. Earth Embankment - Walk the crest, abutments, groins, side slopes and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlements, slumps, slides, and animal burrows. These are described as follows:

    a) Surface Erosion - Removal of vegetative cover by water action or animal, pedestrian or vehicle usage, which can lead to the development of ruts or gullies.

    b) Seepage - The passage of water through and/or underneath the earth embankment, at the contacts between the abutments and natural ground-line, 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.

    c) 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) direction. 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.

    d) 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.

    e) Slumps/Slides - A slow or sudden movement of the earth embankment slope on either face toward the toe of the dam.

    f) Animal Burrows - Animal burrows result in a loss of earth embankment material and can provide seepage paths for water through the embankment.

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.

3. 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 or within 20 feet of the toe of the embankment and appurtenant structures.

4. Drop Inlet - Check for any debris or other obstructions around the inlet crest and grate that 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.

5. Dewatering Valves – Check for any debris or other obstructions around the pipe inlets that may block or restrict the free flow of water. Operate each valve from the fully closed to the fully open position taking note of the physical and operating conditions of the system. Lubricate the stem, stem guides, and valve in accordance with the manufacturer's instructions.

6. Outlet Conduit – Check for any debris or other obstructions in the conduit which may block or restrict the free flow of water. Note any deformation or change in alignment of the conduit. Check the downstream end of the conduit for any seepage of water under the conduit.

7. Stilling Well - Check for any debris or other obstructions in the stilling well which may block or restrict the free flow of water. Check for the development of any rusty areas on the concrete, and cracking, breaking, or spalling of the concrete.

8. Riprap - Check for any debris or other obstructions in the riprap 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 riprap 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.

9. HDPE Liner – Wherever exposed, the HDPE Liner should be inspected for abrasion and tears, gouges, and protrusions under the liner.

10. Downstream Floodplain - Check the floodplain downstream of the dam for a distance of at least 100 feet for signs of seepage or boils.

Dam Inspection Report

Name of Dam: Joppa Power Station N & S Ash Ponds Dam ID No.: None

Permit Number: None Class of Dam: NA

Location: NW 1/4 Section 14 Township 15S Range 3E, 3rd PM

Owner: Dynegy Midwest Generation, LLC (Name) 618-543-3300 (Telephone Number (Day))

2100 Portland Road (Street) 618-543-3300 (Telephone Number (Night))

Joppa, IL (City) 62953 (Zip Code) County: Massac

Type of Dam: Earth Embankment

Type of Spillway: Drop Structures with concrete pipe conduits

Date(s) Inspected: 18-Nov-20

Weather When Inspected: Clear

Temperature When Inspected: 45° F

Pool Elevation When Inspected: 374 South Pond ; NA North Pond - flow through

Tailwater Elevation When Inspected: Stilling basin at toe of embankment at NE Corner of N. Ash Pond. Approx. EL 353

12/30/2020

EXP 11/30/21

Professional Engineer's Seal

Inspection Personnel:

Name	Title
James Knutelski, P.E.	Geotechnical Engineer
Jason Campbell, P.E.	Dynegy - Dam Safety
Paul Mauer	IDNR-OWR

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

EARTH EMBANKMENT

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Surface Cracks	NE		
Vertical and Horizontal Alignment of Crest	GC		
Unusual Movement or Cracking At or Beyond Toe	NE		
Sloughing or Erosion of Embankment and Abutment Slopes	NE		
Upstream Face Slope Protection	GC		
Seepage	NE/OB		Toe of exterior slope on east side of South Ash Pond and drains should be periodically observed for signs of seepage.
Filter and Filter Drains	NA		

R001087

EARTH EMBANKMENT
(Continued)

ITEM	CONDITION CODE	DEFICIENCIES	RECOMMENDED REMEDIAL MEASURES AND IMPLEMENTATION SCHEDULE
Animal Damage	MM	Animal burrow on south side near crest.	Fill burrow.
Embankment Drainage Ditches	NE		
Vegetative Cover	GC		
Outlet Channel at Toe of East Side	NE		
Other	NA		
Other	NA		
Other	NA		

R001088

SUMMARY OF MAINTENANCE DONE AND/OR

REPAIRS MADE SINCE THE LAST INSPECTION

DATE OF PRESENT INSPECTION 18-Nov-20

DATE OF LAST INSPECTION 4-Sep-19

1. EARTH EMBANKMENT DAMS
   Mowing of vegetated slopes. Sprayed slope protection. Installed blanket drain on east side at access roadway.

2. CONCRETE MASONRY DAMS
   NA

3. PRINCIPAL SPILLWAY
   None reported.

4. OUTLET WORKS
   NA

5. EMERGENCY SPILLWAY
   NA

West side – East Ash Pond exterior

West side – East Ash Pond crest and interior

East Ash Pond interior

East side – East Ash Pond exterior

East side – East Ash Pond exterior

East side – East Ash Pond crest and interior

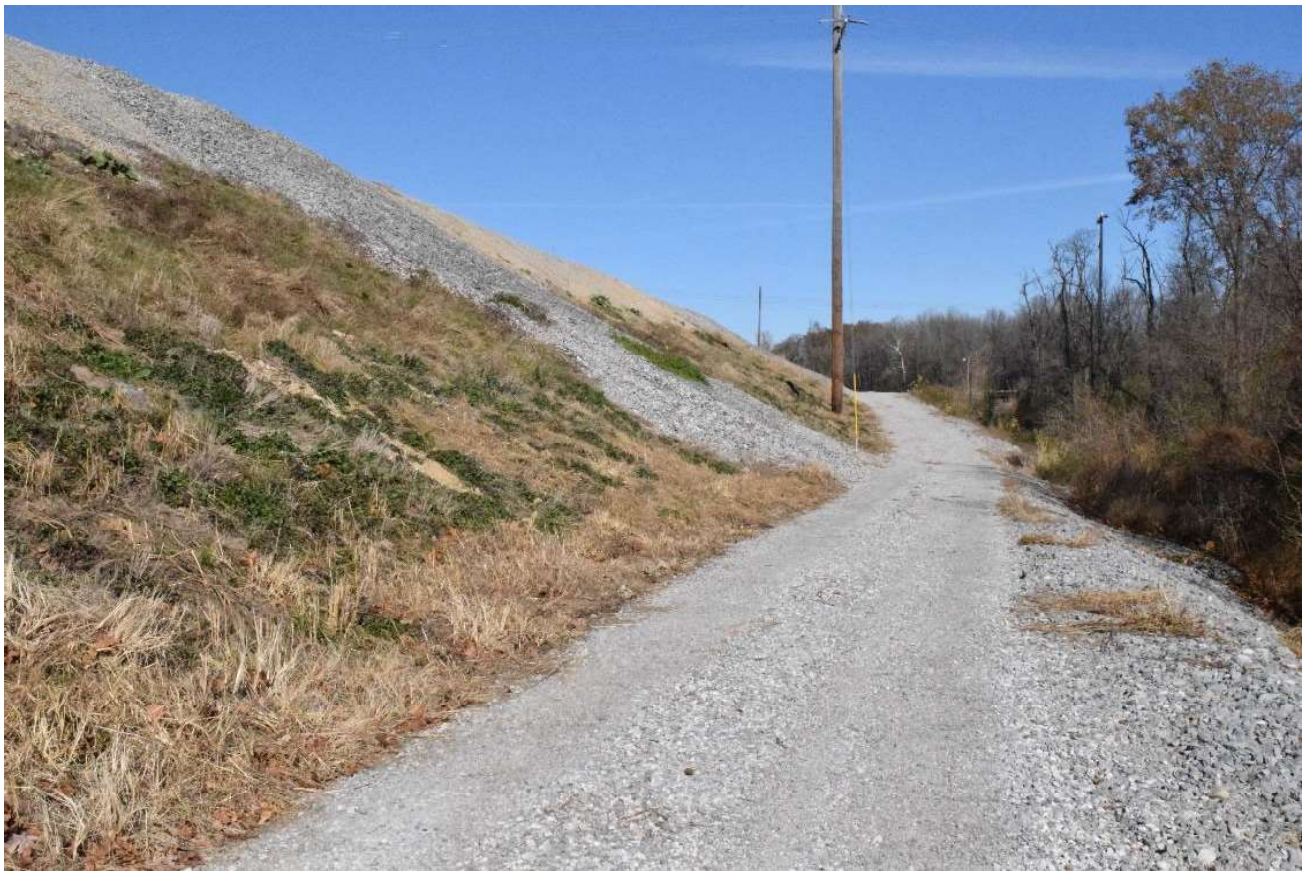
East Ash Pond – west exterior slope

East Ash Pond – west exterior slope

East Ash Pond – south side crest and interior

East Ash Pond – south exterior slope

East Ash Pond east side crest



East Ash Pond east side exterior

East Ash Pond east side exterior – blanket drain

East Ash Pond east side exterior – blanket drain

ATTACHMENT K

October 2021

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	Joppa Power Plant / 2100 Portland Road, Joppa, IL 62953		
Owner Name / Address	Electric Energy, Inc. / 6555 Sierra Drive Irving, Texas 75039		
CCR Unit	East Ash Pond	Closure Method and Final Cover Type	Close In-Place Clayey Soil Cover with Vegetation

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 in 40 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 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, 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) 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.	Electric Energy, Inc. 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 an operating electric generation facility. Planned uses of the property during the post-closure period are currentlyunknown, 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. Following closure of the CCR unit, 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 Joppa East Ash Pond 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 40 C.F.R. § 257.104(e) and 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: Electric Energy, Inc.; Joppa Power Plant; East Ash Pond

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

9/29/2021

Date

ATTACHMENT M

October 2021

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 Joppa Power Plant East Ash Pond, Illinois Environmental Protection Agency (IEPA) ID No. W1270100004-02.

Note

Groundwater concentrations from 2015 to 2021 presented in the Hydrogeologic Site Characterization Report (HCR) Table 4-1, and evaluated and summarized in the following tables, 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.

Background Concentrations

Background monitoring wells identified in the GMP include G01D and G02D.

For monitoring wells that have been historically monitored in accordance with Title 40, Code of Federal Regulations, Part 257, Subpart D (Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments), 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.

For all other monitoring wells, either newly constructed in 2021 or existing wells not monitored under Title 40, Code of Federal Regulations, Part 257, Subpart D, background concentrations calculated from the eight sampling events required by 35 I.A.C. § 845.650(b)(1)(A), to be collected within 180 days from April 21, 2021, were compared to the standards identified in 35 I.A.C. § 845.600(a)(1). For constituents with calculated background concentrations greater than the standards in 35 I.A.C. § 845.600(a)(1), those calculated background concentrations were used as GWPSs. Compliance well statistical calculations from that same time period were compared to the GWPSs to determine potential exceedances.

Corrective Action

No corrective actions have been taken to remediate the groundwater.

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G03	UA	845	Antimony, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G03	UA	845	Arsenic, total	mg/L	03/05/2021 - 07/21/2021	CB around linear reg	-0.00081	0.010	0.0017	0.01	Standard
G03	UA	845	Barium, total	mg/L	03/05/2021 - 07/21/2021	CB around linear reg	0.035	2.0	0.25	2	Standard
G03	UA	845	Beryllium, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G03	UA	845	Boron, total	mg/L	03/05/2021 - 07/21/2021	CI around geomean	0.20	2.0	0.053	2	Standard
G03	UA	845	Cadmium, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G03	UA	845	Chloride, total	mg/L	03/05/2021 - 07/21/2021	CI around mean	19	200	32	200	Standard
G03	UA	845	Chromium, total	mg/L	03/05/2021 - 07/21/2021	CB around linear reg	-0.00758	0.10	0.0039	0.1	Standard
G03	UA	845	Cobalt, total	mg/L	03/05/2021 - 07/21/2021	CB around linear reg	-0.00129	0.006	0.0015	0.006	Standard
G03	UA	845	Fluoride, total	mg/L	03/05/2021 - 07/21/2021	CI around mean	0.20	4.0	0.25	4	Standard
G03	UA	845	Lead, total	mg/L	03/05/2021 - 07/21/2021	CB around linear reg	-0.00104	0.0075	0.0015	0.0075	Standard
G03	UA	845	Lithium, total	mg/L	03/05/2021 - 07/21/2021	CI around median	0.003	0.040	0.003	0.04	Standard
G03	UA	845	Mercury, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G03	UA	845	Molybdenum, total	mg/L	03/05/2021 - 07/21/2021	CI around median	0.001	0.10	0.0015	0.1	Standard
G03	UA	845	pH (field)	SU	03/05/2021 - 07/21/2021	CI around mean	6.2	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G03	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/05/2021 - 07/21/2021	CI around mean	-0.0133	5.0	1.7	5	Standard
G03	UA	845	Selenium, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G03	UA	845	Sulfate, total	mg/L	03/05/2021 - 07/21/2021	CI around mean	62	400	39	400	Standard
G03	UA	845	Thallium, total	mg/L	03/05/2021 - 07/21/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G03	UA	845	Total Dissolved Solids	mg/L	03/05/2021 - 07/21/2021	CI around geomean	273	1200	334	1200	Standard
G04	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G04	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G04	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.19	2.0	0.25	2	Standard
G04	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard

RAMBOLL

R001104

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G04	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0	2.0	0.053	2	Standard
G04	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G04	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	22	200	32	200	Standard
G04	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0039	0.1	Standard
G04	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.000558	0.006	0.0015	0.006	Standard
G04	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.22	4.0	0.25	4	Standard
G04	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0	0.0075	0.0015	0.0075	Standard
G04	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.003	0.040	0.003	0.04	Standard
G04	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G04	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00292	0.10	0.0015	0.1	Standard
G04	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	6.2	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G04	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.041	5.0	1.7	5	Standard
G04	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.0012	0.050	0.0042	0.05	Standard
G04	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	-3.96	400	39	400	Standard
G04	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G04	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	228	1200	334	1200	Standard
G05	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G05	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G05	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.13	2.0	0.25	2	Standard
G05	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G05	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.11	2.0	0.053	2	Standard
G05	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G05	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	15	200	32	200	Standard
G05	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around geomean	0.00114	0.10	0.0039	0.1	Standard

RAMBOLL

R001105

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G05	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.00392	0.006	0.0015	0.006	Standard
G05	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.30	4.0	0.25	4	Standard
G05	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G05	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.003	0.040	0.003	0.04	Standard
G05	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G05	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00447	0.10	0.0015	0.1	Standard
G05	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	6.4	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G05	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.14	5.0	1.7	5	Standard
G05	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00118	0.050	0.0042	0.05	Standard
G05	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	84	400	39	400	Standard
G05	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.002	0.002	0.002	Standard
G05	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	347	1200	334	1200	Standard
G06	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G06	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.010	0.0017	0.01	Standard
G06	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.016	2.0	0.25	2	Standard
G06	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G06	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.0	2.0	0.053	2	Standard
G06	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G06	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	21	200	32	200	Standard
G06	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around geomean	0.00107	0.10	0.0039	0.1	Standard
G06	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.006	0.0015	0.006	Standard
G06	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.26	4.0	0.25	4	Standard
G06	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.0075	0.0015	0.0075	Standard
G06	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00334	0.040	0.003	0.04	Standard

RAMBOLL

R001106

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G06	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G06	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G06	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CB around linear reg	6.2	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G06	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.32	5.0	1.7	5	Standard
G06	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G06	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	212	400	39	400	Standard
G06	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G06	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around median	500	1200	334	1200	Standard
G06S	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G06S	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G06S	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.078	2.0	0.25	2	Standard
G06S	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G06S	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.23	2.0	0.053	2	Standard
G06S	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G06S	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0	200	32	200	Standard
G06S	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0039	0.1	Standard
G06S	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	-0.00119	0.006	0.0015	0.006	Standard
G06S	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.25	4.0	0.25	4	Standard
G06S	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G06S	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.0022	0.040	0.003	0.04	Standard
G06S	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G06S	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G06S	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	5.5	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G06S	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	-0.187	5.0	1.7	5	Standard

RAMBOLL

R001107

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G06S	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G06S	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	28	400	39	400	Standard
G06S	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G06S	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	140	1200	334	1200	Standard
G07	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G07	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.010	0.0017	0.01	Standard
G07	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.035	2.0	0.25	2	Standard
G07	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G07	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	4.2	2.0	0.053	2	Standard
G07	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G07	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	20	200	32	200	Standard
G07	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around geomean	0.00108	0.10	0.0039	0.1	Standard
G07	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	-0.00149	0.006	0.0015	0.006	Standard
G07	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.20	4.0	0.25	4	Standard
G07	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.0075	0.0015	0.0075	Standard
G07	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.003	0.040	0.003	0.04	Standard
G07	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G07	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G07	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CB around linear reg	5.9	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G07	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.088	5.0	1.7	5	Standard
G07	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G07	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	246	400	39	400	Standard
G07	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G07	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	564	1200	334	1200	Standard

RAMBOLL

R001108

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G08	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G08	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00634	0.010	0.0017	0.01	Standard
G08	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	-0.0117	2.0	0.25	2	Standard
G08	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G08	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.9	2.0	0.053	2	Standard
G08	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G08	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	13	200	32	200	Standard
G08	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00083	0.10	0.0039	0.1	Standard
G08	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00213	0.006	0.0015	0.006	Standard
G08	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.27	4.0	0.25	4	Standard
G08	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.0075	0.0015	0.0075	Standard
G08	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.003	0.040	0.003	0.04	Standard
G08	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G08	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.0017	0.10	0.0015	0.1	Standard
G08	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	6.8	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G08	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.23	5.0	1.7	5	Standard
G08	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G08	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	202	400	39	400	Standard
G08	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G08	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	528	1200	334	1200	Standard
G09	UA	845	Antimony, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G09	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.00125	0.010	0.0017	0.01	Standard
G09	UA	845	Barium, total	mg/L	03/04/2021 - 07/21/2021	CB around linear reg	-0.0084	2.0	0.25	2	Standard
G09	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0.001	0.004	0.0011	0.004	Standard

RAMBOLL

R001109

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G09	UA	845	Boron, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0.28	2.0	0.053	2	Standard
G09	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G09	UA	845	Chloride, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	20	200	32	200	Standard
G09	UA	845	Chromium, total	mg/L	03/04/2021 - 07/21/2021	CI around geomean	0.00115	0.10	0.0039	0.1	Standard
G09	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/21/2021	CB around linear reg	-0.00201	0.006	0.0015	0.006	Standard
G09	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.28	4.0	0.25	4	Standard
G09	UA	845	Lead, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0.001	0.0075	0.0015	0.0075	Standard
G09	UA	845	Lithium, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.00298	0.040	0.003	0.04	Standard
G09	UA	845	Mercury, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G09	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G09	UA	845	pH (field)	SU	03/04/2021 - 07/21/2021	CI around mean	6.0	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G09	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/21/2021	CI around geomean	0.20	5.0	1.7	5	Standard
G09	UA	845	Selenium, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0.001	0.050	0.0042	0.05	Standard
G09	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/21/2021	CI around median	272	400	39	400	Standard
G09	UA	845	Thallium, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G09	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/21/2021	CB around linear reg	576	1200	334	1200	Standard
G09M	LAU	845	Antimony, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G09M	LAU	845	Arsenic, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.00321	0.010	0.0017	0.01	Standard
G09M	LAU	845	Barium, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.29	2.0	0.25	2	Standard
G09M	LAU	845	Beryllium, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G09M	LAU	845	Boron, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.014	2.0	0.053	2	Standard
G09M	LAU	845	Cadmium, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0	0.005	0.001	0.005	Standard
G09M	LAU	845	Chloride, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0	200	32	200	Standard
G09M	LAU	845	Chromium, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	-0.00498	0.10	0.0039	0.1	Standard

RAMBOLL

R001110

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G09M	LAU	845	Cobalt, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.000244	0.006	0.0015	0.006	Standard
G09M	LAU	845	Fluoride, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.26	4.0	0.25	4	Standard
G09M	LAU	845	Lead, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	-0.00138	0.0075	0.0015	0.0075	Standard
G09M	LAU	845	Lithium, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.0049	0.040	0.003	0.04	Standard
G09M	LAU	845	Mercury, total	mg/L	03/04/2021 - 07/21/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G09M	LAU	845	Molybdenum, total	mg/L	03/04/2021 - 07/21/2021	CI around mean	0.00359	0.10	0.0015	0.1	Standard
G09M	LAU	845	pH (field)	SU	03/04/2021 - 07/21/2021	CI around mean	6.7	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G09M	LAU	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/21/2021	CI around mean	0.17	5.0	1.7	5	Standard
G09M	LAU	845	Selenium, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0	0.050	0.0042	0.05	Standard
G09M	LAU	845	Sulfate, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0	400	39	400	Standard
G09M	LAU	845	Thallium, total	mg/L	03/04/2021 - 07/21/2021	CI around median	0	0.002	0.002	0.002	Standard
G09M	LAU	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/21/2021	CI around mean	239	1200	334	1200	Standard
G10	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G10	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.000915	0.010	0.0017	0.01	Standard
G10	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.031	2.0	0.25	2	Standard
G10	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G10	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.9	2.0	0.053	2	Standard
G10	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G10	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	25	200	32	200	Standard
G10	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.000925	0.10	0.0039	0.1	Standard
G10	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.002	0.006	0.0015	0.006	Standard
G10	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.27	4.0	0.25	4	Standard
G10	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G10	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.003	0.040	0.003	0.04	Standard

RAMBOLL

R001111

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G10	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G10	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00128	0.10	0.0015	0.1	Standard
G10	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	6.4	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G10	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.45	5.0	1.7	5	Standard
G10	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G10	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	372	400	39	400	Standard
G10	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G10	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	743	1200	334	1200	Standard
G11	UA	845	Antimony, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G11	UA	845	Arsenic, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G11	UA	845	Barium, total	mg/L	03/04/2021 - 07/20/2021	CB around linear reg	0.0062	2.0	0.25	2	Standard
G11	UA	845	Beryllium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G11	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.26	2.0	0.053	2	Standard
G11	UA	845	Cadmium, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G11	UA	845	Chloride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	32	200	32	200	Standard
G11	UA	845	Chromium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.10	0.0039	0.1	Standard
G11	UA	845	Cobalt, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.000633	0.006	0.0015	0.006	Standard
G11	UA	845	Fluoride, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.17	4.0	0.25	4	Standard
G11	UA	845	Lead, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G11	UA	845	Lithium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00319	0.040	0.003	0.04	Standard
G11	UA	845	Mercury, total	mg/L	03/04/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G11	UA	845	Molybdenum, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.10	0.0015	0.1	Standard
G11	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	5.8	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G11	UA	845	Radium-226 + Radium 228, tot	pCi/L	03/04/2021 - 07/20/2021	CI around mean	0.16	5.0	1.7	5	Standard

RAMBOLL

R001112

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G11	UA	845	Selenium, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	0.00407	0.050	0.0042	0.05	Standard
G11	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	443	400	39	400	Standard
G11	UA	845	Thallium, total	mg/L	03/04/2021 - 07/20/2021	CI around median	0.001	0.002	0.002	0.002	Standard
G11	UA	845	Total Dissolved Solids	mg/L	03/04/2021 - 07/20/2021	CI around mean	824	1200	334	1200	Standard
G51D	UA	257	Antimony, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G51D	UA	257	Arsenic, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.010	0.0026	0.01	Standard
G51D	UA	257	Barium, total	mg/L	12/03/2015 - 03/24/2021	CB around T-S line	-0.0404	2.0	0.30	2	Standard
G51D	UA	257	Beryllium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.004	0.001	0.004	Standard
G51D	UA	257	Boron, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.61	2.0	0.055	2	Standard
G51D	UA	257	Cadmium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G51D	UA	257	Chloride, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	3.7	200	29	200	Standard
G51D	UA	257	Chromium, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00138	0.10	0.0093	0.1	Standard
G51D	UA	257	Cobalt, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	-0.00924	0.037	0.037	0.006	Background
G51D	UA	257	Fluoride, total	mg/L	12/03/2015 - 03/24/2021	CI around median	0.10	4.0	0.29	4	Standard
G51D	UA	257	Lead, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.0075	0.0018	0.0075	Standard
G51D	UA	257	Lithium, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00563	0.040	0.0024	0.04	Standard
G51D	UA	257	Mercury, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G51D	UA	257	Molybdenum, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.0015	0.10	0.0018	0.1	Standard
G51D	UA	257	pH (field)	SU	12/03/2015 - 03/24/2021	CI around mean	5.6	6.2/9.0	6.2/6.9	6.5/9	Background/Standard
G51D	UA	257	Radium-226 + Radium 228, tot	pCi/L	12/03/2015 - 03/24/2021	CI around mean	0.39	5.0	1.5	5	Standard
G51D	UA	257	Selenium, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00498	0.050	0.0039	0.05	Standard
G51D	UA	257	Sulfate, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	121	400	203	400	Standard
G51D	UA	257	Thallium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.002	0.002	0.001	0.002	Standard
G51D	UA	257	Total Dissolved Solids	mg/L	12/03/2015 - 03/24/2021	CI around mean	314	1200	541	1200	Standard

RAMBOLL

R001113

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G52D	UA	257	Antimony, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G52D	UA	257	Arsenic, total	mg/L	12/03/2015 - 03/25/2021	CB around linear reg	-0.00145	0.010	0.0026	0.01	Standard
G52D	UA	257	Barium, total	mg/L	12/03/2015 - 03/25/2021	CB around T-S line	0.14	2.0	0.30	2	Standard
G52D	UA	257	Beryllium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.004	0.001	0.004	Standard
G52D	UA	257	Boron, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.025	2.0	0.055	2	Standard
G52D	UA	257	Cadmium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G52D	UA	257	Chloride, total	mg/L	12/03/2015 - 03/25/2021	CB around linear reg	9.0	200	29	200	Standard
G52D	UA	257	Chromium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.0015	0.10	0.0093	0.1	Standard
G52D	UA	257	Cobalt, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	0.00276	0.037	0.037	0.006	Background
G52D	UA	257	Fluoride, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	0.25	4.0	0.29	4	Standard
G52D	UA	257	Lead, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.0075	0.0018	0.0075	Standard
G52D	UA	257	Lithium, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	0.00269	0.040	0.0024	0.04	Standard
G52D	UA	257	Mercury, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G52D	UA	257	Molybdenum, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	0.00108	0.10	0.0018	0.1	Standard
G52D	UA	257	pH (field)	SU	12/03/2015 - 03/25/2021	CI around mean	6.2	6.2/9.0	6.2/6.9	6.5/9	Background/Standard
G52D	UA	257	Radium-226 + Radium 228, tot	pCi/L	12/03/2015 - 03/25/2021	CI around mean	0.78	5.0	1.5	5	Standard
G52D	UA	257	Selenium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.050	0.0039	0.05	Standard
G52D	UA	257	Sulfate, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	82	400	203	400	Standard
G52D	UA	257	Thallium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.002	0.002	0.001	0.002	Standard
G52D	UA	257	Total Dissolved Solids	mg/L	12/03/2015 - 03/25/2021	CI around mean	348	1200	541	1200	Standard
G53D	UA	257	Antimony, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G53D	UA	257	Arsenic, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.010	0.0026	0.01	Standard
G53D	UA	257	Barium, total	mg/L	12/03/2015 - 03/25/2021	CB around linear reg	-0.00254	2.0	0.30	2	Standard
G53D	UA	257	Beryllium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.004	0.001	0.004	Standard

RAMBOLL

R001114

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G53D	UA	257	Boron, total	mg/L	12/03/2015 - 03/25/2021	CI around median	0.33	2.0	0.055	2	Standard
G53D	UA	257	Cadmium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G53D	UA	257	Chloride, total	mg/L	12/03/2015 - 03/25/2021	CI around median	17	200	29	200	Standard
G53D	UA	257	Chromium, total	mg/L	12/03/2015 - 03/25/2021	CI around median	0.001	0.10	0.0093	0.1	Standard
G53D	UA	257	Cobalt, total	mg/L	12/03/2015 - 03/25/2021	CI around geomean	0.00133	0.037	0.037	0.006	Background
G53D	UA	257	Fluoride, total	mg/L	12/03/2015 - 03/25/2021	CI around mean	0.62	4.0	0.29	4	Standard
G53D	UA	257	Lead, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.0075	0.0018	0.0075	Standard
G53D	UA	257	Lithium, total	mg/L	12/03/2015 - 03/25/2021	CI around geomean	0.0017	0.040	0.0024	0.04	Standard
G53D	UA	257	Mercury, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G53D	UA	257	Molybdenum, total	mg/L	12/03/2015 - 03/25/2021	CI around median	0.001	0.10	0.0018	0.1	Standard
G53D	UA	257	pH (field)	SU	12/03/2015 - 03/25/2021	CI around mean	6.5	6.2/9.0	6.2/6.9	6.5/9	Background/Standard
G53D	UA	257	Radium-226 + Radium 228, tot	pCi/L	12/03/2015 - 03/25/2021	CI around mean	0.26	5.0	1.5	5	Standard
G53D	UA	257	Selenium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.001	0.050	0.0039	0.05	Standard
G53D	UA	257	Sulfate, total	mg/L	12/03/2015 - 03/25/2021	CB around T-S line	38	400	203	400	Standard
G53D	UA	257	Thallium, total	mg/L	12/03/2015 - 03/25/2021	All ND - Last	0.002	0.002	0.001	0.002	Standard
G53D	UA	257	Total Dissolved Solids	mg/L	12/03/2015 - 03/25/2021	CI around mean	318	1200	541	1200	Standard
G54S	UCU	845	Antimony, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G54S	UCU	845	Arsenic, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G54S	UCU	845	Barium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.037	2.0	0.25	2	Standard
G54S	UCU	845	Beryllium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G54S	UCU	845	Boron, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.015	2.0	0.053	2	Standard
G54S	UCU	845	Cadmium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G54S	UCU	845	Chloride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	28	200	32	200	Standard
G54S	UCU	845	Chromium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0039	0.1	Standard

RAMBOLL

R001115

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G54S	UCU	845	Cobalt, total	mg/L	03/03/2021 - 07/20/2021	Most recent sample	0.001	0.006	0.0015	0.006	Standard
G54S	UCU	845	Fluoride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.25	4.0	0.25	4	Standard
G54S	UCU	845	Lead, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	0.0075	0.0015	0.0075	Standard
G54S	UCU	845	Lithium, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	0.040	0.003	0.04	Standard
G54S	UCU	845	Mercury, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G54S	UCU	845	Molybdenum, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00242	0.10	0.0015	0.1	Standard
G54S	UCU	845	pH (field)	SU	03/03/2021 - 07/20/2021	CI around mean	6.2	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G54S	UCU	845	Radium-226 + Radium 228, tot	pCi/L	03/03/2021 - 07/20/2021	CI around mean	-0.211	5.0	1.7	5	Standard
G54S	UCU	845	Selenium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.018	0.050	0.0042	0.05	Standard
G54S	UCU	845	Sulfate, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	-10.2	400	39	400	Standard
G54S	UCU	845	Thallium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G54S	UCU	845	Total Dissolved Solids	mg/L	03/03/2021 - 07/20/2021	CI around mean	263	1200	334	1200	Standard
G54D	UA	257	Antimony, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G54D	UA	257	Arsenic, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	-0.000224	0.010	0.0026	0.01	Standard
G54D	UA	257	Barium, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	0.11	2.0	0.30	2	Standard
G54D	UA	257	Beryllium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.004	0.001	0.004	Standard
G54D	UA	257	Boron, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	0.54	2.0	0.055	2	Standard
G54D	UA	257	Cadmium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G54D	UA	257	Chloride, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	14	200	29	200	Standard
G54D	UA	257	Chromium, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	0.00122	0.10	0.0093	0.1	Standard
G54D	UA	257	Cobalt, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00344	0.037	0.037	0.006	Background
G54D	UA	257	Fluoride, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	0.32	4.0	0.29	4	Standard
G54D	UA	257	Lead, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.0075	0.0018	0.0075	Standard
G54D	UA	257	Lithium, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00187	0.040	0.0024	0.04	Standard

RAMBOLL

R001116

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G54D	UA	257	Mercury, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G54D	UA	257	Molybdenum, total	mg/L	12/03/2015 - 03/24/2021	CB around linear reg	0.00135	0.10	0.0018	0.1	Standard
G54D	UA	257	pH (field)	SU	12/03/2015 - 03/24/2021	CI around mean	6.6	6.2/9.0	6.2/6.9	6.5/9	Background/Standard
G54D	UA	257	Radium-226 + Radium 228, tot	pCi/L	12/03/2015 - 03/24/2021	CI around mean	0.51	5.0	1.5	5	Standard
G54D	UA	257	Selenium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.001	0.050	0.0039	0.05	Standard
G54D	UA	257	Sulfate, total	mg/L	12/03/2015 - 03/24/2021	CI around mean	145	400	203	400	Standard
G54D	UA	257	Thallium, total	mg/L	12/03/2015 - 03/24/2021	All ND - Last	0.002	0.002	0.001	0.002	Standard
G54D	UA	257	Total Dissolved Solids	mg/L	12/03/2015 - 03/24/2021	CI around mean	483	1200	541	1200	Standard
G151	UCU	845	Antimony, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G151	UCU	845	Arsenic, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G151	UCU	845	Barium, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	2.0	0.25	2	Standard
G151	UCU	845	Beryllium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G151	UCU	845	Boron, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.088	2.0	0.053	2	Standard
G151	UCU	845	Cadmium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G151	UCU	845	Chloride, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	200	32	200	Standard
G151	UCU	845	Chromium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.000532	0.10	0.0039	0.1	Standard
G151	UCU	845	Cobalt, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	0.006	0.0015	0.006	Standard
G151	UCU	845	Fluoride, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.10	4.0	0.25	4	Standard
G151	UCU	845	Lead, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G151	UCU	845	Lithium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00476	0.040	0.003	0.04	Standard
G151	UCU	845	Mercury, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G151	UCU	845	Molybdenum, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G151	UCU	845	pH (field)	SU	03/03/2021 - 07/20/2021	CI around mean	5.4	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G151	UCU	845	Radium-226 + Radium 228, tot	pCi/L	03/03/2021 - 07/20/2021	CI around mean	-0.378	5.0	1.7	5	Standard

RAMBOLL

R001117

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G151	UCU	845	Selenium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00217	0.050	0.0042	0.05	Standard
G151	UCU	845	Sulfate, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	97	400	39	400	Standard
G151	UCU	845	Thallium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G151	UCU	845	Total Dissolved Solids	mg/L	03/03/2021 - 07/20/2021	CI around mean	254	1200	334	1200	Standard
G152B	UCU	845	Antimony, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G152B	UCU	845	Arsenic, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G152B	UCU	845	Barium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.54	2.0	0.25	2	Standard
G152B	UCU	845	Beryllium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G152B	UCU	845	Boron, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.025	2.0	0.053	2	Standard
G152B	UCU	845	Cadmium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G152B	UCU	845	Chloride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	42	200	32	200	Standard
G152B	UCU	845	Chromium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00213	0.10	0.0039	0.1	Standard
G152B	UCU	845	Cobalt, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.0015	0.006	Standard
G152B	UCU	845	Fluoride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.46	4.0	0.25	4	Standard
G152B	UCU	845	Lead, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G152B	UCU	845	Lithium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00426	0.040	0.003	0.04	Standard
G152B	UCU	845	Mercury, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G152B	UCU	845	Molybdenum, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0015	0.10	0.0015	0.1	Standard
G152B	UCU	845	pH (field)	SU	03/03/2021 - 07/20/2021	CI around mean	6.4	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G152B	UCU	845	Radium-226 + Radium 228, tot	pCi/L	03/03/2021 - 07/20/2021	CI around mean	-0.0622	5.0	1.7	5	Standard
G152B	UCU	845	Selenium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00424	0.050	0.0042	0.05	Standard
G152B	UCU	845	Sulfate, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	12	400	39	400	Standard
G152B	UCU	845	Thallium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G152B	UCU	845	Total Dissolved Solids	mg/L	03/03/2021 - 07/20/2021	CI around mean	404	1200	334	1200	Standard

RAMBOLL

R001118

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G153	UCU	845	Antimony, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.001	0.006	Standard
G153	UCU	845	Arsenic, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.010	0.0017	0.01	Standard
G153	UCU	845	Barium, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.16	2.0	0.25	2	Standard
G153	UCU	845	Beryllium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.004	0.0011	0.004	Standard
G153	UCU	845	Boron, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.025	2.0	0.053	2	Standard
G153	UCU	845	Cadmium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.005	0.001	0.005	Standard
G153	UCU	845	Chloride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	22	200	32	200	Standard
G153	UCU	845	Chromium, total	mg/L	03/03/2021 - 07/20/2021	CI around median	0	0.10	0.0039	0.1	Standard
G153	UCU	845	Cobalt, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.006	0.0015	0.006	Standard
G153	UCU	845	Fluoride, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.85	4.0	0.25	4	Standard
G153	UCU	845	Lead, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.0075	0.0015	0.0075	Standard
G153	UCU	845	Lithium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.003	0.040	0.003	0.04	Standard
G153	UCU	845	Mercury, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.0002	0.002	0.0002	0.002	Standard
G153	UCU	845	Molybdenum, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	0.00186	0.10	0.0015	0.1	Standard
G153	UCU	845	pH (field)	SU	03/03/2021 - 07/20/2021	CI around mean	6.5	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G153	UCU	845	Radium-226 + Radium 228, tot	pCi/L	03/03/2021 - 07/20/2021	CI around mean	-0.315	5.0	1.7	5	Standard
G153	UCU	845	Selenium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.001	0.050	0.0042	0.05	Standard
G153	UCU	845	Sulfate, total	mg/L	03/03/2021 - 07/20/2021	CI around mean	66	400	39	400	Standard
G153	UCU	845	Thallium, total	mg/L	03/03/2021 - 07/20/2021	All ND - Last	0.002	0.002	0.002	0.002	Standard
G153	UCU	845	Total Dissolved Solids	mg/L	03/03/2021 - 07/20/2021	CI around mean	315	1200	334	1200	Standard

RAMBOLL

R001119

TABLE 1. DETERMINATION OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Notes:
Potential exceedance of GWPS
HSU = hydrostratigraphic unit:
  LAU = Lower Aquifer Unit
  UA = Uppermost Aquifer
  UCU = Upper Confining Unit
Program = regulatory program data were collected under:
  257 = 40 C.F.R. Part 257 Subpart D (Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments)
  845 = 35 I.A.C. Part 845 (Sampling events completed to assess well locations for inclusion in the Part 845 monitoring well network)
mg/L = milligrams per liter
pCi/L = picoCuries per liter
SU = standard units
Sample Count = number of samples from Sampled Date Range used to calculate the Statistical Result
Statistical Calculation = method used to calculate the statistical result:
  All ND - Last = All results were below the reporting limit, and the last determined reporting limit is shown
  CB around linear reg = Confidence band around linear regression
  CB around T-S line = Confidence band around Thiel-Sen line
  CI around geomean = Confidence interval around the geometric mean
  CI around mean = Confidence interval around the mean
  CI around median = Confidence interval around the median
  Most recent sample = Result for the most recently collected sample used due to insufficient data
Statistical Result = calculated in accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
For pH, the values presented are the lower / upper limits
GWPS = Groundwater Protection Standard
GWPS Source:
  Standard = standard specified in 35 I.A.C. § 845.600(a)(1)
  Background = background concentration (see cover page for additional information)

RAMBOLL

R001120

TABLE 2. SUMMARY OF POTENTIAL EXCEEDANCES
HISTORY OF POTENTIAL EXCEEDANCES
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Sample Location	HSU	Program	Constituent	Result Unit	Sample Date Range	Statistical Calculation	Statistical Result	GWPS	Background	Part 845 Standard	GWPS Source
G06	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.0	2.0	0.053	2	Standard
G06S	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	5.5	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G07	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	4.2	2.0	0.053	2	Standard
G07	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CB around linear reg	5.9	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G08	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.9	2.0	0.053	2	Standard
G10	UA	845	Boron, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	3.9	2.0	0.053	2	Standard
G11	UA	845	pH (field)	SU	03/04/2021 - 07/20/2021	CI around mean	5.8	6.0/9.0	6.0/6.8	6.5/9	Background/Standard
G11	UA	845	Sulfate, total	mg/L	03/04/2021 - 07/20/2021	CI around mean	443	400	39	400	Standard
G51D	UA	257	pH (field)	SU	12/03/2015 - 03/24/2021	CI around mean	5.6	6.2/9.0	6.2/6.9	6.5/9	Background/Standard
G151	UCU	845	pH (field)	SU	03/03/2021 - 07/20/2021	CI around mean	5.4	6.0/9.0	6.0/6.8	6.5/9	Background/Standard

Notes:
HSU = hydrostratigraphic unit:
UA = Uppermost Aquifer
UCU = Upper Confining Unit
Program = regulatory program data were collected under:
257 = 40 C.F.R. Part 257 Subpart D (Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments)
845 = 35 I.A.C. Part 845 (Sampling events completed to assess well locations for inclusion in the Part 845 monitoring well network)
mg/L = milligrams per liter
pCi/L = picoCuries per liter
SU = standard units
Sample Count = number of samples from Sampled Date Range used to calculate the Statistical Result
Statistical Calculation = method used to calculate the statistical result:
CB around linear reg = Confidence band around linear regression
CI around mean = Confidence interval around the mean
Statistical Result = calculated in accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
For pH, the values presented are the lower / upper limits
GWPS = Groundwater Protection Standard
GWPS Source:
Standard = standard specified in 35 I.A.C. § 845.600(a)(1)
Background = background concentration (see cover page for additional information)

RAMBOLL

R001121

ATTACHMENT N

October 2021

Certification of Financial Assurance Requirements

On June 17, 2021, Electric Energy, Inc. provided financial assurance in the form of a performance bond to the Illinois Environmental Protection Agency in the amount of $31,809,402 for East Ash Pond 2 at the Joppa Power Plant.[1]

I, Matthew A. Goering, Senior Vice President of Electric Energy, Inc., do hereby certify to the best of my knowledge for the above referenced CCR Unit that the financial assurance instrument satisfies the requirements of 35 I.A.C. Part 845, Subpart I.

Matthew A. Goering
Senior Vice President
Electric Energy, Inc.

[1] In the operating permit application, the East Ash Pond 2 is referred to as the East Ash Pond.

ATTACHMENT O

October 2021

Stantec Consulting Services Inc.
1859 Bowles Avenue Suite 250, Fenton MO 63026-1944

October 12, 2016
File: let_008_175666013_certification
Revision 0

Initial Hazard Potential Classification Assessment
EPA Final CCR Rule
East Ash Pond
Joppa Power Station
Massac County, Illinois

1.0 PURPOSE

This report documents Stantec's certification of the initial hazard potential classification assessment for the Joppa Power Station East Ash Pond.

40 CFR 257.73(a)(2) requires the owner or operator of an existing CCR surface impoundment to conduct an initial hazard potential classification assessment and document the hazard potential classification, and the basis for the classification, of the CCR unit as either a high hazard potential CCR surface impoundment, a significant hazard potential CCR surface impoundment, or a low hazard potential CCR surface impoundment.

2.0 FINDINGS

A breach analysis was performed to evaluate potential hazards associated with a failure of the East Ash Pond perimeter containment dike. Breach failure scenarios were modeled at six different locations around the circumference of the perimeter dike. Breach locations were selected based on locations of nearby downstream structures and locations that are typically occupied by people. Breach scenarios were simulated using water volumes corresponding to the maximum water surface elevation calculated within the East Ash Pond during the Probable Maximum Precipitation (PMP) storm event.

Analyses indicate that a potential breach of the East Ash Pond results in depths greater than two feet and velocities greater than or equal to five feet per second impacting occupied structures in the vicinity of the East Ash Pond. The analyses indicate that a failure of the East Ash Pond's east embankment would discharge into the low area to the east of Joppa Power Station reaching within approximately 400 feet of Joppa High School. Breaches of the East Ash Pond west and south embankments would primarily affect Joppa Power Station. A breach to the north would affect the properties to the north of the pond across County Road 1000 N. Due to breach simulation resultant maximum depths and velocities at various nearby residences and public facilities, it was concluded that a failure at certain locations along the East Ash Pond's perimeter dike will probably cause loss of human life.

40 CFR 257.53 defines a "high hazard potential CCR surface impoundment" as a diked surface impoundment where failure or mis-operation will probably cause loss of human life.

Based on the results of the analysis summarized above, the East Ash Pond was assigned a High hazard potential classification per 40 CFR 257.53.

3.0 QUALIFIED PROFESSIONAL ENGINEER CERTIFICATION

I, Matthew Hoy, being a Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief that;

1. the information contained in this report and the underlying data in the operating record was prepared in accordance with the accepted practice of engineering and is accurate as of the date of my signature below; and

2. the initial hazard potential classification assessment for the Joppa Power Station East Ash Pond was conducted in accordance with the requirements specified in 40 CFR 257.73.

SIGNATURE _____ DATE 10/12/16

ADDRESS: Stantec Consulting Services Inc.
1859 Bowles Avenue Suite 250
Fenton MO 63026-1944

TELEPHONE: (636) 343-3880

Documentation of Initial Hazard Potential Classification Assessment

East Ash Pond
Joppa Power Station
Massac County, Illinois

Stantec Consulting Services Inc.
Design with community in mind
www.stantec.com

Prepared for:
Dynegy
October 12, 2016

Table of Contents

Section **Page No.**

Executive Summary **1**

1. Introduction **2**
1.1. Background 2
1.2. Location 2

2. Source Data **3**

3. Potential Failure Scenarios **4**
3.1. Facility Description 4
3.2. Failure Scenarios 4
3.2.1. PMP Scenario 4
3.2.2. Breach Locations 5
3.3. Breach Parameter Development 7
3.4. Hydraulic Model Development 8
3.4.1. Digital elevation model (DEM) 9
3.4.2. Mesh 9
3.4.3. Material Cover 9
3.4.4. Break Lines 10
3.4.5. SA/2D Model Connections 10
3.4.6. Boundary Conditions 10
3.5. Breach Modeling Results 10

4. Hazard Classification **11**

List of Appendixes

Appendix A Breach Parameters

Executive Summary

This report documents the hazard potential classification assessment for the East Ash Pond at the Joppa Power Station as required per the CCR Rule in 40 C.F.R. § 257.73-(a)(2). The applicable hazard potential classifications are defined in 40 C.F.R. § 257.53 as follows:

> (1) High hazard potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.
>
> (2) Significant hazard potential 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.
>
> (3) Low hazard potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Based on these definitions and the analysis herein, the East Ash Pond is classified as a High hazard potential CCR surface impoundment.

This report contains supporting documentation for the hazard potential classification assessment. The hazard potential classification for this CCR unit was determined by a breach analysis conducted by Stantec in August, 2016.

1. Introduction

1.1. Background

The CCR Rule was published in the Federal Register on April 17, 2015. The Rule requires that a hazard potential classification assessment be performed for existing CCR surface impoundments that are not incised. A previously completed assessment may be used in lieu of the initial assessment provided the previous hazard assessment was completed no earlier than April 17, 2013. The applicable hazard potential classifications are defined in the CCR Rule 40 C.F.R. § 257.53 as follows:

High Hazard Potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.

Significant Hazard Potential 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.

Low Hazard Potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Dynegy has contracted Stantec Consulting Services Inc. (Stantec) to prepare hazard potential classification assessments for selected impoundments[1].

It was determined that there was no existing available hazard potential classification assessment documentation for the East Ash Pond.

1.2. Location

The Joppa Power Station is located in Massac County, Illinois approximately 18 miles downstream of the confluence of the Tennessee River and the Ohio River. The plant is located on the northern bank of the Ohio River, adjacent to the village of Joppa. The East Ash Pond is located to the north of the main facility. The project site overview can be seen in Figure 1.

[1] Dynegy Administrative Services Company (Dynegy) contracted Stantec on behalf of the Joppa Power Station owner, Electric Energy, Inc. Thus, Dynegy is referenced in this report.

Figure 1 Site Overview

2. Source Data

The following information was used to perform the hazard assessment of the East Ash Pond:

- 2012 Digital Elevation Model (DEM) obtained from Illinois Height Modernization (ILHMP) Program for Massac County
- Imagery from Bing Maps
- 1-foot contours provided by Dynegy, developed from 2015 Survey and Bathometric data
- 2011 National Land Cover Data obtained from National Land Cover Database (NLCD 2011) Multi-Resolution Land Characteristics (MRLC) Consortium
- Wapora, Inc., "Proposed East Ash Pond Effluent pH Control Tank", Electric Energy, Inc., Dynegy File: 00651 PDF, December 27, 1972

- Brown, Hoffmann & Roberts, Inc., "Ash Lagoon Overflow – Cover Sheet, Plan/Profile, Cross-sections, and Detail Sheet", Electric Energy, Inc., Dynegy File: 02199 Sheet 1-8, April 27, 1992

- Wapora, Inc., "Proposed East Ash Pond", Electric Energy, Inc., Dynegy File: 4229-08200 PDF, December 7, 1972

- Wapora, Inc., "East Ash Pond Sulfuric Acid Storage Tanks and pH Control System", Electric Energy, Inc., Dynegy File: 4229-08212 PDF, May 24, 1973

- Wapora, Inc., "East Ash Pond Plan, Sections and Details", Electric Energy, Inc., Dynegy File: 4229-08218 PDF, June 22, 1973

- Wapora, Inc., "East Ash Pond Sulfuric Acid Storage Tanks and pH Control System Plan, Sections and Details", Electric Energy, Inc., Dynegy File: 4229-08221 PDF, July 3, 1973

3. Potential Failure Scenarios

3.1. Facility Description

The East Ash Pond has a surface area of approximately 103 acres with approximately 32 acres holding water. The remaining area contains coal combustion residuals (CCR). The maximum embankment height is approximately 45 feet. The crest of the pond is at approximate elevation 380 feet with a normal pool of approximately 374 feet. There is a 24 inch diameter corrugated metal pipe (CMP) through the central dike that connects the northern section and southern section to manage flow between the sections, which is not controlled. The southern section's primary outlet structure is a 24 inch diameter steel "T" structure connected to a 24 inch diameter pipe that passes through the eastern embankment. The northern section discharges through a 30 inch diameter pipe that passes through the most northern embankment. Flow from the pond discharges to an open channel then through a concrete culvert under the Station's coal-delivery railroad before discharging into the Ohio River 2,400 feet downstream of the railroad.

3.2. Failure Scenarios

3.2.1. PMP Scenario

The breach scenario evaluated for the East Ash Pond was a piping breach during the Probable Maximum Precipitation (PMP) event. The East Ash Pond is perched and inflow from storm events would consist of rainfall falling directly on the pond. The freeboard for the pond is greater than the PMP volume, therefore the pool elevation for the breach scenario was the normal pool plus the volume of the PMP event (38 inch depth across a 103 acre footprint). Since the PMP event does not overtop the crest of the East Ash Pond, a piping breach was evaluated instead of an overtopping breach.

3.2.2. Breach Locations

Six breach locations were selected around the East Ash Pond. These locations include: one to the north, two breaches to the west, one breach to the south and two breaches to the east. The six breach scenarios can be seen in Figure 2. Breach locations were selected to evaluate inundation at representative and reasonable breach locations at which a failure might occur.

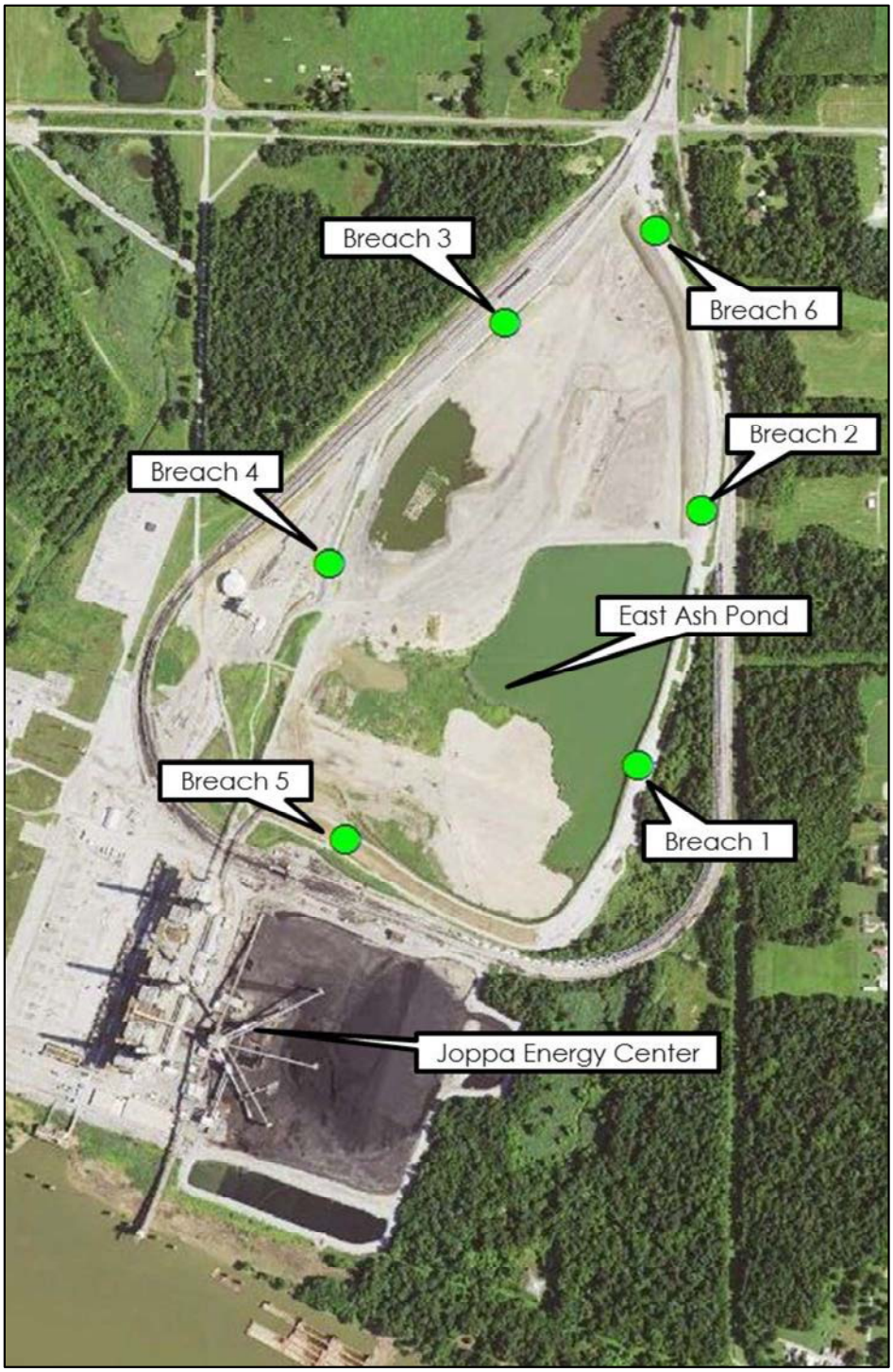


Figure 2 Joppa East Ash Pond Breach Locations

3.3. Breach Parameter Development

The breach function of HEC-RAS 5.0.1 requires input of estimated breach parameters and impounded volumes. Breach parameters were determined using empirical equations. Since there is uncertainty in predicting dam breach parameters, Stantec used several empirical equations and based final breach parameters on the average of the estimates and engineering judgment (References 3 - 11).

Table 1 summarizes the breach parameters estimated for this analysis. These values are based on the assumed failure conditions, height of breach, impoundment water volume above breach, and width of the embankment. The empirical calculations that served as the basis for the breach parameters' estimation are included in Appendix A.

Based on visual inspection of aerials as well as information from the EPA Dam Safety Assessment of CCW Impoundments Joppa Plant report (Reference 2), the north section of the East Ash Pond appears to be a dry stack of CCR. The EPA report (Reference 2) also states that the East Ash Pond has CCR that consists of bottom ash and fly ash, with the northern section being drained. There is a 24 inch diameter CMP connecting the northern and southern sections of the pond that is uncontrolled. Due to uncertainty of the sub layers within the pond and water quantity within the stack of CCR, the breach bottom elevation was set to the toe elevation of the embankment. Setting the breach bottom elevation to the toe of the embankment resulted in conservative breach scenarios.

Table 1 Breach Modeling Parameters for East Ash Pond

Breach Scenario	Pool Elevation at Start of Breach (feet)	Breach Bottom Elevation (feet)	Breach Bottom Width (feet)	Breach Side Slopes (Horizontal : Vertical)	Breach Development Time (hour)
"PMP – Pipe Penetration" Breach Scenario - 1	379.5	333	47.0	0.9	0.41
"PMP – Pipe Penetration" Breach Scenario - 2	379.5	357	57.3	0.9	0.77
"PMP – Pipe Penetration" Breach Scenario - 3	379.5	360	57.9	0.9	0.88

Breach Scenario	Pool Elevation at Start of Breach (feet)	Breach Bottom Elevation (feet)	Breach Bottom Width (feet)	Breach Side Slopes (Horizontal : Vertical)	Breach Development Time (hour)
"PMP – Pipe Penetration" Breach Scenario - 4	379.5	362	58.2	0.9	0.97
"PMP – Pipe Penetration" Breach Scenario - 5	379.5	355	56.7	0.9	0.72
"PMP – Pipe Penetration" Breach Scenario - 6	379.5	350	55.0	0.9	0.61

A stage-storage curve for the pond was developed based on 1-foot contours, Light Detection and Ranging (LiDAR) and record drawings provided by Dynegy. The elevations and volumes that were calculated for input into the HEC-RAS model storage basin are listed in Table 2.

Table 2 Elevation Storage Data for Ash Pond

Elevation (NAVD88)	Cumulative Volume (Acre-feet)
333	0
335	3.9
340	31.5
345	74.0
350	131.6
355	203.7
360	288.1
365	384.9
370	498.8
375	697.2
380	1076.8

3.4. Hydraulic Model Development

For breach inundation modeling, Stantec used the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS), version 5.0.1, computer program to perform hydraulic routing calculations. The HEC-RAS breach simulation was configured as an unsteady flood routing model. A two-dimensional flood routing model was selected for simulating potential breach

impacts along the embankment of the East Ash Pond. A breach from the embankment to the north, west or south would travel in multiple flow directions following the topography of the land while a breach to the east would travel in a concentrated flow direction through a natural valley towards the Ohio River.

3.4.1. Digital elevation model (DEM)

A database of elevations for the area to be modeled, known as a digital elevation model (DEM), was constructed using Geographic Information System (GIS) software, ERSI ArcGIS 2015. The DEM utilized a raster format of LiDAR data obtained from the Illinois Height Modernization (ILHMP) Program for Massac County Illinois. The LiDAR data was referenced to the North American Vertical Datum of 1988 (NAVD88) and using the North American Datum of 1983 (in feet) with Illinois State Plane East projection. The dataset has an accuracy of 0.3 feet vertically and a horizontal positional accuracy of 2.8 feet.

3.4.2. Mesh

HEC-RAS 5.0.1 utilizes a mesh based solver which requires the user to create a fixed Cartesian grid of equal x and y dimensions. The program then creates orthogonal mesh cells along the 2D boundary resulting in a hybrid mesh. HEC-RAS 5.0.1 has the capability of using large computational mesh spacing. A mesh cell size of 50 feet was used in this application since it effectively captured the important features of the DEM.

3.4.3. Material Cover

Land use files were obtained from the National Land Cover Data Set (2011) and utilized to develop a spatial reference for Manning's roughness values to be applied to the numerical model. Aerial imagery was compared to the land use files to verify that Manning's roughness values reflected current conditions.

Land cover GIS files were imported into HEC-RAS from ArcGIS with corresponding Manning's values. The Manning's "n" values were determined using past hydraulic models and engineering judgment. The GIS land cover file was converted to a GeoTiff file so that HEC-RAS could read in the data and apply the roughness value to the mesh cells. A table of Manning's "n" values to corresponding land cover can be seen in Table 3.

Table 3 Manning's Roughness Values

Land Cover Type	Manning's "n" Value
Barren Land	0.020
Cultivated Crops	0.045
Deciduous Forest	0.120
Developed, Low Intensity	0.060
Developed, Medium Intensity	0.080

Land Cover Type	Manning's "n" Value
Developed, High Intensity	0.100
Developed, Open Space	0.040
Emergent Herbaceous Wetlands	0.100
Open Water	0.035
Pasture/Hay	0.035
Woody Wetlands	0.060

3.4.4. Break Lines

Break lines were created within HEC-RAS to capture important features of the DEM. These break lines force cell faces to align along features such as roadways, railways, or levees in the DEM, allowing critical features to be captured in the model mesh. This process was especially important for the railroad that travels around the east and south of the East Ash Pond. A break line was created along the centerline of the railroad, surrounding roadways and Old Ash Pond embankment.

3.4.5. SA/2D Model Connections

The outflow location (embankment breach area) was connected to the 2D flow area (floodplain) using a SA/2D connection. The SA/2D connection was located along the East Ash Pond embankment, typically at the top of crest of the embankment in six different breach locations. A weir coefficient of 2.6 was applied to the breach because this is the HEC-RAS default value for earth dams.

3.4.6. Boundary Conditions

The downstream boundary conditions for the 2D portion of the model were set to normal depth, which utilized the average slope of the channel/topography throughout the model. All breach simulations used a 2D boundary condition of normal depth with a slope of 0.005.

3.5. Breach Modeling Results

Inundation limits for each of the breach scenarios were evaluated to determine the potential impacts on property and structures and the potential risk to human life. Faster moving water creates greater risk for damage to infrastructure and greater chance of loss of life; according to the National Flood Insurance Program (NFIP), water moving at more than five feet per second is considered to be moving with high velocity (Reference 12).

Analyses indicate that a potential breach of the East Ash Pond results in depths greater than two feet and velocities greater than or equal to five feet per second impacting occupied structures nearby the East Ash Pond. The analyses indicate that a failure of the East Ash Pond's east embankment will discharge into the low area to the east of Joppa Power Station reaching within approximately 400 feet of Joppa

High School. Breaches of the East Ash Pond west and south embankments mainly affect Joppa Power Station. A breach to the north would affect the properties to the north of the pond across County Road 1000 N. In the breach scenarios evaluated, discharge eventually flows to the Ohio River. Table 4 below shows the breach results for the selected areas surrounding the East Ash Pond along with the number of impacted structures.

Table 4 Area of Interest Breach Results

Area of Interest Relative to East Ash Pond	# of Impacted Structures	Maximum Flood Depth (feet)	Maximum Flood Velocity (feet/sec)
North	2	>2	>5
East	4	>2	>5
West	1	>3	>=5
South	1	>4	>5

4. Hazard Classification

Areas of potential impact were identified with results discussed in Section 3.5 of this report. Based on these results, it is Stantec's opinion that a breach of the East Ash Pond represents a probable threat to human life. Therefore, the impoundment fits the definition for a High hazard potential CCR surface impoundment (as defined in the CCR Rule §257.53) (Reference 1).

5. References

1. US Environmental Protection Agency. (2015). *Disposal of Coal Combustion Residuals from Electric Utilities, 40 CFR § 257 and § 261* (effective April 17, 2015).

2. US Environmental Protection Agency. (2010). *Dam Safety Assessment of CCW Impoundments Joppa Plant,* Prepared by O'Brien & Gere Engineers, Inc. (dated September 24, 2010).

3. Johnson, F.A and Illes, P. (1976). "A Classification of Dam Failures." *Water Power Dam Construction,* 28, 43-45.

4. Singh, Krishan P. and Snorrason, A. (1982*). SWS Contract Report 288: Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models*. Illinois Department of Energy and Natural Resources, State Water Survey Division.

5. Singh, Krishan P. and Snorrason, A. (1984*).* "Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models." *Journal of Hydrology*, 68, 295-310.

6. MacDonald, T. C., and Langridge-Monopolis, J. (1984). "Breaching Characteristics of Dam Failures." *Journal of Hydraulic Engineering*, 110 (5), 567-586.

7. Federal Energy Regulatory Commission (FERC). (1987). *FERC 0119-1: Engineering Guidelines for the Evaluation of Hydropower Projects*. Office of Hydropower Licensing.

8. Froehlich, D. C. (1987). "Embankment Dam Breach Parameters." *Proceedings of the 1987 National Conference on Hydraulic Engineering*, ASCE, Williamsburg Virginia, 570-575.

9. US Bureau of Reclamation (USBR). (1988). *ACER Technical Memorandum No. 11: Downstream Hazard Classification Guidelines*. Assistant Commissioner-Engineering and Research, Denver, Colorado, 57.

10. Von Thun, Lawrence J. and D. R. Gillette. (1990). *Guidance on Breach Parameters*, unpublished internal document, USBR, Denver, Colorado, 17. (Referenced in Wahl 1998).

11. Froehlich, D. C. (1995). "Embankment Dam Breach Parameters Revisited." *Proceedings of the 1995 ASCE Conference on Water Resources Engineering*, ASCE, San Antonio, Texas, 887-891.

12. Federal Emergency Management Association (FEMA). (2004). *Hazard Potential Classification System for Dams.*

Appendix A

Breach Parameters

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 1
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	47.0	feet	14.3	meters	User Input Data
Height of breach	h_b	47.0	feet	14.3	meters	Default calculation, user can
Height/depth of water during breach	h_w	46.5	feet	14.2	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	89.3	feet	27.2	meters	126.7	feet	38.6	meters
Breach bottom width	B_W	47.0	feet	14.3	meters	89.4	feet	27.3	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.41	hours	0.41	hours
Peak discharge	Q_p	36,768	ft^3/s	1041.2	m^3/s	74,036	ft^3/s	2096.6	m^3/s
Breach side slope	Z	0.90		0.90		0.79		0.79	
Volume of embankment eroded	V_{er}	273119.4	ft^3	7734.2	m^3	387,189	ft^3	10,964	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	25.1	82.3						
2 - Singh and Snorrason 1982, 1984	50.2	164.5						
3 - MacDonald and Langridge-Monopolis 1984	36.1	118.5		10257.9				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	43.0	141.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	31.0	101.8			1.0			
8 - Froehlich 1987			0.934			19.8	1.0	
9 - USBR 1988	42.5	139.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	53.7	176.3						18.3
12 - Froehlich 1995	27.2	89.3			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 1
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	47.0	feet	14.3	meters	User Input Data
Height of breach	h_b	47.0	feet	14.3	meters	Default calculation, user can
Height/depth of water during breach	h_w	46.5	feet	14.2	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	89.3	feet	27.2	meters	126.7	feet	38.6	meters
Breach bottom width	B_W	47.0	feet	14.3	meters	89.4	feet	27.3	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.41	hours	0.41	hours
Peak discharge	Q_p	36,768	ft^3/s	1041.2	m^3/s	74,036	ft^3/s	2096.6	m^3/s
Breach side slope	Z	0.90		0.90		0.79		0.79	
Volume of embankment eroded	V_{er}	273119.4	ft^3	7734.2	m^3	387,189	ft^3	10,964	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.516
16 - FERC 1987	0.550
17 - Froehlich 1987	0.469
18 - USBR 1988	0.300
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.213
22 - Von Thun and Gillette 1990	0.231
23 - Froehlich 1995	0.407

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 1
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	47.0	feet	14.3	meters	User Input Data
Height of breach	h_b	47.0	feet	14.3	meters	Default calculation, user can
Height/depth of water during breach	h_w	46.5	feet	14.2	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	89.3	feet	27.2	meters	126.7	feet	38.6	meters
Breach bottom width	B_W	47.0	feet	14.3	meters	89.4	feet	27.3	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.41	hours	0.41	hours
Peak discharge	Q_p	36,768	ft^3/s	1041.2	m^3/s	74,036	ft^3/s	2096.6	m^3/s
Breach side slope	Z	0.90		0.90		0.79		0.79	
Volume of embankment eroded	V_{er}	273119.4	ft^3	7734.2	m^3	387,189	ft^3	10,964	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	**η**	**k**	**d**
24 - Kirkpatrick 1977	1011.1	35,680			
25 - SCS 1981	2241.5	79,095			
26 - Hagen 1982	2356.0	83,138			
27 - USBR 1982	2579.0	91,007			
28 - Singh and Snorrason 1984	2052.9	72,442			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	1146.8	40,467			
31 - MacDonald and Langridge-Monopolis 1984	3762.3	132,763			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	1119.7	39,510			
34 - Costa 1985	4203.7	148,337			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	1041.2	36,741			
37 - Webby 1996	1003.5	35,409			
38 - Walder and O'Connor 1997	2853.2	100,682	95.6	55	10.75

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 2
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	23.0	feet	7.0	meters	User Input Data
Height of breach	h_b	23.0	feet	7.0	meters	Default calculation, user can change
Height/depth of water during breach	h_w	22.5	feet	6.9	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	78.0	feet	23.8	meters	84.4	feet	25.7	meters
Breach bottom width	B_W	57.3	feet	17.5	meters	63.4	feet	19.3	meters
Breach formation time	t_f	0.77	hours	0.77	hours	0.49	hours	0.49	hours
Peak discharge	Q_p	14,946	ft^3/s	423.3	m^3/s	43,542	ft^3/s	1233.0	m^3/s
Breach side slope	Z	0.90		0.90		0.91		0.91	
Volume of embankment eroded	V_{er}	116684.3	ft^3	3304.3	m^3	126,276	ft^3	3,576	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	**$\overline{W}$** (m)	K_c	**C_b**
1 - Johnson and Illes 1976	12.3	40.3						
2 - Singh and Snorrason 1982, 1984	24.5	80.5						
3 - MacDonald and Langridge-Monopolis 1984	42.2	138.5		5869.7				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	21.0	69.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	26.0	85.2			1.0			
8 - Froehlich 1987			1.547			19.8	1.0	
9 - USBR 1988	20.6	67.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	35.4	116.3						18.3
12 - Froehlich 1995	23.8	78.0			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 2
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	23.0	feet	7.0	meters	User Input Data
Height of breach	h_b	23.0	feet	7.0	meters	Default calculation, user can change
Height/depth of water during breach	h_w	22.5	feet	6.9	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	78.0	feet	23.8	meters	84.4	feet	25.7	meters
Breach bottom width	B_W	57.3	feet	17.5	meters	63.4	feet	19.3	meters
Breach formation time	t_f	0.77	hours	0.77	hours	0.49	hours	0.49	hours
Peak discharge	Q_p	14,946	ft^3/s	423.3	m^3/s	43,542	ft^3/s	1233.0	m^3/s
Breach side slope	Z	0.90		0.90		0.91		0.91	
Volume of embankment eroded	V_{er}	116684.3	ft^3	3304.3	m^3	126,276	ft^3	3,576	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.421
16 - FERC 1987	0.550
17 - Froehlich 1987	0.899
18 - USBR 1988	0.262
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.103
22 - Von Thun and Gillette 1990	0.269
23 - Froehlich 1995	0.774

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 2
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	23.0	feet	7.0	meters	User Input Data
Height of breach	h_b	23.0	feet	7.0	meters	Default calculation, user can change
Height/depth of water during breach	h_w	22.5	feet	6.9	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	78.0	feet	23.8	meters	84.4	feet	25.7	meters
Breach bottom width	B_W	57.3	feet	17.5	meters	63.4	feet	19.3	meters
Breach formation time	t_f	0.77	hours	0.77	hours	0.49	hours	0.49	hours
Peak discharge	Q_p	14,946	ft^3/s	423.3	m^3/s	43,542	ft^3/s	1233.0	m^3/s
Breach side slope	Z	0.90		0.90		0.91		0.91	
Volume of embankment eroded	V_{er}	116684.3	ft^3	3304.3	m^3	126,276	ft^3	3,576	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	173.9	6,137			
25 - SCS 1981	585.2	20,649			
26 - Hagen 1982	1648.1	58,159			
27 - USBR 1982	673.3	23,759			
28 - Singh and Snorrason 1984	531.8	18,767			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	850.3	30,006			
31 - MacDonald and Langridge-Monopolis 1984	2791.8	98,515			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	829.3	29,265			
34 - Costa 1985	3069.5	108,314			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	423.3	14,936			
37 - Webby 1996	363.2	12,816			
38 - Walder and O'Connor 1997	478.0	16,867	1166.1	55	5.26

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach location 3
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	20.0	feet	6.1	meters
Height of breach	h_b	20.0	feet	6.1	meters
Height/depth of water during breach	h_w	19.5	feet	5.9	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	75.9	feet	23.2	meters	79.2	feet	24.1	meters
Breach bottom width	B_W	57.9	feet	17.7	meters	60.2	feet	18.4	meters
Breach formation time	t_f	0.88	hours	0.88	hours	0.51	hours	0.51	hours
Peak discharge	Q_p	12,516	ft^3/s	354.4	m^3/s	40,500	ft^3/s	1146.9	m^3/s
Breach side slope	Z	0.90		0.90		0.95		0.95	
Volume of embankment eroded	V_{er}	98805.7	ft^3	2798.0	m^3	102,969	ft^3	2,916	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	10.7	35.0						
2 - Singh and Snorrason 1982, 1984	21.3	70.0						
3 - MacDonald and Langridge-Monopolis 1984	43.5	142.7		5258.1				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	18.3	60.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	25.1	82.2			1.0			
8 - Froehlich 1987			1.704			19.8	1.0	
9 - USBR 1988	17.8	58.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	33.2	108.8						18.3
12 - Froehlich 1995	23.2	75.9			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach location 3
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	20.0	feet	6.1	meters
Height of breach	h_b	20.0	feet	6.1	meters
Height/depth of water during breach	h_w	19.5	feet	5.9	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	75.9	feet	23.2	meters	79.2	feet	24.1	meters
Breach bottom width	B_W	57.9	feet	17.7	meters	60.2	feet	18.4	meters
Breach formation time	t_f	0.88	hours	0.88	hours	0.51	hours	0.51	hours
Peak discharge	Q_p	12,516	ft^3/s	354.4	m^3/s	40,500	ft^3/s	1146.9	m^3/s
Breach side slope	Z	0.90		0.90		0.95		0.95	
Volume of embankment eroded	V_{er}	98805.7	ft^3	2798.0	m^3	102,969	ft^3	2,916	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.405
16 - FERC 1987	0.550
17 - Froehlich 1987	1.021
18 - USBR 1988	0.255
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.089
22 - Von Thun and Gillette 1990	0.273
23 - Froehlich 1995	0.878

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach location 3
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	20.0	feet	6.1	meters
Height of breach	h_b	20.0	feet	6.1	meters
Height/depth of water during breach	h_w	19.5	feet	5.9	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	75.9	feet	23.2	meters	79.2	feet	24.1	meters
Breach bottom width	B_W	57.9	feet	17.7	meters	60.2	feet	18.4	meters
Breach formation time	t_f	0.88	hours	0.88	hours	0.51	hours	0.51	hours
Peak discharge	Q_p	12,516	ft^3/s	354.4	m^3/s	40,500	ft^3/s	1146.9	m^3/s
Breach side slope	Z	0.90		0.90		0.95		0.95	
Volume of embankment eroded	V_{er}	98805.7	ft^3	2798.0	m^3	102,969	ft^3	2,916	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	k	d
24 - Kirkpatrick 1977	123.6	4,361			
25 - SCS 1981	449.1	15,846			
26 - Hagen 1982	1536.9	54,233			
27 - USBR 1982	516.7	18,233			
28 - Singh and Snorrason 1984	408.4	14,410			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	801.6	28,288			
31 - MacDonald and Langridge-Monopolis 1984	2632.3	92,888			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	782.1	27,597			
34 - Costa 1985	2886.4	101,854			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	354.4	12,507			
37 - Webby 1996	297.2	10,489			
38 - Walder and O'Connor 1997	337.0	11,893	1901.9	55	4.57

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 4
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water during breach	h_w	17.5	feet	5.3	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	74.4	feet	22.7	meters	75.7	feet	23.1	meters
Breach bottom width	B_W	58.2	feet	17.8	meters	58.2	feet	17.7	meters
Breach formation time	t_f	0.97	hours	0.97	hours	0.53	hours	0.53	hours
Peak discharge	Q_p	10,945	ft^3/s	309.9	m^3/s	38,536	ft^3/s	1091.3	m^3/s
Breach side slope	Z	0.90		0.90		0.97		0.97	
Volume of embankment eroded	V_{er}	87162.6	ft^3	2468.3	m^3	88,582	ft^3	2,508	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	**$\overline{W}$** (m)	K_c	**C_b**
1 - Johnson and Illes 1976	9.6	31.5						
2 - Singh and Snorrason 1982, 1984	19.2	63.0						
3 - MacDonald and Langridge-Monopolis 1984	44.5	145.9		4838.2				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	16.5	54.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	24.4	80.1			1.0			
8 - Froehlich 1987			1.832			19.8	1.0	
9 - USBR 1988	16.0	52.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	31.6	103.8						18.3
12 - Froehlich 1995	22.7	74.4			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 4
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water during breach	h_w	17.5	feet	5.3	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	74.4	feet	22.7	meters	75.7	feet	23.1	meters
Breach bottom width	B_W	58.2	feet	17.8	meters	58.2	feet	17.7	meters
Breach formation time	t_f	0.97	hours	0.97	hours	0.53	hours	0.53	hours
Peak discharge	Q_p	10,945	ft^3/s	309.9	m^3/s	38,536	ft^3/s	1091.3	m^3/s
Breach side slope	Z	0.90		0.90		0.97		0.97	
Volume of embankment eroded	V_{er}	87162.6	ft^3	2468.3	m^3	88,582	ft^3	2,508	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.393
16 - FERC 1987	0.550
17 - Froehlich 1987	1.124
18 - USBR 1988	0.250
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.080
22 - Von Thun and Gillette 1990	0.276
23 - Froehlich 1995	0.965

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 4
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water during breach	h_w	17.5	feet	5.3	meters
Storage	S	1077.0	ac-feet	1328459.9	m^3
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3
Width of dam at base	W_{base}	100.0	feet	30.5	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can
- Calculated value.
- Adj. value

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	74.4	feet	22.7	meters	75.7	feet	23.1	meters
Breach bottom width	B_W	58.2	feet	17.8	meters	58.2	feet	17.7	meters
Breach formation time	t_f	0.97	hours	0.97	hours	0.53	hours	0.53	hours
Peak discharge	Q_p	10,945	ft^3/s	309.9	m^3/s	38,536	ft^3/s	1091.3	m^3/s
Breach side slope	Z	0.90		0.90		0.97		0.97	
Volume of embankment eroded	V_{er}	87162.6	ft^3	2468.3	m^3	88,582	ft^3	2,508	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	k	d
24 - Kirkpatrick 1977	95.6	3,373			
25 - SCS 1981	367.6	12,971			
26 - Hagen 1982	1458.0	51,450			
27 - USBR 1982	422.9	14,925			
28 - Singh and Snorrason 1984	334.6	11,808			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	766.7	27,054			
31 - MacDonald and Langridge-Monopolis 1984	2517.8	88,847			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	748.2	26,402			
34 - Costa 1985	2755.7	97,240			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	309.9	10,937			
37 - Webby 1996	255.5	9,014			
38 - Walder and O'Connor 1997	259.0	9,139	2750.0	55	4.12

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 5
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	25.0	feet	7.6	meters	User Input Data
Height of breach	h_b	25.0	feet	7.6	meters	Default calculation, user can change
Height/depth of water during breach	h_w	24.5	feet	7.5	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	79.2	feet	24.2	meters	87.9	feet	26.8	meters
Breach bottom width	B_W	56.7	feet	17.3	meters	65.5	feet	20.0	meters
Breach formation time	t_f	0.72	hours	0.72	hours	0.48	hours	0.48	hours
Peak discharge	Q_p	16,611	ft^3/s	470.4	m^3/s	45,644	ft^3/s	1292.6	m^3/s
Breach side slope	Z	0.90		0.90		0.90		0.90	
Volume of embankment eroded	V_{er}	128856.0	ft^3	3648.9	m^3	142,965	ft^3	4,048	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	**$\overline{W}$** (m)	K_c	**C_b**
1 - Johnson and Illes 1976	13.3	43.8						
2 - Singh and Snorrason 1982, 1984	26.7	87.5						
3 - MacDonald and Langridge-Monopolis 1984	41.5	136.1		6267.0				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	22.9	75.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	26.5	87.0			1.0			
8 - Froehlich 1987			1.460			19.8	1.0	
9 - USBR 1988	22.4	73.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	37.0	121.3						18.3
12 - Froehlich 1995	24.2	79.2			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 5
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	25.0	feet	7.6	meters	User Input Data
Height of breach	h_b	25.0	feet	7.6	meters	Default calculation, user can change
Height/depth of water during breach	h_w	24.5	feet	7.5	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	79.2	feet	24.2	meters	87.9	feet	26.8	meters
Breach bottom width	B_W	56.7	feet	17.3	meters	65.5	feet	20.0	meters
Breach formation time	t_f	0.72	hours	0.72	hours	0.48	hours	0.48	hours
Peak discharge	Q_p	16,611	ft^3/s	470.4	m^3/s	45,644	ft^3/s	1292.6	m^3/s
Breach side slope	Z	0.90		0.90		0.90		0.90	
Volume of embankment eroded	V_{er}	128856.0	ft^3	3648.9	m^3	142,965	ft^3	4,048	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.432
16 - FERC 1987	0.550
17 - Froehlich 1987	0.834
18 - USBR 1988	0.266
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.112
22 - Von Thun and Gillette 1990	0.266
23 - Froehlich 1995	0.718

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 5
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	25.0	feet	7.6	meters	User Input Data
Height of breach	h_b	25.0	feet	7.6	meters	Default calculation, user can change
Height/depth of water during breach	h_w	24.5	feet	7.5	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	79.2	feet	24.2	meters	87.9	feet	26.8	meters
Breach bottom width	B_W	56.7	feet	17.3	meters	65.5	feet	20.0	meters
Breach formation time	t_f	0.72	hours	0.72	hours	0.48	hours	0.48	hours
Peak discharge	Q_p	16,611	ft^3/s	470.4	m^3/s	45,644	ft^3/s	1292.6	m^3/s
Breach side slope	Z	0.90		0.90		0.90		0.90	
Volume of embankment eroded	V_{er}	128856.0	ft^3	3648.9	m^3	142,965	ft^3	4,048	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	213.4	7,529			
25 - SCS 1981	685.0	24,172			
26 - Hagen 1982	1718.3	60,635			
27 - USBR 1982	788.2	27,813			
28 - Singh and Snorrason 1984	622.6	21,970			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	880.7	31,077			
31 - MacDonald and Langridge-Monopolis 1984	2891.2	102,024			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	858.9	30,309			
34 - Costa 1985	3184.2	112,362			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	470.4	16,599			
37 - Webby 1996	409.2	14,438			
38 - Walder and O'Connor 1997	588.8	20,776	871.0	55	5.72

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 6
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	30.0	feet	9.1	meters	User Input Data
Height of breach	h_b	30.0	feet	9.1	meters	Default calculation, user can
Height/depth of water during breach	h_w	29.5	feet	9.0	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	82.0	feet	25.0	meters	96.7	feet	29.5	meters
Breach bottom width	B_W	55.0	feet	16.8	meters	70.9	feet	21.6	meters
Breach formation time	t_f	0.61	hours	0.61	hours	0.45	hours	0.45	hours
Peak discharge	Q_p	20,913	ft^3/s	592.2	m^3/s	51,204	ft^3/s	1450.0	m^3/s
Breach side slope	Z	0.90		0.90		0.86		0.86	
Volume of embankment eroded	V_{er}	160077.6	ft^3	4533.1	m^3	188,713	ft^3	5,344	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	16.0	52.5						
2 - Singh and Snorrason 1982, 1984	32.0	105.0						
3 - MacDonald and Langridge-Monopolis 1984	39.9	130.8		7229.1				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	27.4	90.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	27.7	91.0			1.0			
8 - Froehlich 1987			1.284			19.8	1.0	
9 - USBR 1988	27.0	88.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	40.8	133.8						18.3
12 - Froehlich 1995	25.0	82.0			1.0			
13 - Froehlich 1995			0.900					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 6
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	30.0	feet	9.1	meters	User Input Data
Height of breach	h_b	30.0	feet	9.1	meters	Default calculation, user can
Height/depth of water during breach	h_w	29.5	feet	9.0	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	82.0	feet	25.0	meters	96.7	feet	29.5	meters
Breach bottom width	B_W	55.0	feet	16.8	meters	70.9	feet	21.6	meters
Breach formation time	t_f	0.61	hours	0.61	hours	0.45	hours	0.45	hours
Peak discharge	Q_p	20,913	ft^3/s	592.2	m^3/s	51,204	ft^3/s	1450.0	m^3/s
Breach side slope	Z	0.90		0.90		0.86		0.86	
Volume of embankment eroded	V_{er}	160077.6	ft^3	4533.1	m^3	188,713	ft^3	5,344	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.455
16 - FERC 1987	0.550
17 - Froehlich 1987	0.706
18 - USBR 1988	0.275
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.135
22 - Von Thun and Gillette 1990	0.258
23 - Froehlich 1995	0.610

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: Joppa - Ash Pond
Location: Joppa, Illinois
Notes: "PMP" Breach of Embankment - Breach Location 6
Piping Failure Assumed

Inputs:

		English Units		SI Units		Data Convention:
Height of dam	h_d	30.0	feet	9.1	meters	User Input Data
Height of breach	h_b	30.0	feet	9.1	meters	Default calculation, user can
Height/depth of water during breach	h_w	29.5	feet	9.0	meters	
Storage	S	1077.0	ac-feet	1328459.9	m^3	Calculated value.
Volume of water at breach	V_w	1077.0	ac-feet	1328459.9	m^3	Adj. value
Width of dam at base	W_{base}	100.0	feet	30.5	meters	
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters	
Estimated breach side slope	Z	1.0		1.0		
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s	
Type of Failure		Piping				
Dam has core wall?		No				
Erosion resistant embankment?		No				

Froelich '95 Calculated Values:		**Froelich '95 Calculated Values:**				**Average Calculated Values:**			
Breach width	B_{AVG}	82.0	feet	25.0	meters	96.7	feet	29.5	meters
Breach bottom width	B_W	55.0	feet	16.8	meters	70.9	feet	21.6	meters
Breach formation time	t_f	0.61	hours	0.61	hours	0.45	hours	0.45	hours
Peak discharge	Q_p	20,913	ft^3/s	592.2	m^3/s	51,204	ft^3/s	1450.0	m^3/s
Breach side slope	Z	0.90		0.90		0.86		0.86	
Volume of embankment eroded	V_{er}	160077.6	ft^3	4533.1	m^3	188,713	ft^3	5,344	m^3
Volume of water discharged	V_o,V_{out}	1077.00	ac-feet	1328459.9	m^3	1077.0	ac-feet	1,328,460	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	Q_p (m^3/s)	Q_p (ft^3/s)	η	k	d
24 - Kirkpatrick 1977	333.9	11,782			
25 - SCS 1981	965.9	34,083			
26 - Hagen 1982	1882.3	66,422			
27 - USBR 1982	1111.3	39,216			
28 - Singh and Snorrason 1984	878.7	31,009			
29 - Singh and Snorrason 1984	1341.0	47,319			
30 - MacDonald and Langridge-Monopolis 1984	950.7	33,549			
31 - MacDonald and Langridge-Monopolis 1984	3120.5	110,116			
32 - Costa 1985	3469.8	122,440			
33 - Costa 1985	927.3	32,721			
34 - Costa 1985	3450.1	121,747			
35 - Evans 1986	1266.8	44,702			
36 - Froehlich 1995	592.2	20,897			
37 - Webby 1996	530.7	18,726			
38 - Walder and O'Connor 1997	928.7	32,773	460.1	55	6.86

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

Assumptions:

- Equations here were extracted from the USBR Report "Prediction of Embankment Dam Breach Parameters" and the Journal of Hydraulic Engineering article "Uncertainty of Predictions of Embankment Dam Breach Parameters" by the same author (Tony L. Wahl, USBR). Citation for that reference is included below, but recursive references have been omitted.
- All earthen embankments.
- Measurements are in SI units (meters, m^3/s, hours) unless otherwise noted. Spreadsheet is set up to do the English-SI input conversions, then convert answers back to English units.

Input Parameters, Constants, and Variables:

h_d = height of dam: input
h_b = height of breach: input, generally = h_d
h_w = height (depth) of water at failure above breach bottom: input
S = storage: input parameter
V_w = volume of water above breach invert at time of breach: input, generally = S
W = Embankment width: input
Z = breach opening side slope: input or calculated

g = acceleration of gravity = 9.8 m/s^2 =127,008,000 m/hr^2

B = average breach width: calculated (see below)
B_W = breach bottom width: calculated using B, h_b, and Z (see equation 39)
t_f = breach formation time, hours: calculated (see below)
Q_p = peak breach outflow: calculated (see below)
Z = breach opening side slope: input or calculated (see below)
V_{er} = volume of embankment material eroded: generally calculated (see Equation 40)
V_o,V_{out} = volume of water discharged: calculated = S + inflow during breach

Breach Width & Dimension Equations:

Johnson and Illes 1976

(1) $0.5h_d \leq B \leq 3h_d$

Singh and Snorrason 1982, 1984

(2) $2h_d \leq B \leq 5h_d$

MacDonald and Langridge-Monopolis 1984

(3) $V_{er} = 0.0261(V_{out}h_w)^{0.769}$

(4) $Z = 1H{:}2V$

FERC 1987

(5) $2h_d \leq B \leq 4h_d$

(6) $0.25 \leq Z \leq 1.0$

Froehlich 1987

$$\overline{B^*} = \frac{\overline{B}}{h} = 0.47K_o(S^*)^{0.25}$$

$$S^* = \frac{S}{{h_b}^3}$$

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

(7) $\overline{B} = 0.47 h_b K_o \left(\frac{S}{h_b{}^3}\right)^{0.25}$ Ko = 1.4 overtopping; 1.0 otherwise

$Z = 0.75 K_c (h_w{}^*)^{1.57} \left(\overline{W^*}\right)^{0.73}$

$h_w{}^* = \frac{h_w}{h_b}$

$\left(\overline{W^*}\right) = \frac{\overline{W}}{h} = \frac{W_{crest} + W_{bottom}}{2h}$

(8) $Z = 0.75 K_c \left(\frac{h_w}{h_b}\right)^{1.57} \left(\frac{\overline{W}}{h_b}\right)^{0.73}$ Kc = 0.6 with corewall; 1.0 without a corewall

USBR 1988

(9) $B = 3h_w$

Von Thun and Gillette 1990

(10) $Z = 1H{:}1V$

(11) $\overline{B} = 2.5 h_w + C$

$$C_b = f(\text{reservoir size}, m^3) = \begin{Bmatrix} Size & C_b \\ < 1.23x10^6 & 6.1 \\ 1.23x10^6 - 6.17x10^6 & 18.3 \\ 6.17x10^6 - 1.23x10^7 & 42.7 \\ > 1.23x10^7 & 54.9 \end{Bmatrix}$$

Froehlich 1995

(12) $\overline{B} = 0.1803 K_o V_w{}^{0.32} h_b{}^{0.19}$ Ko = 1.4 overtopping; 1.0 otherwise

(13) Z = 1.4 for overtopping, 0.9 otherwise

Failure Time Equations:

Singh and Snorrason 1982, 1984

(14) $0.25 \text{ hr} \le t_f \le 1.0 \text{ hr}$

MacDonald and Langridge-Monopolis 1984

(15) $t_f = 0.0179 (V_{er})^{0.364}$

FERC 1987

(16) $0.10 \text{ hr} \le t_f \le 1.0 \text{ hr}$

Froehlich 1987 (t_f* equation was corrected from the report)

$S^* = \frac{S}{h_b{}^3}$

$t_f{}^* = 79 (S^*)^{0.47} = 79 \left(\frac{S}{h_b{}^3}\right)^{0.47}$

$t_f{}^* = t_f \sqrt{\frac{g}{h}}$

(17) $t_f = \frac{79 \left(\frac{S}{h_b{}^3}\right)^{0.47}}{\sqrt{\frac{g}{h_b}}}$

USBR 1988

(18) $t_f = 0.011 B$

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

Von Thun and Gillette 1990

Erosion Resistant

(19) $t_f = 0.020h_w + 0.25$

(20) $t_f = \frac{\overline{B}}{4h_w}$

Highly Erodible

(21) $t_f = 0.015h_w$

(22) $t_f = \frac{\overline{B}}{4h_w+61.0}$

Froehlich 1995

(23) $t_f = 0.00254V_w{}^{0.53}h_b{}^{(-0.90)}$

Peak Flow Equations:

Kirkpatrick 1977

(24) $Q_p = 1.268(h_w + 0.3)^{2.5}$

SCS 1981

(25) $Q_p = 16.6(h_w)^{1.85}$

Hagen 1982

(26) $Q_p = 0.54(S \times h_d)^{0.5}$

USBR 1982

(27) $Q_p = 19.1(h_w)^{1.85}$

Singh and Snorrason 1984

(28) $Q_p = 13.4(h_d)^{1.89}$

(29) $Q_p = 1.776(S)^{0.47}$

MacDonald and Langridge-Monopolis 1984

(30) $Q_p = 1.154(V_w h_w)^{0.412}$

(31) $Q_p = 3.85(V_w h_w)^{0.411}$

Costa 1985

(32) $Q_p = 1.122(S)^{0.57}$

(33) $Q_p = 0.981(S \times h_d)^{0.42}$

(34) $Q_p = 2.634(S \times h_d)^{0.44}$

Evans 1986

(35) $Q_p = 0.72(V_W)^{0.53}$

Froehlich 1995

(36) $Q_p = 0.607V_w{}^{0.295}h_w{}^{1.24}$

Webby 1996

(37) $Q_p = 0.0443g^{0.5}V_w{}^{0.367}h_w{}^{1.40}$

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

Walder and O'Connor 1997

$$\eta = \frac{kV_o}{g^{0.5}d^{3.5}}$$

k = vertical erosion rate = 10 m/hr – 100 m/hr
d = 50-100% of dam height

$$(38) \qquad Q_p = \begin{cases} 1.51(g^{0.5}d^{2.5})^{0.06}\left(\frac{kV_o}{d}\right)^{0.94} & \eta < \sim 0.6 \\ 1.94g^{0.5}d^{2.5}\left(\frac{h_d}{d}\right)^{0.75} & \eta \gg 1 \end{cases}$$

Other Equations:

Breach Bottom Width

$$(39) \qquad B_W = B - h_b Z$$

Embankment Volume

$$(40) \qquad V_{er} = \left(B_w h_b + Z h_b{}^2\right)\left(\frac{W_{crest} + W_{base}}{2}\right) = (Bh_b)\left(\frac{W_{crest} + W_{base}}{2}\right)$$

$$B = \frac{V_{er}}{h_b\left(\frac{W_{crest} + W_{base}}{2}\right)}$$

References:

U.S. Department of the Interior, Bureau of Reclamation, Dam Safety Office. July 1998. "Prediction of Embankment Dam Breach Parameters, A Literature Review and Needs Assessment, DSO-98-004, Dam Safety Research Report", Tony L. Wahl, Water Resources Research Laboratory. 67 pp.

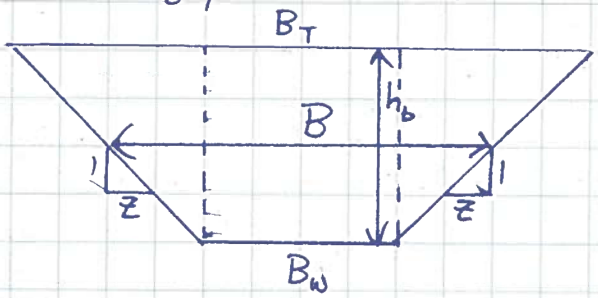
"Uncertainty of Predictions of Embankment Dam Breach Parameters", Tony L. Wahl. Journal of Hydraulic Engineering, Vol. 130, No. 5, May 1, 2004. 9 pp.

Stantec

DAM BREACH EQUATIONS

DERIVATIONS NOT SHOWN

1. BREACH BOTTOM WIDTH GIVEN AVG. BREACH WIDTH B, BREACH HEIGHT H_b, AND BREACH SIDE SLOPES Z



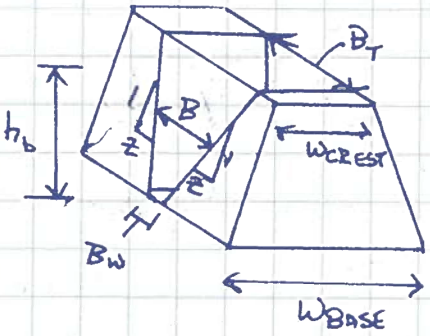
$$B = \frac{B_T + B_W}{2}$$

$$B_T = B_W + 2h_b Z$$

$$B = \frac{(B_W + 2h_b Z) + B_W}{2} = \frac{2B_W + 2h_b Z}{2} = B_W + h_b Z$$

$$B_W = B - h_b Z$$

2. VOLUME OF EMBANKMENT ERODED



AREA AT CENTER

$$A_c = B_W h_b + Z h_b^2$$

$$\forall = A_c W_{CREST} + 2\frac{A_c}{2}\frac{(W_{BASE} - W_{CREST})}{2}(W_{CREST} + W_{BASE})$$

$$= A_c W_c + \frac{A_c}{2} W_B - \frac{A_c}{2} W_c$$

$$= \frac{A_c W_c}{2} + \frac{A_c W_B}{2}$$

$$= A_c\left(\frac{W_c + W_B}{2}\right)$$

$$\forall = \left(B_W h_b + Z h_b^2\right)\left(\frac{W_c + W_B}{2}\right)$$

$$\forall = B h_b \left(\frac{W_c + W_B}{2}\right) \rightarrow B = \frac{\forall}{h_b\left(\frac{W_c + W_B}{2}\right)}$$

Designed by: Checked by:

RECYCLED Paper FSC FSC® C101537

Printed on FSC®-certified and 100 percent recycled postconsumer waste paper.

ATTACHMENT P

October 2021

AECOM

Submitted to
Electric Energy, Inc.
2200 Portland Road
Metropolis, IL 62960

Submitted by
AECOM
1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110

October 2016

CCR Rule Report: Initial Structural Stability Assessment

For

East Ash Pond

At Joppa Power Station

1 Introduction

This Coal Combustion Residual (CCR) Rule Report documents that the East Ash Pond at the Electric Energy, Inc. (EEI) Joppa Power Station meets the structural stability assessment requirements specified in 40 Code of Federal Regulations (CFR) §257.73(d), except as noted herein. The East Ash Pond is located near Joppa, Illinois in Massac County, approximately 0.1 miles northeast of the Joppa Power Station. The East Ash Pond serves as the wet impoundment basin for CCRs produced by the Joppa Power Station.

The East Ash Pond is an existing CCR surface impoundment as defined by 40 CFR §257.53. The CCR Rule requires that an initial structural stability assessment for an existing CCR surface impoundment be completed by October 17, 2016. In general, the initial structural stability assessment must document that the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering practices.

The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial structural stability assessment was conducted in accordance with the requirements of 40 CFR §257.73(d). The owner or operator must prepare a periodic structural stability assessment every five years.

2 Initial Structural Stability Assessment

40 CFR §257.73(d)(1)
The owner or operator of the CCR unit must conduct initial and periodic structural stability assessments and document whether the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR and CCR wastewater which can be impounded therein. The assessment must, at a minimum, document whether the CCR unit has been designed, constructed, operated, and maintained with [the standards in (d)(1)(i)-(vii)].

An initial structural stability assessment has been performed to document that the design, construction, operation and maintenance of the East Ash Pond is consistent with recognized and generally accepted good engineering practices. The results of the structural stability assessment are discussed in the following sections. Based on the assessment and its results, the design, construction, operation, and maintenance of the Joppa East Ash Pond were found to be consistent with recognized and generally accepted good engineering practices, and meet the standards in §257.73(d)(1)(i)-(vii), except as noted herein.

2.1 Foundations and Abutments (§257.73(d)(1)(i))

CCR unit designed, constructed, operated, and maintained with stable foundations and abutments.

The stability of the foundations was evaluated using soil data from field investigations and reviewing design drawings, operational and maintenance procedures, and conditions observed in the field by AECOM. Additionally, slope stability analyses were performed to evaluate slip surfaces passing through the foundations. The East Ash Pond is a ring dike structure and does not have abutments.

The foundation consists of medium stiff to stiff clay overlying medium dense to dense sand, which indicates stable foundations. Ash placed before 1973 was identified below the compacted embankment of the dike and above the naturally occurring foundation materials near the southeast corner of the East Ash Pond embankment; however this condition was modified by installing a Deep Soil Mixed (DMM), wet soil cement mixed method, zone in 2016. Slope stability analyses exceed the criteria listed in §257.73(e)(1) for slip surfaces passing through the foundation. The slope stability analyses are discussed in the *CCR Rule Report: Initial Safety Factor Assessment for East Ash Pond at Joppa Power Station* (October 2016). Additional slope stability analyses were performed to evaluate the effects of liquefaction in the foundation and were found to satisfy the criteria in §257.73(e)(1)(iv) applicable to dikes. A review of information about operations and maintenance as well as current and past performance of the dikes has determined appropriate processes are in place for continued operational performance.

Based on the conditions observed by AECOM, the East Ash Pond was designed and constructed with stable foundations. Any issues related to the stability of the foundation are addressed during operations and maintenance; therefore, the East Ash Pond meets the requirements in §257.73(d)(1)(i).

2.2 Slope Protection (§257.73(d)(1)(ii))

CCR unit designed, constructed, operated, and maintained with adequate slope protection to protect against surface erosion, wave action and adverse effects of sudden drawdown.

The adequacy of slope protection was evaluated by reviewing design drawings, information about operations and maintenance, and conditions observed in the field by AECOM.

Based on this evaluation, adequate slope protection was designed and constructed at the East Ash Pond. No evidence of significant areas of erosion or wave action was observed. The exterior dike slopes are covered with crushed stone and vegetation for slope protection. EEI regularly maintains the slopes, including repairing observed surface erosion and addressing areas of poor vegetation growth, as required. As the exterior slopes are not adjacent to a downstream water body, they are not susceptible to wave action or sudden drawdown. AECOM observed the vegetation to be adequately protecting against surface erosion.

The interior dike slopes have a 1.5H:1V orientation and are covered with vegetation, stacked CCRs, and some limited areas of crushed stone. Sudden drawdown conditions are not expected to occur due to the characteristics of the outfall structure at the East Ash Pond. EEI regularly maintains the interior slopes, including repairing observed surface erosion and addressing areas of poor vegetation growth, as required. AECOM observed the vegetation to be adequately protecting against surface erosion and wave action. Therefore, the East Ash Pond meets the requirements in §257.73(d)(1)(ii).

2.3 Dike Compaction (§257.73(d)(1)(iii))

CCR unit designed, constructed, operated, and maintained with dikes mechanically compacted to a density sufficient to withstand the range of loading conditions in the CCR unit.

The density of the dike materials was evaluated using soil strength data from field investigations and reviewing design drawings, information about operations and maintenance, and conditions observed in the field by AECOM. Additionally, slope stability analyses were performed to evaluate slip surfaces passing through the dike over the range of expected loading conditions as defined within §257.73(e)(1).

Based on this evaluation, the dike consists of medium stiff to stiff material, which is indicative of properly mechanically compacted dikes. Slope stability analyses exceed the criteria listed in §257.73(e)(1) for slip surfaces passing through the dike. The slope stability analyses are discussed in the *CCR Rule Report: Initial Safety Factor Assessment for East Ash Pond at Joppa Power Station* (October 2016); therefore, the original design and construction of the East Ash Pond included sufficient dike compaction. Operational and maintenance procedures are in place to identify and mitigate deficiencies in order to maintain sufficient compaction and density of the dikes to withstand the range of loading conditions. Therefore, the East Ash Pond meets the requirements in §257.73(d)(1)(iii).

2.4 Vegetated Slopes (§257.73(d)(1)(iv))[1]

CCR unit designed, constructed, operated, and maintained with vegetated slopes of dikes and surrounding areas, except for slopes which have an alternate form or forms of slope protection.

The adequacy of slope vegetation was evaluated by reviewing design drawings, information about operations and maintenance, and conditions observed in the field by AECOM.

Based on this evaluation, the vegetation on the exterior slopes is adequate as no substantial bare or overgrown areas were observed. The exterior slopes were vegetated or covered with crushed stone and the interior slopes were covered with vegetation, crushed stone, or mechanically-stacked CCR which are alternate forms of slope protection. Therefore, the original design and construction of the East Ash Pond included adequate vegetation of the dikes and surrounding areas. Adequate operational and maintenance practices are in place to regularly manage vegetation growth, including mowing and seeding any bare areas, as evidenced by the conditions observed by AECOM. Therefore, the East Ash Pond meets the requirements in §257.73(d)(1)(iv).

[1] As modified by court order issued June 14, 2016, Utility Solid Waste Activities Group v. EPA, D.C. Cir. No. 15-1219 (order granting remand and vacatur of specific regulatory provisions).

2.5 Spillways (§257.73(d)(1)(v))

CCR unit designed, constructed, operated, and maintained with a single spillway or a combination of spillways configured as specified in [paragraph (A) and (B)]:

(A) All spillways must be either:

(1) of non-erodible construction and designed to carry sustained flows; or

(2) 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:

(1) Probable maximum flood (PMF) for a high hazard potential CCR surface impoundment; or

(2) 1000-year flood for a significant hazard potential CCR surface impoundment; or

(3) 100-year flood for a low hazard potential CCR surface impoundment.

The spillways were evaluated using design drawings, information about operations and maintenance, and conditions observed in the field by AECOM. Additionally, hydrologic and hydraulic analyses were completed to evaluate the capacity of the spillway relative to inflow estimated for the probable maximum flood event for the high hazard potential East Ash Pond.

Two spillway structures are present at the East Ash Pond, including a ductile iron pipe and high-density polyethylene (HDPE) spillway pipe and a reinforced concrete pipe (RCP) spillway. The ductile iron, HDPE, and reinforced concrete are non-erodible materials designed to carry sustained flows. The capacity of the spillways was evaluated using hydrologic and hydraulic analysis performed per §257.82(a). The analysis found that the spillways can adequately manage flow during peak discharge resulting from the probable maximum flood event without overtopping of the embankments. The hydrologic and hydraulic analyses are discussed in the *CCR Rule Report: Initial Inflow Design Flood Control System Plan for East Ash Pond at Joppa Power Station* (October 2016). Therefore, the East Ash Pond meets the requirements in §257.73(d)(1)(v).

2.6 Stability and Structural Integrity of Hydraulic Structures (§257.73(d)(1)(vi))

CCR unit designed, constructed, operated, and maintained with hydraulic structures underlying the base of the CCR unit or passing through the dike of the CCR unit that maintain structural integrity and are free of significant deterioration, deformation, distortion, bedding deficiencies, sedimentation, and debris which may negatively affect the operation of the hydraulic structure.

Two hydraulic structures pass through the dike of the East Ash Pond: the south-sub-basin 26-inch diameter HDPE spillway pipe and the north sub-basin 48-inch RCP spillway pipe. The stability and structural integrity of both pipes were evaluated using design drawings, information about operations and maintenance, inspections, and conditions observed in the field by AECOM. No other hydraulic structures are known to pass through the dike of or underlie the base of the East Ash Pond.

Closed circuit television (CCTV) inspections of both pipes were attempted in 2016. The 48-inch RCP was successfully visually inspected and noted to contain 12-inches of cemented CCR materials. However, the pipe was free of significant deterioration, deformation, distortion, and bedding deficiencies that may negatively affect the operation of the hydraulic structure. The presence of the cemented CCR materials was accounted for in the hydrologic and hydraulic analyses discussed in the *CCR Rule Report: Initial Inflow Design Flood Control System Plan for East Ash Pond at Joppa Power Station* (October 2016), and were not found sufficient enough to negatively affect the operation of the hydraulic structure. The inspection of the HDPE spillway pipe could not be fully completed due to access issues that prevented an inspection of the entire pipe. However, the evaluation of design drawings, operational and maintenance procedures, and conditions observed in the field did not identify any issues with the HDPE spillway pipe.

Based on this evaluation, all East Ash Pond hydraulic structures cannot be certified to meet the requirements of §257.73(d)(1)(vi) because a complete CCTV inspection of the 26-inch HDPE pipe has not yet been performed, thus, precluding completion of the evaluation of the stability and structural integrity of that pipe. In accordance

with §257.73(d)(2), AECOM recommends that a CCTV pipe inspection of the 26-inch HDPE pipe be completed as soon as feasible and that this assessment be updated once the inspection is completed.

2.7 Downstream Slope Inundation/Stability (§257.73(d)(1)(vii))

CCR unit designed, constructed, operated, and maintained with, for CCR units with downstream slopes which 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.

The structural stability of the downstream slope of the East Ash Pond was evaluated by comparing the location of the East Pond relative to published flood maps for the area. The East Ash Pond is located outside of the 100-year flood zone shown on the FEMA Federal Insurance Rate Map (FIRM) map for Massac County, Illinois and the village of Joppa, Illinois. Therefore, adjacent water bodies that could potentially inundate the downstream slopes of the East Ash Pond are not present. Based on this evaluation, the requirements in §257.73(d)(1)(vii) are not applicable to the East Ash Pond, as inundation of the downstream slopes is not expected to occur during 100-year or lesser flood conditions.

3 Certification Statement

CCR Unit: Electric Energy, Inc.; Joppa Power Station; East Ash Pond

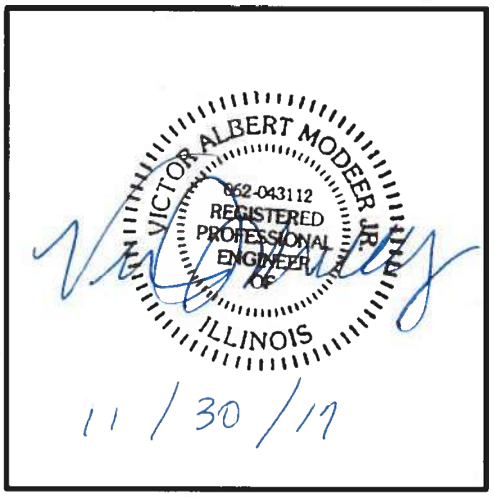
I, Victor A. Modeer, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief that the information contained in this CCR Rule Report, and the underlying data in the operating record, has been prepared in accordance with the accepted practice of engineering. I certify, for the above-referenced CCR Unit, that the initial structural stability assessment dated October 14, 2016 was conducted in accordance with the requirements of 40 CFR §257.73.

Victor A. Modeer Jr

Printed Name

10/14/16

Date



About AECOM

AECOM (NYSE: ACM) is a global provider of professional technical and management support services to a broad range of markets, including transportation, facilities, environmental, energy, water and government. With nearly 100,000 employees around the world, AECOM is a leader in all of the key markets that it serves. AECOM provides a blend of global reach, local knowledge, innovation, and collaborative technical excellence in delivering solutions that enhance and sustain the world's built, natural, and social environments. A Fortune 500 company, AECOM serves clients in more than 100 countries and has annual revenue in excess of $19 billion.

More information on AECOM and its services can be found at www.aecom.com.

1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110
1-314-429-0100

ATTACHMENT Q

October 2021

AECOM

Submitted to
Electric Energy, Inc.
2200 Portland Road
Metropolis, IL 62960

Submitted by
AECOM
1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110

October 2016

CCR Rule Report: Initial Safety Factor Assessment

For

East Ash Pond

At Joppa Power Station

1 Introduction

This Coal Combustion Residual (CCR) Rule Report documents that the East Ash Pond at the Electric Energy, Inc. (EEI) Joppa Power Station meets the safety factor assessment requirements specified in 40 Code of Federal Regulations (CFR) §257.73(e). The East Ash Pond is located near Joppa, Illinois in Massac County, approximately 0.1 miles northeast of the Joppa Power Station. The East Ash Pond serves as the ash impoundment basin for CCRs produced at the Joppa Power Station.

The East Ash Pond is an existing CCR surface impoundment as defined by 40 CFR §257.53. The CCR Rule requires that the initial safety factor assessment for an existing CCR surface impoundment be completed by October 17, 2016.

The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial safety factor assessment meets the requirements of 40 CFR § 257.73(e). The owner or operator must prepare a safety factor assessment every five years.

2 Initial Safety Factor Assessment

40 CFR §257.73(e)(1)
The owner or operator must conduct initial and periodic safety factor assessments for each CCR unit and document whether the calculated factors of safety for each CCR unit achieve the minimum safety factors specified in (e)(1)(i) through (iv) of 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.

(i) The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.50.
(ii) The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40.
(iii) The calculated seismic factor of safety must equal or exceed 1.00.
(iv) For dikes constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

A geotechnical investigation program and stability analyses were performed to evaluate the design, performance, and condition of the earthen dikes of the East Ash Pond. The exploration consisted of hollow-stem auger borings, cone penetration testing with seismic wave velocity measurements and pore pressure dissipation testing, piezometer installation and monitoring, and a laboratory program including strength and index testing. Data collected from the geotechnical investigation, available design drawings, construction records, inspection reports, previous engineering investigations, and other pertinent historic documents were utilized to perform the safety factor assessment and geotechnical analyses.

The East Ash Pond embankment is generally medium stiff to stiff and overlies predominantly alluvial foundation materials. The alluvial foundation consists of soft to stiff clay overlying medium dense to dense sand. A zone of sluiced flyash that existed before the embankment dike was constructed was encountered below the compacted embankment in the southeast corner. The zone of sluiced flyash was modified by the installation of Deep Mixing Method (DMM) ground improvement technology using the wet soil mixing method. Explorations were terminated in the soil overburden and were not extended to bedrock. The phreatic surface is typically at or slightly above the embankment/foundation interface.

Six (6) representative cross sections were analyzed using limit equilibrium slope stability analysis software to evaluate stability of the perimeter dike system and foundations. The cross sections were located to represent critical surface geometry, subsurface stratigraphy, and phreatic conditions across the CCR unit. Each cross section was evaluated for each of the loading conditions stipulated in §257.73(e)(1).

The Soils Susceptible to Liquefaction loading condition, §257.73(e)(1)(iv), was not evaluated because a liquefaction susceptibly evaluation did not find soils susceptible to liquefaction within the East Ash Pond dikes. As a result, this loading condition is not applicable to the East Ash Pond at the Joppa Power Station.

Results of the Initial Safety Factor Assessments, for the critical cross-section for each loading condition (i.e., the lowest calculated factor of safety out of the cross sections analyzed for each loading condition), are listed in Table 1.

Table 1 – Summary of Initial Safety Factor Assessments

Loading Conditions	§257.73(e)(1) Subsection	Minimum Factor of Safety	Calculated Factor of Safety
Maximum Storage Pool Loading	(i)	1.50	1.59
Maximum Surcharge Pool Loading	(ii)	1.40	1.57
Seismic	(iii)	1.00	1.01
Soils Susceptible to Liquefaction	(iv)	1.20	Not Applicable

Based on this evaluation, the East Ash Pond meets the requirements in §257.73(e)(1).

3 Certification Statement

CCR Unit: Electric Energy, Inc.; Joppa Power Station; East Ash Pond

I, Victor A. Modeer, 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 CCR Rule Report, and the underlying data in the operating record, has been prepared in accordance with the accepted practice of engineering. I certify, for the above-referenced CCR Unit, that the initial safety factor assessment dated October 14, 2016 meets the requirements of 40 CFR §257.73.

Victor A. Modeer Jr

Printed Name

10 / 14 / 16

Date

About AECOM

AECOM (NYSE: ACM) is a global provider of professional technical and management support services to a broad range of markets, including transportation, facilities, environmental, energy, water and government. With nearly 100,000 employees around the world, AECOM is a leader in all of the key markets that it serves. AECOM provides a blend of global reach, local knowledge, innovation, and collaborative technical excellence in delivering solutions that enhance and sustain the world's built, natural, and social environments. A Fortune 500 company, AECOM serves clients in more than 100 countries and has annual revenue in excess of $19 billion.

More information on AECOM and its services can be found at www.aecom.com.

1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110
1-314-429-0100

ATTACHMENT R

October 2021

AECOM

Submitted to
Electric Energy, Inc.
2200 Portland Road
Metropolis, IL 62960

Submitted by
AECOM
1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110

October 2016

CCR Rule Report: Initial Inflow Design Flood Control System Plan

For

East Ash Pond

At Joppa Power Station

1 Introduction

This Coal Combustion Residual (CCR) Rule Report documents that the initial inflow design flood control system plan for East Ash Pond at the Electric Energy, Inc. (EEI) Joppa Power Station meets the requirements specified in 40 Code of Federal Regulations (CFR) §257.82. The East Ash Pond is located near Joppa, Illinois in Massac County, approximately 0.1 miles northeast of the Joppa Power Station. The East Ash Pond serves as the wet impoundment basin for CCRs produced by the Joppa Power Station.

The East Ash Pond is an existing CCR surface impoundment as defined by 40 CFR §257.53. The CCR Rule requires that the initial inflow design flood control system plan for an existing CCR surface impoundment be prepared by October 17, 2016. The plan must document how the inflow design flood control system has been designed and constructed to meet the requirements of 40 CFR §257.82 and be supported by appropriate engineering calculations.

The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the inflow design flood control system meets the requirements of 40 CFR §257.82. The owner or operator must prepare an inflow design flood control system plan every five years.

2 Initial Inflow Design Flood Control System Plan

40 CFR §257.82
(a) The owner or operator of an existing … CCR surface impoundment … must design, construct, operate, and maintain an inflow design flood control system as specified in paragraphs (a)(1) and (2) of this section.

(1) The inflow design flood control system must adequately manage flow into the CCR unit during and following the peak discharge of the inflow design flood specified in paragraph (a)(3) of this section.

(2) The inflow design flood control system must adequately manage flow from the CCR unit to collect and control the peak discharge resulting from the inflow design flood specified in paragraph (a)(3) of this section.

(3) The inflow design flood is:

(i) For a high hazard potential CCR surface impoundment, …, the probable maximum flood;

(ii) For a significant hazard potential CCR surface impoundment, …, the 1,000-year flood;

(iii) For a low hazard potential CCR surface impoundment, …, the 100-year flood; or

(iv)For an incised CCR surface impoundment, the 25-year flood.

(b) Discharge from the CCR unit must be handled in accordance with the surface water requirements under §257.3-3.

Analyses completed for the initial inflow design flood control system plan of the East Ash Pond are described in the following subsections. Data and analysis results in the following subsections are based on spillway design information shown on design drawings, construction information, topographic surveys, information about operational and maintenance procedures provided by Electric Energy, Inc., and field measurements collected by AECOM. The analysis approach and results of the hydrologic and hydraulic analyses are presented in the following subsections.

The East Ash Pond has a high hazard potential, based on the initial hazard potential classification performed by Stantec in 2016, in accordance with §257.73(a)(2). Therefore, the inflow design flood (IDF) is the probable maximum flood (PMF).

2.1 Initial Inflow Design Flood Control Systems (§257.82(a))

An initial inflow design flood control system plan, supported by a hydraulic and hydrologic analysis, was developed for the East Ash Pond by evaluating the effects of a 24-hour duration design storm for the PMF IDF using a hydraulic HydroCAD (Version 10.0) computer model, and starting water surface elevations of 370.0 feet and 373.2 feet for the north and south sub-basins, respectively. The computer model evaluated the East Ash Pond's ability to collect and control the PMF IDF under existing operational and maintenance practices. Rainfall data for the PMF IDF, which corresponds to a Probable Maximum Precipitation rainfall event, was obtained from the Hydrometeorological Reports 51 and 52, Probable Maximum Precipitation Events, United States East of the 105th Meridian (HMR 51 and 52). The PMF rainfall depth was determined to be 36 inches.

The HydroCAD model results for the East Ash Pond indicate that the CCR unit has sufficient storage capacity and spillway structures to adequately manage (1) flow into the CCR unit during and following the peak discharge of the PMF IDF and (2) flow from the CCR unit to collect and control the peak discharge resulting from the PMF IDF. The peak water surface elevation for the north sub-basin is 376.2 feet and the minimum crest elevation for the north sub-basin is 378.0 feet. The peak water surface elevation for the south sub-basin is 377.6 feet and the minimum crest elevation for the south sub-basin is 378.0 feet. Therefore, overtopping is not expected. Based on this evaluation, the East Ash Pond meets the requirements in §257.82(a).

2.2 Discharge from the CCR Unit (§257.82(b))

40 CFR §257.82(b) provides that the discharge from the CCR unit must be handled in accordance with the surface water requirements under 40 CFR §257.3-3, which states the following:

(a) For purposes of section 4004(a) of the Act, a facility shall 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, as amended.

(b) For purposes of section 4004(a) of the Act, a facility shall 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 shall not cause non-point source pollution of waters of the United States that violates applicable legal requirements implementing an area wide or statewide water quality management plan that has been approved by the Administrator under section 208 of the Clean Water Act, as amended.

(d) Definitions of the terms Discharge of dredged material, Point source, Pollutant, Waters of the United States, and Wetlands can be found in the Clean Water Act, as amended, 33 U.S.C. 1251 et seq., and implementing regulations, specifically 33 CFR part 323 (42 FR 37122, July 19, 1977).

The handling of discharge was evaluated by reviewing design drawings, operational and maintenance procedures, conditions observed in the field by AECOM, and the inflow design flood control system plan developed per §257.82(a).

Based on this evaluation, outflow from the East Ash Pond is ultimately routed through a NPDES-permitted discharge into the Ohio River. Hydraulic and hydrologic analyses performed as part of the initial inflow design flood control system plan found that the East Ash Pond adequately manages outflow during the PMF IDF, as overtopping of the East Ash Pond embankments is not expected.

Therefore, discharge of pollutants in violation of the NPDES permit is not expected as all discharge is routed and controlled through the existing spillway system and NPDES-permitted outfall during both normal and IDF conditions. Based on this evaluation, the East Ash Pond meets the requirements in §257.82(b).

3 Certification Statement

CCR Unit: Electric Energy, Inc.; Joppa Power Station; East Ash Pond

I, Victor A. Modeer, 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 CCR Rule Report, and the underlying data in the operating record, has been prepared in accordance with the accepted practice of engineering. I certify, for the above-referenced CCR Unit, that the initial inflow design flood control system plan dated October 12, 2016 meets the requirements of 40 CFR §257.82.

Victor A. Modeer Jr

Printed Name

10 / 14 / 16

Date

About AECOM

AECOM (NYSE: ACM) is a global provider of professional technical and management support services to a broad range of markets, including transportation, facilities, environmental, energy, water and government. With nearly 100,000 employees around the world, AECOM is a leader in all of the key markets that it serves. AECOM provides a blend of global reach, local knowledge, innovation, and collaborative technical excellence in delivering solutions that enhance and sustain the world's built, natural, and social environments. A Fortune 500 company, AECOM serves clients in more than 100 countries and has annual revenue in excess of $19 billion.

More information on AECOM and its services can be found at www.aecom.com.

1001 Highlands Plaza Drive West
Suite 300
St. Louis, MO 63110
1-314-429-0100

ATTACHMENT S

October 2021

PART 845 SAFETY AND HEALTH PLAN

JOPPA POWER PLANT EAST ASH POND

CONTENTS

REVISION SUMMARY		**1**
PREFACE		**2**
1.	**INTRODUCTION**	**3**
1.1	Site Description/History	3
1.2	Facility Personnel	3
1.3	Responsibilities	3
1.3.1	**EEI Point of Contact**	3
1.3.2	**EEI Employees**	4
1.3.3	**Contract Workers**	4
1.3.4	**Third-Party Contractor Employees**	4
1.3.5	**Third-Party Contractor Safety Competent Person**	4
2.	**SITE ACCESS & CONTROL**	**5**
2.1	Facility Security	5
2.2	Third-Party Contractor Management	5
2.3	Third-Party Contractor Safety and Health Plan	5
2.4	Authorized Personnel	5
2.5	Visitors	5
2.6	Communication	5
3.	**TRAINING & MEDICAL REQUIREMENTS**	**6**
3.1	HAZWOPER Training	6
3.2	OSHA Construction Outreach Training	6
3.3	EAP Safety and Health Plan Review	6
3.4	Emergency and Monitoring Equipment Training	7
3.5	Hazard Communication	7
3.6	Medical Surveillance	7
3.7	Drug Screen and Background Investigations	8
3.8	COVID-19 Site Entry Guidelines	8
3.9	Document Management	8
3.10	Industrial Hygiene Sampling Records	8
4.	**HAZARD & CONTROLS**	**9**
4.1	Ash/Unstable Surfaces	9
4.2	Ash Inhalation/Airborne Exposure	10
4.3	Stuck Vehicles/Equipment	11
4.4	Working Near/Over Water	11
4.5	Heavy Equipment	12
4.6	Overhead Powerlines	13
4.7	Severe Weather	14
4.8	Heat Stress	15
4.8.1	**Heat Stress Prevention**	15
4.9	Cold Stress	17
4.10	Biological Hazards	18
4.10.1	**Ticks (Lyme Disease) & Mites**	18
4.10.2	**Insect Bites/Stings**	20
4.10.3	**Venomous Snakes**	21
4.10.4	**Poisonous Plants and Plant Hazards**	22
4.11	Working Alone	23
5.	**HAZARD COMMUNICATION**	**25**
5.1	Coal Combustion Residuals	25
5.2	Sulfuric Acid	26
5.3	Safety Data Sheets	26
5.4	Signage	26
6.	**EMERGENCY RESPONSE PLAN**	**27**
6.1	Emergency Phone Numbers & Notifications	27
6.2	Evacuation Signal	27

6.3	Muster Point	27
6.4	Calls for Emergency Support	27
6.5	Fire & Explosion Response Plan	27
6.6	Injury Response Plan	28
6.7	Spill Response Plan	28
6.8	CCR Spill or Release Response Plan	28
6.9	Ash Pond Rescue	29
6.10	Incident Reporting	29

APPENDICES

Appendix A	Site Map
Appendix B	Safety and Health Plan Acknowledgment Form
Appendix C	Vistra Drug Screen Policies and Supplemental Terms
Appendix D	COVID-19 Vistra Site Entry Guidelines
Appendix E	Safety Data Sheets

ACRONYMS & ABBREVIATIONS

%	Percent
§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
29 C.F.R.	Title 29 of the Code of Federal Regulations
ACGIH	American Conference of Governmental Industrial Hygienists
CCR	Coal Combustion Residual
EAP	East Ash Pond
EEI	Electric Energy, Inc.
HAZWOPER	Hazardous Waste Operations and Emergency Response
ID	identification
IDLH	Immediately Dangerous to Life and Health
IEPA	Illinois Environmental Protection Agency
JPP	Joppa Power Plant
kV	kilovolt
NAVD88	North American Vertical Datum of 1988
NID	National Inventory of Dams
NIOSH	National Institute for Occupational Safety and Health
No.	number
OSHA	Occupational Safety and Health Administration
Part 845	35 I.A.C. Part 845: Residuals in Surface Impoundments
PEL	Permissible Exposure Level
PFAS	Per- and polyfluoroalkyl substances
PFD	Personal Flotation Device
PNOR	particulates not otherwise recognized
POC	Point of Contact
PPE	personal protective equipment
ppm	parts per million
SDS	Safety Data Sheet
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TWA	time-weighted averages
USCG	United States Coast Guard

REVISION SUMMARY

Revision Date	**Description of Changes** (Section title or number – description)	**Responsible Party** (individual name or title, company / agency name, document reference and date)

PREFACE

Electric Energy, Inc. (EEI) has prepared this Safety and Health Plan in accordance with requirements set forth in Title 35 of the Illinois Administrative Code (35 I.A.C.) Part 845: Residuals in Surface Impoundments (Part 845), Section (§) 845.530. EEI assessed health and safety hazards of its coal combustion residual (CCR) surface impoundments to develop and update this Safety and Health Plan.

This document describes the minimum anticipated protective measures necessary for worker health and safety at the Joppa Power Plant (JPP) East Ash Pond (EAP; Vistra identification [ID] number [No.] 401, Illinois Environmental Protection Agency [IEPA] ID No. W1270100004-02, National Inventory of Dams [NID] No. IL50714), herein referred to as the Site. Employees of EEI, contract workers, and third-party contractors must read and comply with the contents of this document. The contents of this document are not intended to cover all situations that may arise nor to waive any provisions specified in Federal, State, and local regulations or site owner / contractor health and safety requirements.

Third-party contractors are accountable for the health and safety of their employees. Third-party contractors are required to prepare a Safety and Health Plan that meets the minimum requirements herein. However, no requirements or provisions within this plan shall be construed as an assumption of EEI of their legal responsibilities as an employer.

This Safety and Health Plan will be reviewed and updated annually, at a minimum. The Safety and Health Plan will also be updated if facility operations change, or a new hazard is identified.

1. INTRODUCTION

This Safety and Health Plan has been developed to outline the requirements to be met by employees of EEI, contract workers, and third-party contractors while performing any activity to construct, operate, or close the EAP. This Safety and Health Plan has been developed to meet the requirements of 35 I.A.C. § 845.530 and describes the responsibilities, training requirements, protective equipment, and safety procedures necessary to minimize the risk of injury, fires, explosion, chemical spills, material damage incidents, and near misses related to CCR activities. This Safety and Health Plan incorporates by reference the Occupational Safety and Health Administration (OSHA) regulations contained in Title 29 of the Code of Federal Regulations (29 C.F.R.) § 1910 and 29 C.F.R. § 1926.

The requirements and guidelines in this Safety and Health Plan are based on a review of available information and data, and an evaluation of identified on-site hazards. This Safety and Health Plan will be reviewed with persons assigned to work at the EAP and will be available on-site.

1.1 Site Description/History

The JPP is west of the Village of Joppa in Massac County, Illinois, northeast of the Ohio River in Section 14, Township 15 South, Range 3 East. The JPP property is bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north, the Village of Joppa to the east and the Ohio River to the south. The EAP is located in the west half of Section 14 directly north of the power plant, and is within the railway right-of-way for the spur servicing the JPP (Appendix A).

1.2 Facility Personnel

The following table outlines key personnel with respect to facility operations and health and safety. The Plant Control Room is the first point of contact for plant communication, including emergencies.

Name	Position	Phone Number
Bruce Parker	Point of Contact (POC)/Environmental Manager	318-543-3458
Roger Faughn	Plant Supervisor - Environmental/Chemistry	270-210-3232
Control Room (24/7)		618-543-3301
Bryon Veech	Plant Manager	318-543-3483
Plant Shift Supervisor (24/7)		318-543-3346 318-543-3348
Don Watson	Director of Health and Safety	618-406-3615
Matt Ballance	Engineering Manager	618-343-7739 (office) 618-792-7274 (mobile)
Jason Campbell	Dam Safety Manager	271-753-8904 (Springfield) 217-622-3491 (mobile)
Stu Cravens	Senior Technical Expert	217-390-1503 (mobile)
Vic Modeer	Engineering Manager	618-541-0878

1.3 Responsibilities

The following persons have responsibilities associated with communicating and implementing the Safety and Health Plan for the EAP.

1.3.1 EEI Point of Contact

The EEI Point of Contact (POC) is a management-level person who is requiring employees, contract workers, or third-party contractors to enter the EAP. The EEI POC is responsible to

communicate Safety and Health Plan information and requirements to employees, contract workers, and third-party contractors, and oversee work performed in the EAP to the extent necessary to confirm implementation of Safety and Health Plan requirements.

1.3.2 EEI Employees

EEI employees are directly hired by EEI. They are required to implement and/or follow Safety and Health Plan requirements as applicable to their work and exercise their "stop work authority" if safety requirements are unclear or unanticipated site conditions or hazards are observed.

1.3.3 Contract Workers

Contract workers are those hired by EEI through an agency firm. Similar to EEI employees, contract workers are required to implement and/or follow Safety and Health Plan requirements as applicable to their work and exercise their "stop work authority" if safety requirements are unclear or unanticipated site conditions or hazards are observed.

1.3.4 Third-Party Contractor Employees

Third-party contractor employees work for firms under contract to EEI. Third-party contractors include prime contractors and all of their lower tier subcontractors. Similar to EEI employees, third-party contractors are required to implement Safety and Health Plan requirements as applicable to their work and exercise their "stop work authority" if safety requirements are unclear or unanticipated site conditions or hazards are observed.

1.3.5 Third-Party Contractor Safety Competent Person

Third-party contractors will be required to designate a Safety Competent Person. The Safety Competent Person must be in a management position (*e.g.,* superintendent, foreman, etc.) with OSHA 30-hour construction safety certification who may perform other duties, unless EEI requires a dedicated Safety Competent Person. A Safety Competent Person must be on site at all times when the subcontractor has employees performing work for EEI and must possess a sound working knowledge of pertinent OSHA regulations, this Safety and Health Plan, and other applicable safety requirements related to the scope of work. Third-party contractors must also designate a backup Safety Competent Person that possesses the same authority and training. The competent person will ensure timely correction of safety deficiencies identified by EEI. The Safety Competent Person is responsible to ensure Safety and Health Plan requirements have been communicated to lower-tier subcontractors and enforce Safety and Health Plan requirements.

2. SITE ACCESS & CONTROL

This section outlines requirements for ensuring that only authorized personnel and visitors are permitted at the Site.

2.1 Facility Security

Elements of site control include restricting access to the Site to persons until they have met the training requirements outlined in this Safety and Health Plan and have been authorized to do so by the JPP POC or their representative.

Upon arrival to the site, all EEI employees, contract workers, and third-party contractors must report to Guardhouse 3. They then must contact the POC/Environmental Manager or the Plant Supervisor.

Upon arrival to the site, all EEI employees, contract workers, and third-party contractors must check in/out at Security. A COVID-19 screening must also be completed per Section 3.8.

2.2 Third-Party Contractor Management

Prior to working at the EAP, all third-party prime contractors must maintain an active registration with ISNetworld and maintain a grade of A or B. Lower tier subcontractors are currently not required to be registered in ISNetworld, but this requirement may change at the discretion of EEI.

2.3 Third-Party Contractor Safety and Health Plan

Prior to being authorized to conduct work at the EAP, third-party contractors must develop and submit a Safety and Health Plan. The third-party contractor's Safety and Health Plan must be specific to the scope of work that they will be performing at the EAP. The third-party contractor's Safety and Health Plan must meet or exceed all the requirements in this Safety and Health Plan, other EEI requirements, and applicable regulations. All lower tier subcontractors of third-party contractors must meet the requirements in this Safety and Health Plan as well as the requirements outlined in the Safety and Health Plan of the third-party with whom they are contracted.

2.4 Authorized Personnel

At a minimum, authorized personnel who will be granted unescorted access to the project include EEI employees, contract workers, and third-party contractors that meet the following:

- Reviewed this Safety and Health Plan and other applicable safety planning documentation
- Have completed all the training, medical surveillance, and drug screen and background investigation requirements as outlined in Section 3 of this Safety and Health Plan.
- Have completed the JPP Site Orientation Training

2.5 Visitors

Visitors must be escorted by Authorized Personnel through the EAP if they have not reviewed this Safety and Health Plan or completed the training requirements outlined in Section 3 of this Safety and Health Plan. Visitors may not undertake any activity to construct, operate, or close a CCR surface impoundment.

2.6 Communication

Communication between workers and emergency services must be maintained at all times. Cellular service is consistently available and can be relied upon to summon emergency services.

3. TRAINING & MEDICAL REQUIREMENTS

Project personnel must be properly trained for the type of work being performed and in accordance with 35 I.A.C. § 845.530, 29 C.F.R. § 1926 and 29 C.F.R. § 1910, and EEI policies. Additionally, personnel working in areas regulated by the OSHA Hazardous Waste Operations and Emergency Response (HAZWOPER) standards (29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65) must have current medical surveillance. All employees, contractors, and third-party contractors must complete the following prior to beginning any activity to construct, operate, or close the EAP.

3.1 HAZWOPER Training

35 I.A.C. § 845.530(c)(2)(E) requires that all employees, contract workers, and third-party contractors be trained in accordance with 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65. The following training will be completed as required by job function:

- **OSHA 40-Hour Training** per 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65, for those personnel who are expected to have extensive contact with contaminated materials and/or may be required to wear a respirator.
- **OSHA 24-Hour Training** per 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65, for those personnel who are expected to have minimal contact with contaminated materials and will NOT be required to wear a respirator.
- **OSHA 8-hour Supervisor Training** per 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65, for Site Supervisors, Foremen, Superintendents, and others who will be directing and managing site activities.
- **OSHA 8-hour Refresher** per 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65, completed within 12 months of initial 40-hour or 24-hour training and annually thereafter.

The following matrix outlines HAZWOPER training requirements based on typical job functions at the EAP. It is not intended to be all inclusive, new job functions must be evaluated per 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65.

Training	Job Function
OSHA 40-hour	Ash handlers
OSHA 24-hour	Personnel not required to handle CCR materials
OSHA 8-hour Supervisor Training	Third-Party Contractor Safety Competent Persons
OSHA 8-hour refresher	All personnel

3.2 OSHA Construction Outreach Training

35 I.A.C. § 845.530(c)(2)(E) requires that all employees, contract workers, and third-party contractors complete an OSHA 10-hour or 30-hour construction safety training. These trainings will be completed as follows:

- All employees, contract workers, and third-party contract employees: OSHA 10-hour or 30-hour construction outreach training.
- Supervisors, superintendents, foreman, and safety professionals: OSHA 30-hour construction outreach training.

3.3 EAP Safety and Health Plan Review

Pursuant to 35 I.A.C. § 845.530(d)(e), before beginning any activity at the EAP, and annually thereafter, all EEI employees, contract workers, and third-party contractors must review the content of this HASP. After reviewing this Safety and Health Plan all personnel will understand the following:

- Procedures for using, inspecting, repairing, and replacing facility emergency and monitoring equipment
- Communications or alarm systems outlined in Section 6
- Response to fires and explosions outlined in Section 6
- Response to a spill or release of CCR
- Information about chemical hazards and hazardous materials outlined in Section 5
- The use of engineering controls, administrative controls, and personal protective equipment (PPE) outlined in Section 4

All personnel will acknowledge this HASP by signing the *Safety and Health Plan Acknowledgment Form (Appendix B).*

3.4 Emergency and Monitoring Equipment Training

All EEI employees, contract workers, and third-party contractors must be aware of how to respond to alarms and other emergencies as outlined in Section 6 of this plan. Individuals may only use facility emergency and monitoring equipment if they have been trained in their use and authorized to do so by the designated POC. Additionally, a written release may need to be completed as required by Vistra Corporate Procedure FFA-POL-0006.

Individual EEI employees and contract workers may be responsible for using, inspecting, repairing and replacing facility emergency monitoring equipment. These individuals will be trained in accordance with procedures identified by EEI. These individuals will review and adhere to the manufacturer's instructions, where applicable.

Third-party contractors are responsible for inspecting, repairing, and replacing any owned emergency (*i.e.*, fire extinguishers) and monitoring equipment (*i.e.*, air monitoring equipment). Third-party contractors will maintain procedures for using, inspecting, repairing, and replacing owned emergency and monitoring equipment that is consistent with the manufacturer's requirements. Third-party contractor employees who are responsible for this equipment will be trained in procedures for using, inspecting, and repairing owned equipment by their employer.

3.5 Hazard Communication

All employees, contract workers, and third-party contractors must be trained in chemical hazards (if any) associated with their work in accordance with 29 C.F.R. § 1910.1200. Work tasks performed on the EAP may include exposure to compounds identified in the Hazard Communication section of this Safety and Health Plan and is included as part of the Safety and Health Plan Review outlined in Section 3.3.

3.6 Medical Surveillance

All employees, contract workers, and third-party contractors engaged in operations specified in 29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65 and meet one of the criteria outlined in 29 C.F.R. § 1910.120(f)(2) and 29 C.F.R. § 1926.65(f)(2) must participate in a medical surveillance program that is administered by their employer. The criteria for participating in a medical surveillance program are:

- All employees who are or may be exposed to hazardous substances at or above the established permissible exposure limit, without regard to the use of respirators, for 30 days or more a year;
- All employees who wear a respirator for 30 days or more a year; or
- All employees who are injured, become ill or develop signs or symptoms due to possible overexposure involving hazardous substances or health hazards from an emergency response or hazardous waste operation.

The medical surveillance program must result in documentation that an individual is cleared to work on sites covered by 29 C.F.R. § 1910.120 and 20 C.F.R. § 1926.65 and is medically fit to wear a respirator when applicable.

3.7 Drug Screen and Background Investigations

EEI requires that contract worker agencies and third-party contractors are responsible for ensuring that all personnel have completed and passed a drug and alcohol test and background investigation prior to on-site work as described in Appendix C.

3.8 COVID-19 Site Entry Guidelines

All personnel entering Vistra work sites shall review and adhere to the site entry guidelines provided in Appendix D.

3.9 Document Management

Human Resources will maintain employee and contract employee training and medical surveillance records. Third-party contractors are responsible for maintaining training and medical surveillance documentation for their employees. Third-party contractors will produce documentation upon EEI request.

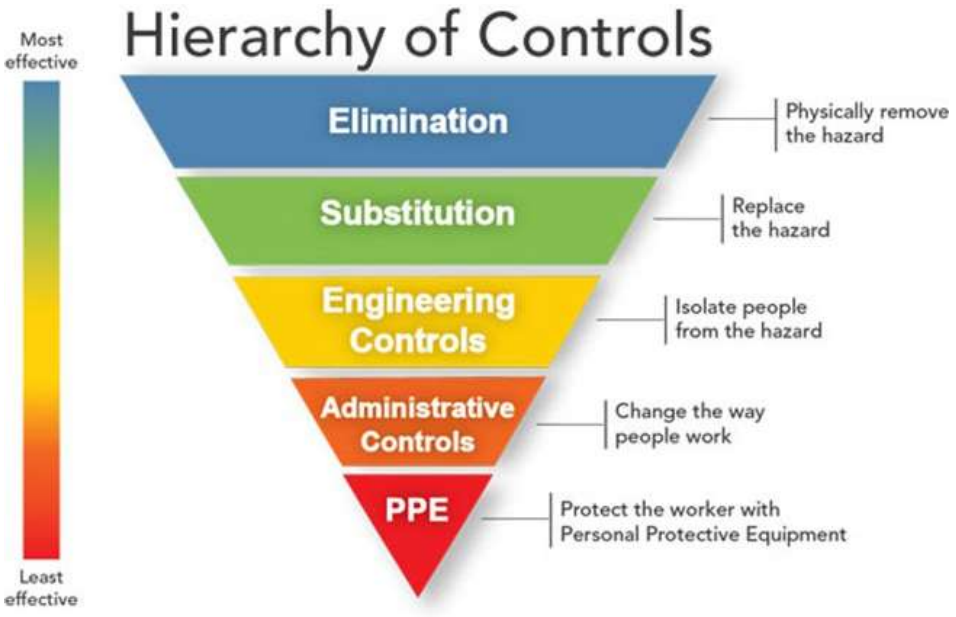
3.10 Industrial Hygiene Sampling Records

Upon receipt of exposure sampling results EEI and third-party contractors must distribute exposure sampling results to employees within 15 business days unless otherwise required by applicable regulation. All personnel exposure sampling results and records must be maintained by the employee’s company for at least 30 years following termination of employment.

4. HAZARD & CONTROLS

The following section outlines general controls for the hazards and controls. Third-party contractors are still responsible for developing a Safety and Health Plan that incorporates requirements of this Safety and Health Plan, other safety requirements for the JPP, as well as the third-party contractor's safety policies and procedures. Safety and Health Plans developed by third-party contractors must be specific to the site and the anticipated work means and methods. Safety and Health Plans that consist of only standard operating procedures or are not otherwise specific to the work performed at the EAP will not be accepted by EEI.

EEI requires that a hierarchy of controls be considered when performing work at the EAP. Implement controls that favor elimination, substitution, and engineering over the use of administrative controls and PPE when feasible. See the figure below for additional guidance (courtesy of the National Institute for Occupational Safety and Health [NIOSH]).



4.1 Ash/Unstable Surfaces

Prior to working in or on an ash pond, third-party contractors must notify the facility POC and Plant Security. Work in or on an ash pond may not begin until the facility POC has approved the work. Upon completion of the work, third-party contractors must notify the POC and Plant Security that they have left the ash pond.

When working on ash ponds or unstable surfaces the following requirements must be implemented where applicable and feasible. The following table summarizes safety controls for work performed in ash ponds and on unstable surfaces and are aligned to the hierarchy of controls:

Elimination	Substitution	Engineering	Administrative	PPE
Change the work task or work methods so that work on ash ponds is no longer required	Use the lightest available tracked equipment to reduce ground pressure	Use crane mats or other cribbing to support heavy equipment on ash ponds	Traverse compacted paths that have previously been used by heavy equipment	Use a restraint (tethering) system to prevent falls or slips into unstable ash pond surfaces or surface water that represents a drowning hazard

Elimination	Substitution	Engineering	Administrative	PPE
			If an unstable condition exists, complete a Next Level Up Pre-Job Brief prior to accessing the ash pond.	
			Approach the ash pond from the most stable direction	
			Inspect travel paths for recent terrain shifts, particularly following heavy rains or rapid dewatering	
			Working alone on ash ponds is prohibited without pre-approval from the POC.	
			When a drowning hazard exists, implement requirements for working on/near water as outlined in Section 4.4.	
			Implement an emergency response plan with trained responders for falls into (or engulfment by) ash	

4.2 Ash Inhalation/Airborne Exposure

Ash that becomes airborne due to site activities or environmental conditions may result in an exposure to its components as outlined in Section 5.1. EEI and third-party contractors are responsible for ensuring their respective employees' and contract workers' exposures are below occupational exposure limits. Upon request, third-party contractors must demonstrate to EEI that exposure control methods are adequate. The following table summarizes airborne exposure controls and is aligned to the hierarchy of controls:

Elimination	Substitution	Engineering	Administrative	PPE
Change the work task or work methods so that work on ash ponds is no longer required	Substitute manual work methods for those that can be completed from the cab of a vehicle	Continually wet work areas to reduce the amount of ash that becomes airborne Equip vehicles and heavy equipment cabs with filters. Clean and change filters as required	Conduct air monitoring or exposure sampling to confirm that airborne exposure is below regulatory limits	If exposure levels are above the PEL, equip employees with respirators appropriate to the level of exposure

4.3 Stuck Vehicles/Equipment

If a vehicle or piece of equipment becomes stuck, a third-party towing or wrecking company who is trained in vehicle extraction must be retained and the JPP POC will be notified. The towing or wrecking company must report to Guardhouse 3 and complete the JPP Site Orientation Training upon arrival to the Site. Third-party contractors may extract their own vehicle if they have an approved extraction plan and a competent person is on site to implement the extraction. The extraction plan shall be included as part of the third-party contractor's reviewed and approved Safety and Health Plan. The above notifications are still required.

The hazards presented by stuck vehicles/equipment must not be underestimated. While the weight of the stuck equipment can be calculated, it's impossible to precisely calculate the other forces that are pulling against the towing vehicle which requires special training and experience to properly size towing equipment and select towing techniques. This is especially true for "complex" or high-hazard extractions involving equipment stuck at axle depth (or beyond) or sloped surfaces or any area where extraction activities could trigger shifts in the ground surface. No chains shall be used to remove stuck vehicles/equipment.

The following table summarizes safety controls related to stuck vehicles and equipment and are aligned to the hierarchy of controls:

Elimination	Substitution	Engineering	Administrative	PPE
Change the work task or work methods so that work on ash ponds is no longer required	Use the lightest available tracked equipment to reduce ground pressure Substitute tracked equipment for wheeled equipment	Use crane mats or other cribbing to support heavy equipment on ash ponds Lighten the load – Remove materials from stuck vehicles or equipment prior to extraction if possible	Only persons trained in vehicle extraction are permitted to remove stuck vehicles/equipment A professional towing/wrecking service is required Prepare for spills (damage to fuel or hydraulic systems)	All persons involved in removing stuck equipment must wear PPE that includes hard hat, safety boots, safety glasses, high visibility vests, and cut resistant gloves

4.4 Working Near/Over Water

All employees, contract workers, and third-party contractors must wear a United States Coast Guard (USCG) approved personal floatation device (PFD), when within 6 feet of water, over water, and/or wading in water where the danger of drowning exists. The PFD must be properly

secured to the wearer, free of all defects including rips, tears, stress, and fading, and be kept clean and free of excessive dirt and oil.

If the possibility of falling into water has been eliminated through the use of guardrails, fall restraint, or other method, the use of a PFD is no longer required.

When performing work on water from a vessel, at least one lifesaving rescue vessel (*e.g.,* a skiff) shall be immediately available at locations where employees are working over, in, on, or adjacent to water where the danger of drowning exists. However, if the water is so shallow that rescuers could simply walk/run into the water body without endangering themselves and/or others or the work was being conducted very close to shore (*e.g.,* the length of the skiff from shore would be greater than the working distance from shore and/or the skiff would foul on the bottom), a skiff would not be required.

The following table summarizes the requirements for working over/near water where a drowning hazard exists and are aligned to the hierarchy of controls:

Elimination	Substitution	Engineering	Administrative	PPE
Change the work task or work methods so that work near a drowning hazard is no longer required		Install guardrails that separate work areas from the drowning hazard	All work to be performed by at least two people where each is equipped with proper safety gear and capable of summoning emergency rescue	All personnel are required to wear suitable PFDs
		Utilize equipment (crowd-control barricades, safety fence, etc.) that will keep personnel at least 6 feet from a drowning hazard	When working on water use of a rescue skiff as outlined above	
			Use of a ring buoy with 90 feet of braided polycarbonate (or equivalent) line	
			Ring buoys must be positioned within 100 feet of work (maximum of 200 feet spacing)	

4.5 Heavy Equipment

All heavy equipment operators must be competent and authorized to operate each piece of heavy equipment. Forklift and telehandler (*e.g.,* Lull, JLG) operators must have a license or certificate that indicates they have passed a written test and "road" test for the equipment they will be operating within the last 3 years. Third-party contractors will provide proof of qualification upon request of EEI.

Persons working around heavy equipment must implement the “25 Foot Rule.” The 25 Foot Rule requires that persons get the operator’s attention and permission prior to approaching closer than 25 feet to heavy equipment. Persons must walk quickly through blind spots. Loitering in heavy equipment blind spots (especially to the rear) must be avoided.

Temporary fuel storage tanks will be labelled as to their content and be protected from collision by Site vehicles using solid barricades including balusters, chain link fence, or equivalent. Spill kit (55-gallon sorbent capacity contained in an overpack) and one 20-pound Type ABC fire extinguisher will be located within 45 feet of fueling areas. Tanks will be rated for above ground use and will be double walled or have secondary containment in case of a leak. Tanks and dispensing hose will be bonded and grounded. On-site filling of fuel storage tanks will be completed with trucks that have automatic over-flow shutoffs. These trucks will be properly bonded to the storage tank and meet all of the other storage tank requirements. Temporary secondary containment must be provided in the refueling area that includes the storage tank and dispensing hoses.

Elimination	Substitution	Engineering	Administrative	PPE
		Heavy equipment (and vehicles) must be equipped with backup alarms, horns, roll-over protection (when feasible)	Operators must be competent and authorized	Operators must use seatbelts when equipped
		Vehicles and heavy equipment operated at night must have headlights, tail lamps, and reflectors	Forklift operators must have a current license or certificate (within 3 years)	High visibility vests are required when working around heavy equipment
			All vehicles and equipment must be turned off when not in use	
			Operators must inspect equipment daily prior to use	
			Persons working near heavy equipment must follow the "25 Foot Rule" and avoid lingering in blind spots as outlined above	
			Always obey site speed limits – 15 mph unless otherwise posted	

4.6 Overhead Powerlines

All overhead powerlines must be assumed to be energized until confirmed otherwise. The minimum clearance distance for equipment working near energized power lines must be in accordance with the table found in 29 C.F.R. § 1926.1408(h).

The following table summarizes safety controls for work near energized power lines:

Elimination	Substitution	Engineering	Administrative	PPE
Plan to work away from powerlines	Use heavy equipment with shorter booms/attachments to avoid coming close to power lines	Contact the utility owner to deenergize the line	Install signs to warn personnel of overhead powerlines	
		Contact the utility owner to install insulated sleeves over energized lines	Install a non-conductive distance marker to delineate minimum clearance	
			Use a dedicated spotter to ensure equipment does not enter minimum clearance distances	

4.7 Severe Weather

Severe weather conditions include but are not limited to high winds, electrical storms, heavy rain, and tornados can cause hazardous conditions at CCR surface impoundments. The primary control for severe weather is monitoring weather reports prior to beginning work and as work occurs throughout the day.

Monitor lightning using a commercially available mobile application if cellular service is available. When lightning is observed within 10 miles of the CCR surface impoundment, or a storm is imminent, take shelter in the nearest solid structure or fully enclosed vehicle. If possible, secure all tools, materials, and equipment prior to the storm arriving. Work may resume 30 minutes after the last lightning strike is observed within 10 miles. Shelter locations will be reviewed during the Site Orientation Training.

Do not conduct work on a CCR surface impoundment when there is a risk for tornados in the area. If on a CCR surface impoundment and a tornado forms, seek the nearest substantial shelter. If no shelter is available, attempt to evacuate to a shelter using a vehicle. Shelter locations will be reviewed during the Site Orientation Training. If a tornado forms and you are not in a shelter, take one of the following actions:

- Stay in a vehicle with the seat belt on, keep your head below the windows and cover it with your hands
- If there is an area which is noticeably lower than the work area, lie in that area and cover your head with your hands.

The following table summarizes safety controls related to severe weather:

Elimination	Substitution	Engineering	Administrative	PPE
Plan outdoor tasks on days with low potential for severe weather.			Prior to beginning outdoor work monitor the day's weather.	

Elimination	Substitution	Engineering	Administrative	PPE
			Periodically monitor weather throughout the day. Use a weather app which issues alerts for severe weather and lightning, assuming cell service is available	
			Utilize a weather radio if cellular service is inconsistent	
			Stop all outdoor work and seek shelter when lightning is observed	

4.8 Heat Stress

Heat stress can be a significant hazard, especially for workers wearing protective clothing. Depending on the ambient conditions and the work being performed, heat stress can occur very rapidly, within as little as 15 minutes. Employees, contract workers, and third-party contractors will be instructed in the identification of a heat stress victim, the first-aid treatment procedures for the victim, and in the prevention of heat stress incidents.

Workers will be encouraged to immediately report any heat-related problems that they experience or observe in fellow workers. Any worker exhibiting signs of heat stress and exhaustion should be made to rest in a cool location and drink plenty of water. Emergency help by a medical professional is required immediately for anyone exhibiting symptoms of heat stroke, such as red, dry skin, confusion, delirium, or unconsciousness. Heat stroke is a life-threatening condition that must be treated immediately by competent medical authority.

4.8.1 Heat Stress Prevention

To prevent heat stress, EEI employees, contract workers, and third-party contractors will implement heat stress prevention measures as outlined in OSHA's Heat Index (below). A summary of these precautions is described below.

Heat Index	Risk Level	Protective Measures
Less than 91°F	Lower (Caution)	Basic heat safety and planning
91°F to 103°F	Moderate	Implement precautions and heighten awareness
103°F to 115°F	High	Additional precautions to protect workers
Greater than 115°F	Very High to Extreme	Triggers even more aggressive protective measures

Know the Symptoms: Some symptoms associated with heat stress are: Employees should be aware of these symptoms with themselves and with their co-workers:

- Elevated heart rate, lack of concentration, difficulty focusing on a task, fatigue
- Irritability and/or sickness
- Cramps, rash, headache
- Loss of desire to drink water
- Fainting
- Skin clammy, moist, and pale (severe heat exhaustion)
- Skin extremely dry and red (heat stroke)

Acclimatize: When high heat stress conditions arise, employees should be exposed to the heat for short work periods followed by longer periods of work. Acclimatization usually takes five (5) days and should be provided for all new employees and employees returning from an absence of two (2) weeks or more. Contact Corporate Health and Safety for proper procedures.

Hydration & Pace of Work: Make sure all employees intake plenty of water throughout the work day (sometimes as much as a quart per worker per hour) and let employees know where the drinking water is located. Adjust your work pace and expectations on how much work can be done during periods of high heat stress. Workers cannot do as much during periods of high heat stress compared with similar periods of low heat stress. After acclimatization, workers may be able to resume a more "normal" work pace as long as fluid intake is adequate.

Work/Rest Periods: If possible, heavy work should be scheduled during the cooler parts of the day (*i.e.,* early morning) and rest periods should be taken in cool areas for longer periods.

Personal Protective Equipment (PPE): Employees using PPE (*i.e.*, Tyvek® suits or other equipment which may retain heat) can be more susceptible to heat stress due to the fact that heat/sweat often cannot escape the suits and/or the equipment. Persons wearing PPE that contributes to heat stress require more hydration, longer rest periods, or a reduced pace of work. Also, more careful monitoring of each person's health status is required by co-workers and management.

The following table summarizes safety controls for heat related illnesses:

Elimination	Substitution	Engineering	Administrative	PPE
Perform outdoor, strenuous, tasks at cooler times of day/year	Use mechanized equipment in place of manual labor	Install fans or air conditioning units in the work area	Train all personnel to know the signs of heat stress/stroke and how to prevent it	Implement the use of cooling vests or other similar PPE
		Install a canopy to provide shade to work areas	Allow workers to acclimatize to the work environment	
		Provide cool, shaded break areas	Adjust work pace to allow for the effects of heat	
			Implement work/rest periods	

4.9 Cold Stress

The four environmental conditions that cause cold-related stress are low temperatures, high/cool winds (wind chill), dampness, and cold water. One, or any combination of these factors, can cause cold-related hazards. Cold stress, including frostbite and hypothermia, can result in severe health effects. Employees, contract employees, and third-party contractors will be instructed in the identification of a cold stress victim, the first-aid treatment procedures for the victim and in the prevention of heat stress incidents.

A dangerous situation of rapid heat loss may arise for any individual exposed to high winds and cold temperatures. Major risk factors for cold-related stresses include:

- Wearing inadequate or wet clothing thus increasing the effects of cold on the body.
- Taking certain drugs or medications such as alcohol, nicotine, caffeine, and medication thus inhibiting the body's response to the cold and/or impairing judgment.
- Having a cold or certain disease, such as diabetes, heart, vascular and thyroid problems, and thereby increasing susceptibility to the winter elements.
- Lower body-fat composition or other physiological differences. Statistics show that men experience far greater death rates due to cold exposure than women, potentially attributable to participation in risk-taking activities, lower body-fat composition and/or other physiological differences.
- Becoming exhausted or immobilized, especially due to injury or entrapment, thus speeding up the effects of cold weather.

The following table provides the resulting equivalent chill temperature to exposed skin because of increasing wind speeds at decreasing actual temperatures. Personnel shall be aware of predicted weather conditions before beginning site work and stay apprised of changes.

TABLE 2. Cooling Power or Wind on Exposed Flesh Expressed as Equivalent Temperature (under calm conditions)*

Estimated Wind Speed (in mph)	Actual Temperature Reading (°F)											
	50	40	30	20	10	0	−10	−20	−30	−40	−50	−60
	Equivalent Chill Temperature (°F)											
calm	50	40	30	20	10	0	−10	−20	−30	−40	−50	−60
5	48	37	27	16	6	−5	−15	−26	−36	−47	−57	−68
10	40	28	16	4	−9	−24	−33	−46	−58	−70	−83	−95
15	36	22	9	−5	−18	−32	−45	−58	−72	−85	−99	−112
20	32	18	4	−10	−25	−39	−53	−67	−82	−96	−110	−121
25	30	16	0	−15	−29	−44	−59	−74	−88	−104	−118	−133
30	28	13	−2	−18	−33	−48	−63	−79	−94	−109	−125	−140
35	27	11	−4	−20	−35	−51	−67	−82	−98	−113	−129	−145
40	26	10	−6	−21	−37	−53	−69	−85	−100	−116	−132	−148
(Wind speeds greater than 40 mph have little additional effect.)	LITTLE DANGER In < hr with dry skin. Maximum danger of false sense of security				INCREASING DANGER Danger from freezing of exposed flesh within one minute.				GREAT DANGER Flesh may freeze within 30 seconds.			
	Trenchfoot and immersion foot may occur at any point on this chart.											

*Developed by U.S. Army Research Institute of Environmental Medicine, Natick, MA.
Equivalent chilll temperature requiring dry clothing to maintain core body tempearture above 36°C (96.8°F) per cold stress TLV

The following table summarizes safety controls for preventing cold stress:

Elimination	Substitution	Engineering	Administrative	PPE
Perform work during warm parts of the day or warmer parts of the year		Install heaters in enclosed work areas	Train all personnel on the symptoms of cold stress and how to prevent it	All personnel must wear multiple layers of clothing
		Provide a warm break area	Implement work/rest schedule	Utilize hand/foot warmers when required

An additional hazard in cold weather conditions is the increased risk for slips from the accumulation of ice and snow in general work areas, ruts where water is accumulated, and heavy equipment. The following table outlines controls that may be used for preventing slips:

Elimination	Substitution	Engineering	Administrative	PPE
Perform work during warm parts of the day or in areas free of accumulated areas		Clear snow in work areas		Use traction control devices (*i.e.,* YakTrax) on work boots to provide additional traction.
		Apply salt/sand to icy areas		
		Use equipment to access work areas		

4.10 Biological Hazards

The following are biological hazards that may be present at the EAP.

4.10.1 Ticks (Lyme Disease) & Mites

Although Lyme disease has been detected throughout the continental United States, it is prevalent primarily in certain areas in New England, the Mid-Atlantic and the northern Midwest states.

Although Lyme disease is the most common tickborne illness, other tickborne illnesses include southern tick-associated rash illness, Rocky Mountain spotted fever, ehrlichiosis, and tularemia. More information on Lyme disease and other tickborne illnesses can be found from the CDC.

Prevention

- Standard field gear (work boots, socks, and light-colored coveralls) provides good protection against tick bites, particularly if the joints are taped. However, even when wearing field gear, the following precautions shall be taken when working in areas that might be infested with ticks:
  - Wear long pants and long-sleeved shirts that fit tightly at the ankles and wrists, tape cuffs if necessary
  - Wear light colored clothing so ticks can be easily spotted
  - Per- and polyfluoroalkyl substances (PFAS)-free tick repellents (DEET and Permethrin) must be used when walking in all overgrown areas. DEET (≥25 percent [%]) must be applied to skin while permethrin must be applied to clothes and allowed to dry. Spray outer clothing, particularly your pant legs and socks, BUT NOT YOUR SKIN, with an insect repellent that contains permethrin. For heavily infested tick areas, wear spun polypropylene coveralls that have been sprayed with permethrin.
  - Inspect clothing frequently
  - Inspect head and body thoroughly when you return from the field, particularly on your lower legs and areas covered with hair
  - When walking in wooded areas, wear a hard hat, and avoid contact with bushes, tall grass, or brush as much as possible

Removal

- Remove any ticks by tugging with tweezers or special tick removal tools
- Do not squeeze or crush the tick
- DO NOT use matches, a lit cigarette, nail polish, or any other type of chemical to "coax" the tick out

Treatment

- Disinfect the area with alcohol or a similar antiseptic after removal
- Notify the Safety Competent Person of the embedded tick
- For several days to several weeks after removal of the tick, look for the signs of the onset of Lyme disease, such as a rash.
- No further treatment is necessary for ticks embedded <48 hours.
- If other signs or symptoms of Lyme are observed (fever/chills, aches, and pains), then notify the Safety Competent Person and seek medical attention

The following table summarizes safety controls to reduce the hazards associated with ticks and mites.

Elimination	Substitution	Engineering	Administrative	PPE
Use mechanical equipment to remove overgrown vegetation		Remove overgrowth and excessive vegetation from walkways and work areas (provide safe access)	Train personnel on tick and mite prevention. Areas of vegetation overgrowth and/or debris piles should be considered “high risk” areas	Wear light-colored long sleeved shirt tucked into pants. Tuck pant legs into socks

Elimination	Substitution	Engineering	Administrative	PPE
			Perform frequent tick checks in the field and a thorough tick check after completing work activities	Apply Permethrin to clothes and DEET (20% or more) to exposed skin
			Call licensed pesticide contractors to remove infestations of bees, wasps, fire ants, etc.	

4.10.2 Insect Bites/Stings

Stinging/biting insects at the EAP include spiders, wasps, and bees. Contact with these insects may result in project personnel experiencing adverse health effects that range from being mildly uncomfortable to being life-threatening. Therefore, insects present a serious hazard to project personnel, and extreme caution must be exercised whenever Site and weather conditions increase the risk of encountering stinging insects. Some of the factors related to stinging insects that increase the degree of risk associated with accidental contact are as follows:

- The nests for these insects are frequently found in remote wooded or grassy areas or equipment staging areas where equipment has not been moved recently.
- Some people are hypersensitive to the toxins injected by a sting, and when stung, experience a violent and immediate allergic reaction resulting in a life-threatening condition known as anaphylactic shock. Anaphylactic shock manifests itself very rapidly and is characterized by extreme swelling of the body, eyes, face, mouth, and respiratory passages.
- The hypersensitivity needed to cause anaphylactic shock, can in some people accumulate over time and exposure, therefore even if someone has been stung previously and not experienced an allergic reaction, there is no guarantee that they will not have an allergic reaction if they are stung again
- Spider bites generally only cause localized reactions such as swelling, pain, and redness. However, bites from a Black Widow or Brown Recluse, or if you are allergic to spiders, can cause symptoms that are more serious.
- ***If a worker knows that they are hypersensitive to bee, wasp, or hornet stings, or other insects, they must inform the Safety Competent Person prior to site work. Persons who have been prescribed epi-pens by their physician must have an epi-pen on the Site.***
- Inspect any clothing or PPE that has been left for a period of time prior to putting it on. Shake out the clothing and inspect the inside of safety shoes/boots prior to putting them on
- Nests in active work areas must be eradicated. Small nests may be handled by Site personnel using consumer-type insecticide. A pest control contractor should be hired to handle large or difficult to reach nests.

The following table outlines safety controls to reduce the risk of hazards associated with stinging/biting insects.

Elimination	Substitution	Engineering	Administrative	PPE
Use mechanical equipment to remove overgrown vegetation		Remove overgrowth and excessive vegetation from walkways and work areas (provide safe access)	Train personnel on stinging/biting insect prevention. Areas of vegetation overgrowth and/or debris piles should be considered "high risk" areas	Wear light-colored long sleeved shirt tucked into pants. Tuck pant legs into socks
		Eradicate nests in the work area as outlined above.	Instruct personnel to inspect/shake out clothing and work boots that have been left for a period of time.	Apply Permethrin to clothes and DEET (20% or more) to exposed skin – NOTE this will not repel bees/wasps
			Instruct employees who are hypersensitive to insect bites/stings to carry their epi-pen while on site	

4.10.3 Venomous Snakes

There are four species of venomous snakes in Illinois, they are:

- Copperhead
- Cottonmouth Water Moccasin
- Timber rattlesnake
- Eastern Massasauga

Generally, these snakes are found in the southern one-third of the state, with the Cottonmouth Water Moccasin found mostly in the southernmost portions of Illinois. Snakes are generally found in tall grass, wood piles, or other covered areas. Snakes are generally not aggressive towards humans, but if they are encountered avoid the snake and do not provoke it. If bitten by a snake that may be venomous seek medical treatment.

The following table outlines safety controls to reduce the hazard associated with venomous snakes.

Elimination	Substitution	Engineering	Administrative	PPE
Use mechanical equipment to remove overgrown vegetation		Remove debris piles, overgrowth and excessive vegetation from walkways and work areas (provide safe access)	Train personnel on the identification of venomous snakes. Areas of vegetation overgrowth and/or debris piles should be considered "high risk" areas	If working in area with snakes cannot be avoided, wear snake chaps
			Instruct personnel to not disturb snakes if they identify one in their work area	

Elimination	Substitution	Engineering	Administrative	PPE
			Use caution when moving staged tools or materials into which snakes may have moved	

4.10.4 Poisonous Plants and Plant Hazards

Poison ivy and poison oak may be present at the Site. Poison ivy thrives in all types of light and usually grows in the form of a trailing vine; however, it can also grow as a bush and can attain heights of 10 feet or more. Poison ivy has pointed leaves that grow in clusters of three. Poison oak resembles poison ivy except that the poison oak leaves are more rounded rather than jagged like poison ivy, and the underside of poison oak leaves are covered with hair.

The skin reaction associated with contacting these plants is caused by the body's allergic reaction to toxins contained in oils produced by the plant. Becoming contaminated with the oils does not require contact with just the leaves. Contamination can be achieved through contact with other parts of the plant such as the branches, stems or berries, or contact with contaminated items such as tools and clothing. The allergic reaction associated with exposure to these plants will generally cause the following signs and symptoms:

Symptoms

- Blistering at the site of contact, usually occurring within 12 to 48 hours after contact and in many cases, persons experience almost immediate irritation.
- Reddening, swelling, itching, and burning at the site of contact.
- Pain, if the reaction is severe.
- Conjunctivitis, asthma, and other allergic reactions if the person is extremely sensitive to the poisonous plant toxin.

Prevention

- The best treatment appears to be removal of the irritating oil before it has had time to cause inflammation by wiping exposed skin with rubbing alcohol followed by washing with soap and water.
- A visual Site inspection and identification of the plants should be completed prior to starting work so that all individuals are aware of the potential exposure. Avoid contact with any poisonous plants on the Site, and keep a steady watch to identify, report, and mark poisonous plants found on the Site.
- Avoid contact with, and wash daily, contaminated tools, equipment, and clothing.
- Barrier creams (Ivy Block®) and orally administered desensitization may prove effective and should be tried to find the best preventive solution.
- Keeping the skin covered as much as possible (*i.e.*, long pants and long-sleeved shirts) in areas where these plants are known to exist will limit much of the potential exposure. PFAS-free spun polypropylene coveralls or Tyvek® may be worn to prevent contact of skin and clothes with poison ivy.

The following table outlines safety controls to mitigate the hazards associated with poisonous plants.

Elimination	Substitution	Engineering	Administrative	PPE
Use mechanical equipment to remove overgrown vegetation		Remove overgrowth and excessive vegetation from walkways and work areas (provide safe access)	Train personnel on the identification of poisonous plants	Wear pants and long sleeves when working in overgrown areas
			Instruct personnel to avoid areas where poisonous plants have been identified	Consider the use of a coverall when working in areas where these plants are present, especially for hypersensitive employees.
			Provide isopropyl alcohol along with soap and water to remove oils from skin, tools, and equipment.	

4.11 Working Alone

As outlined in Section 4.1, working alone while on the EAP must be pre-approved by the POC. Working alone is prohibited for tasks deemed to be high risk by EEI including, but not limited to, handling highly hazardous chemicals (sulfuric acid), work over/near water, excavation and trenching, hot work (grinding, welding and torch cutting), and elevated work that requires personal fall arrest. Third-party contractors are responsible for identifying potential high-risk tasks in their Safety and Health Plan and requiring that a buddy system be implemented while high risk work is performed. The buddy must be located in a safe area but may perform other tasks that do not prevent observing the person performing high risk work. Working alone may occur on and around other parts of the EAP when there is no drowning hazard or risk of severe injury due to high-risk work.

Elimination	Substitution	Engineering	Administrative	PPE
	Modify work methods by substituting lower hazard methods for high hazard methods	Varies depending on the hazard, but for example, could include installing guardrails (temporary or permanent) which mitigates a fall hazard reducing the risk to levels where working alone may be permitted	Prohibit working alone on ash ponds and for other high hazard tasks without prior approval from the POC.	
			Implement a buddy system whenever feasible (required for high hazard work)	

Elimination	Substitution	Engineering	Administrative	PPE
			Implement a worker check-in, emergency alerting, and monitoring system	

5. HAZARD COMMUNICATION

As required by 35 I.A.C. § 845.530, the OSHA HAZWOPER standards (29 C.F.R. § 1910.120 and 29 C.F.R. § 1926.65) and OSHA Hazard Communication Standard, site personnel, subcontractors, and visitors must be informed of chemical hazards associated with their work area. The information in this section is based on:

- Recommendations in the most recent "NIOSH Pocket Guide to Chemical Hazards" by the Department of Health and Human Services, Centers for Disease Control and Prevention, and the NIOSH Pocket Guide.
- Requirements set forth in the OSHA regulations from as defined in Chapter 17 of 29 C.F.R. § 1910.1200(c) for all hazards not otherwise classified.

5.1 Coal Combustion Residuals

Primary exposure to CCR is through inhalation and skin contact. CCR is typically a fine, black, grey, or tan particulate. CCR is comprised of several components. The following table outlines the components of the CCR. The exact percentage of each component will vary based on the type of ash and location at the surface impoundment.

Chemical	Percentage	PEL	IDLH	ACGIH TLV	Symptoms of Exposure & Health Effects
Crystalline Silica	20-60% (total)	0.05 mg/m^3 (respirable)	25 mg/m^3 (respirable)	0.025 mg/m^3 (respirable)	Cough, dyspnoea (breathing difficulty), wheezing; decreased pulmonary function, progressive respiratory symptoms (silicosis); irritation eyes; [potential occupational carcinogen]
Iron oxide	1-10%	5 mg/m^3	2500 mg/m^3	5 mg/m^3	Benign pneumoconiosis with X-ray shadows indistinguishable from fibrotic pneumoconiosis (siderosis)
Calcium oxide	10-30%	5 mg/m^3	25 mg/m^3	2 mg/m^3	irritation eyes, skin, upper respiratory tract; ulcer, perforation nasal septum; pneumonitis; dermatitis
Titanium dioxide	<3%	15 mg/m^3	ND	10 mg/m^3	Lung fibrosis; [potential occupational carcinogen]
Aluminosilicates	10-60%	15 mg/m^3 (PNOR)	ND	10 mg/m^3 (PNOR)	irritation eyes, skin, throat, upper respiratory system
Magnesium oxide	2-10%				
Magnesium dioxide	<2%				
Phosphorous pentoxide	≤2%				
Sodium oxide	1-10%				
Potassium oxide	≤1%				
Bromide salt	<0.1%				

Footnotes:

All values are 8-hour time-weighted averages (TWAs) unless otherwise indicated.

- PEL: Permissible Exposure Limit, the concentration an employee may be exposed to for an 8-hour work day for a 40-hour work week for which nearly all employees may be repeatedly exposed without adverse health effects.
- IDLH: IMMEDIATELY Dangerous to Life and Health, contaminant concentration which present the possibility for severe health consequences if exposed to the IDLH concentration without the appropriate personal protective equipment (PPE).
- ACGIH TLV: American Conference of Governmental Industrial Hygienists Threshold Limit Value
- mg/m^3 = milligrams per cubic meter of air
- PNOR: Particulates Not Otherwise Regulated
- ND: Not Determined

5.2 Sulfuric Acid

Sulfuric acid is used in the EAP to control pH. Sulfuric acid is a very hazardous corrosive capable of causing immediate chemical burns to eyes and skin as well as damage to the upper respiratory tract and lungs if aerosols are inhaled. Sulfuric acid storage tanks and piping are labelled.

Immediately flush skin and eyes for 15 minutes following contact with sulfuric acid. An emergency shower and eyewash are located adjacent to the sulfuric acid storage tank.

5.3 Safety Data Sheets

Pursuant to 35 I.A.C. § 845.530(b)(3), EEI will provide Safety Data Sheets (SDSs) to all employees, contract workers, and third-party contractors for the CCR located at the Site. Third-party contractors will provide SDSs to the POC/Environmental Manager and Plant Supervisor prior to bringing a material on site. SDSs are provided in Appendix E.

5.4 Signage

The absence of any of the following signage does not mean that a potential hazard does not exist. Signage will be posted by EEI, but employees, contract workers, and third-party contractors must remain vigilant for changing site conditions.

To aid in hazard communication and pursuant to 35 I.A.C. § 845.530(f), EEI will post the following signs at the EAP:

- Signs identifying the hazards of CCR, including dust inhalation when handling CCR.
- Signs identifying unstable CCR areas that make the operation of heavy equipment hazardous.
- Signs identifying the necessary safety measures and necessary precautions, including the proper use of PPE.

The following signs may also be posted at the CCR units to aid in hazard communication:

- Sulfuric acid hazard communication signs or labels on all tanks, drums, or other storage containers. “Sulfuric Acid” labels on piping.
- Overhead electrical lines that may be struck by heavy equipment of vehicles will have signs warning drivers of their presence.

6. EMERGENCY RESPONSE PLAN

This emergency response section details actions to be taken in the event of site emergencies. This section is consistent with the JPP EAP Emergency Action Plan. All personnel on site must be familiar with emergency signals and the content of this section.

6.1 Emergency Phone Numbers & Notifications

Emergency Number	
Site Address	**Emergency Phone Number**
2100 Portland Road Joppa, IL	911
Control Room (24/7)	318-543-3301

Medical Treatment	
Local Hospital	**Phone Number**
Massac Memorial Hospital 28 Chick Street Metropolis, IL 62960	618-524-2176

Incident Notifications		
Title	**Name**	**Contact Number**
Plant Supervisor – Environmental/Chemistry	Roger Faughn	270-210-3232
POC/Environmental Manager	Bruce Parker	618-638-3141
Plant Manager	Byron Veech	815-878-1985

6.2 Evacuation Signal

Notice to evacuate the EAP will be done through the plant PA system.

Upon hearing an evacuation signal, all personnel will leave the work area and proceed to the muster point.

6.3 Muster Point

The muster point for the EAP is located at in the Fly Ash Loading Control Room. The muster point is shown in Appendix A.

6.4 Calls for Emergency Support

In the case of an emergency, site personnel will call 911. The control room will coordinate the arrival of on-site emergency personnel. The individual calling for emergency support will briefly explain the nature of the emergency and site conditions as follows:

- Indicate his/her name
- Location of emergency
- Description of emergency conditions that may require special rescue equipment, such as confined spaces, excavations, and elevated work platforms
- Potential chemical hazards and recommended PPE

6.5 Fire & Explosion Response Plan

Trained site personnel may respond to incipient stage fires using a 20-pound Type ABC dry chemical fire extinguisher or hose. An incipient stage fire is a fire which is in the initial or beginning stage and which can be controlled or extinguished by portable fire extinguishers, Class II standpipe or small hose systems without the need for protective clothing or breathing apparatus. Personnel shall only attempt to extinguish the fire if it is safe to do so.

A fire that CANNOT be readily extinguished with a fire extinguisher will require evacuation of the work area personnel to Muster Point areas per this Safety and Health Plan. If personal injuries result from any fire or explosion, the procedures outlined in the Personal Injury Response Plan will also be followed.

All fires or explosions must be reported to the contacts outlined in Section 6.1 of this Safety and Health Plan.

6.6 Injury Response Plan

Treatment for minor injuries will be provided on site using available first aid supplies and personnel trained in first aid. All third-party contractors must have at least one individual on site who is trained in first aid, CPR, and AED use. Third-party contractors must provide their own first aid kits and AED. For minor injuries that are not life-threatening but require further medical attention, employees should be treated by occupational physicians at occupational clinics whenever possible. Treatment of minor injuries by emergency room or personal physicians should be avoided. When injured workers are released back to work with restrictions, all subcontractors are expected to accommodate those restrictions.

Emergency medical incidents include puncture wounds to the head, chest, and abdomen, serious head and spinal cord injuries, and loss of consciousness must be treated at the hospital emergency room listed in Section 6.1 of this Safety and Health Plan.

All injuries must be reported to the contacts outlined in Section 6.1 of this Safety and Health Plan.

6.7 Spill Response Plan

In general, EEI employees, contract workers, and third-party contractors are trained and equipped to handle small spills associated with their work. Third-party contractors must include an approved spill response plan in their Safety and Health Plan. Site personnel will generally respond to spills as follows:

- Stop the leak immediately if it can be done without directly contacting the leaking material.
- Remove or stop all ignition sources (hot work, generators, etc.) that are within 25 feet of any part of the spill.
- On-site personnel should immediately secure the area to prevent unauthorized entry into the spill area.
- Although not likely given the anticipated types of spills, site personnel must immediately initiate evacuation if a spill may cause an explosion, death, or serious injury.
- Site personnel may only respond to incipient stage fires regardless if such fires are associated with a spill.
- PPE for spills to open areas generally requires Modified Level D PPE (poly-coat Tyvek®, nitrile gloves, and boot covers or boot decontamination). Over-boots or boot covers may also be used if persons cleaning the spill would have to walk on spilled materials. Latex gloves are not acceptable and will degrade with exposure to petroleum products.

6.8 CCR Spill or Release Response Plan

Response to minor or incidental spills of CCR will be managed as outlined in the General Spill Response Plan. An incidental release is a release of a hazardous substance which does not pose a significant safety or health hazard to employees in the immediate vicinity or to the employee cleaning it up, nor does it have the potential to become an emergency within a short time frame. Incidental releases are limited in quantity, exposure potential, or toxicity and present minor safety or health hazards to employees in the immediate work area or those assigned to clean them up. An incidental spill may be safely cleaned up by employees who are familiar with CCR. Response to major releases of CCR will be in accordance with the JPP EAP Emergency Action Plan, which can be found on the Luminant CCR website at https://www.luminant.com/ccr/.

6.9 Ash Pond Rescue

Ash ponds may be unstable and represent an engulfment hazard if persons and equipment traverse the surface, berms, or other unstable areas. Special training is required on behalf of emergency responders to retrieve persons and equipment who become trapped in unstable ash. **Untrained persons must not enter unstable areas** in an attempt to conduct rescue because of the significant potential that they will also become victims. Call the JPP emergency number and state that an "ash pond rescue" is required. The JPP emergency contact will notify the designated service to perform the ash pond rescue. On-site personnel should remain on stand-by to support the ash pond rescue team as necessary.

6.10 Incident Reporting

All incidents must be reported to the contacts outlined in Section 6.1 of this Safety and Health Plan. An Incident Report must be completed for all injuries, illnesses, spills, fire, explosion, or property damage. The absence of an injury does not preclude the need to complete an Incident Report as such incidents will be classified as "near miss" or "other." It will include, but is not limited to, the nature of the problem, time, location, and corrective actions taken to prevent recurrence.

APPENDIX A
SITE MAP

PROJECT: 169000XXXX | DATED: 8/23/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Joppa\Appendix A_JOP Site Map_SnHP.mxd

PART 845 REGULATED UNIT (SUBJECT UNIT)
OTHER UNIT
PROPERTY BOUNDARY

0 250 500 Feet

SITE MAP

APPENDIX A

PART 845 SAFETY AND HEALTH PLAN
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

APPENDIX B
SAFETY AND HEALTH PLAN ACKNOWLEDGMENT FORM

SAFETY AND HEALTH PLAN ACKNOWLEDGEMENT FORM

I HEREBY CERTIFY THAT I HAVE READ AND UNDERSTOOD ALL HEALTH AND SAFETY PROCEDURES AS STATED HEREIN:

Name and Affiliation (printed)	Signature	Date

APPENDIX C
DRUG SCREEN POLICIES AND SUPPLEMENTAL TERMS

Drug and Background Investigations

Contractor is solely responsible for ensuring that all members of Contractor Project Team have completed and passed all drug and alcohol tests and background investigations required under this Attachment and under Contractor's own programs before assigning such personnel to perform Work. Contractor is also solely responsible for ensuring that such testing and investigations are performed in accordance with all applicable laws.

1. **Required Investigations.** Except as otherwise required by applicable law, Required Investigations shall consist of all of the following:

   1.1 a 7-panel drug screening;

   1.2 a background investigation that includes a criminal records check in all counties where the applicable person has resided for at least the last seven (7) years;

   1.3 a third-party verification of previous employment and the highest education level completed by the applicable person;

   1.4 a check of the National Sex Offender Registry and Terrorist Watch List (Denied Parties); and

   1.5 a check of Motor Vehicles Record (if work to be performed by the applicable person requires driving as part of the defined duties).

2. **Notices to Tested Persons Regarding Background Checks.** All background checks will be conducted in compliance with applicable provisions of the Fair Credit Reporting Act.
3. **Forms and Testing Organization for Drug Tests.** Except for those positions subject to Department of Transportation ("DOT") drug and alcohol testing regulations, all drug testing shall be performed using the Universal Toxicology four part "Non-DOT" Chain of Custody and Request Form with white and blue top page, and shall be conducted by an independent third-party organization.

4. **Pass/Fail Standards – Background Checks.** A person shall be deemed to have failed the applicable background check if:

   4.1 information is reported through the background check process indicating that such person has failed to disclose or misrepresented information requested at any time about such a person's criminal background history; or

   4.2 such person has ever committed any felony constituting a violent crime, crime against a person, sexual offense or fraud; or

   4.3 such person has committed any other felony, or has been incarcerated for a felony, within ten (10) years prior to the date of such background check (i.e., for these felonies there must be a ten (10) year lapse in time from the later of the commission and the end of any period of incarceration); or

   4.4 such person has committed any misdemeanor that:

      4.4.1 involves violence that is sexually related; or

4.4.2 consists of a DUI that is the second (or more) DUI in the last two (2) years prior to the date of the background check; or

4.4.3 consists of a theft-related offense; provided that there can be no more than one theft by check and it must have been for an amount less that $100; or

4.4.4 consists of any drug-related misdemeanor committed at any time within forty-eight (48) months prior to the date of the background check.

4.4 For purposes of both felonies and misdemeanors, a person is deemed to have committed the applicable offense if he/she is convicted or enters a plea of guilty or nolo contendere for such offense (to include, without limitation, sentences of probation and deferred adjudication).

5. Pass/Fail Standards – Drug Tests. A person shall be deemed to have failed the applicable drug test if any of the following maximum cut-off levels are exceeded, unless there is a legitimate medical explanation for the presence of a tested substance at or above the applicable cut-off level:

5.1 Amphetamines 500ng/mL

5.2 Barbiturates 150ng/mL

5.3 Benzodiazepines 150ng/mL

5.4 Cocaine 150ng/mL

5.5 Marijuana 150ng/mL

5.6 Opiates 2000ng/mL

5.7 Phencyclidine 25ng/mL

For any positions subject to DOT drug and alcohol testing requirements, testing shall be conducted according to the applicable DOT panel and cutoff levels.

6. Other Requirements.

6.1 Background checks and drug tests will be paid for by Contractor without reimbursement by Company.

6.2 Contractor will keep background checks and drug test records while the applicable persons are working pursuant to this Agreement and for three (3) years thereafter.

6.3 Upon request, Contractor will provide a certification to Company that no person required hereunder to pass a background check or drug test has failed such investigation or test. Contractor will not provide the specific results of the background check or drug test of any individual to Company.

6.4 If any person required under this Agreement to pass a background check or drug test fails such check or test, Contractor will not report the specific results of such check or test to Company and will not allow such individual to perform any Work for Company. Although such person may not be assigned to perform any Work for Company, nothing in this Attachment requires Contractor to take any other action with respect to such person's employment with Contractor.

Supplemental Terms for Onsite Services

1. SAFETY

1.1 Contractor agrees that any safety-related assistance or initiatives undertaken by Company will not relieve Contractor while on Company Property from responsibility for the implementation of, and compliance with, safe working practices, as developed from their own experience, or as imposed by law or regulation, and will not in any way, affect the responsibilities resting with Contractor under the provisions of any agreement to which these policies are attached and to meet all safety requirements as specified by the Occupational Safety & Health Administration (OSHA), the Mine Safety Health Administration (MSHA), including the "Mining Contractor Safety Reference Handbook" located at http://www.vistraenergy.com/wp-content/uploads/2016/12/Contractors-Safety-Handbook_Final-MC-08262016.pdf, the Department of Transportation (DOT) and any other applicable state or federal safety and health laws or regulations.

1.2 In the event that a material safety data sheet, warning label, or other documentation concerning the use of hazardous chemicals at any property owned or controlled by Company or any of its affiliates (collectively, "**Company Properties**"), applies to any materials or equipment provided by Contractor as an aspect of the Work, such documentation will be provided by Contractor to Company prior to the commencement of any such Work.

1.3 Contractor will report to Company all accidents involving personal injuries (including death) and damage to property occurring directly or indirectly as a result of the Work performed by Contractor hereunder immediately, but in no event, no later than 24 hours after the occurrence of any such accident. Any accident or incident occurring directly or indirectly as a result of the Work which Contractor must report to a regulatory agency (e.g. OSHA, MSHA, TCEQ) must also be reported to Company immediately following notification to the regulatory agency.

2. SECURITY

2.1 It will be the affirmative duty of Contractor to ensure that Contractor Group assists in carrying out all security measures, to include reporting all information or knowledge of matters adversely affecting security to Company's designated security personnel.

2.2 Company reserves the right to exclude any of Contractor's employees from any Company Property by denial of access, suspension or revocation of access authorization, preemptory expulsion, or by any other means, without notice or cause. Former Company employees, and any of Contractor's employees who previously have been excluded from any Company Property, may be brought onto Company property or facilities only if prior approval from Company is obtained. If Contractor terminates a member of Contractor Group performing Work on Company's premises, Contractor shall inform Company immediately, but in no event, no later than twenty-four (24) hours after such employee is terminated in order for Company to remove access to Company Property for such employee.

2.3 Company measures may also include investigations, whether by Company or law enforcement officials. Contractor agrees to cooperate in such investigations and understands that Company

reserves the right to require anyone in Contractor Group to authorize appropriate agencies to release his or her criminal records to Contractor as a condition of either initial or continued permission for access to any Company Property. Investigations may include searches of Contractor Group. Such searches may include searches of facilities assigned to Contractor Group, search of all Company Property areas and property at such Company Property areas, searches of including, but not limited to, offices, lockers, desks, lunch boxes, packages and motor vehicles (regardless of ownership). Without limiting the foregoing, Contractor acknowledges and agrees that all members of Contractor Group, to the extent that Company reasonably determines that such members require security badge access prior to entering onto any Company Property, shall be required to comply with Company's standard security badge requirements, including without limitation a background check to be performed by Company.

3. ISNETWORLD

3.1 Contractor agrees to maintain at Contractor's expense a subscription with ISNetworld (www.ISNetworld.com), Company's safety compliance program or any replacement program therefor, as directed by Company, for the Term of the Agreement. Contractor shall also furnish ISNetworld with any information requested by ISNetworld relating to ISNetworld's evaluation of the Contractor's safety program and practices. As a minimum, requested documents will be related to safety, health, and insurance (i.e., regulatory required training, certifications, safety plans, safe and secure workplace practices, insurance certificates, etc.), OSHA and MSHA injury rates and Experience Modification Rate (EMR).

3.2 Contractor has and during the performance of this Agreement shall continue to report full, complete and accurate information to ISNetworld concerning Contractor's employees.

4. MATERIALS, EQUIPMENT AND LABOR. Contractor will be solely responsible for the proper storage, transportation and disposal of any product or waste, other than sandblasting waste, used or generated in connection with the Work in accordance with all applicable Environmental Laws. Contractor will dispose of all waste materials, other than sandblasting waste, at an off-site disposal facility approved for such waste materials pursuant to applicable Environmental Laws and will complete and sign all waste manifests as the generator of such waste. Company will be responsible for the storage, transportation and disposal of any sandblasting waste generated during the performance of the Work.

5. CONDITIONS AFFECTING WORK

5.1 Contractor will investigate and acquaint itself with the conditions affecting the Work, including but not limited to those related to the transportation, disposal, handling and storage of materials and waste; availability of labor, water, electric power and roads; the uncertainties of weather, river stages or similar physical conditions at the site; the conformation and condition of the ground; and the character of equipment and facilities needed preliminary to and during prosecution of the Work. Contractor has satisfied itself as to the character, quality and quantity of surface and subsurface materials or obstacles to be encountered. Contractor's failure to acquaint itself with any conditions affecting the Work or any available related information will not relieve it from responsibility for properly estimating the difficulty or cost of successfully performing the Work.

5.2 Contractor assumes full responsibility for investigating conditions and determining the existence and magnitude of any hazards to the physical well-being of property of Contractor, the employees, agents, and servants of Contractor, or any other person or entity who is or may become involved in

the performance of Work, and any and all other persons in the vicinity of the Work. Contractor will advise all of the above-specified persons or entities of any hazards relating to Work, and will ensure that those persons or entities are advised of and fully understand the nature of the hazards and safety precautions that can be taken to eliminate or minimize dangers relating to the hazards.

5.3 Contractor will provide information to Company regarding hazardous chemicals and/or consumable products that contain constituents listed in 40 CFR 372.65 used at any Company Property. Contractor will report the amount of such material carried on and off the site, the amount actually used and the manner of use. Contractor will provide the maximum quantity of the material stored on site at any one time and if a waste material was collected, where it was disposed of (location name and address). Contractor will provide information on the amount of material used for the previous calendar year by the first of February.

5.4 Contractor will use its best efforts to ensure that the Work is performed so as to minimize any adverse impact upon natural resources and the environment and will use best industry practices in this regard at all times.

5.5 Contractor acknowledges and agrees that all members of Contractor Group performing Work at any Company Generation or Mining Property are required to view Company's "Contractor/Visitor Safety Orientation" video (in the case of Company Generation property), when applicable, and to read and adhere to Company's "Contractor/Visitor Safety Booklet" (in the case of Company Mining property) prior to performing any Work at any Company Generation or Mining Property.

5.6 Contractor will immediately notify Company as soon as Contractor has reason to believe that Contactor, or any employee or other person performing the Work, is not or may not be performing the Work in compliance with applicable Environmental Laws. Contractor will provide Company with written notice to Company of such actual or potential non-compliance within three (3) days following the discovery thereof. Contractor will take immediate steps to ensure compliance with all applicable Environmental Laws and will, if directed by Company, cease all Work until authorized by Company to resume the Work.

5.7 Contractor will report to Company all accidents involving personal injuries (including death) and damage to property occurring directly or indirectly as a result of the Work performed by Contractor hereunder immediately, but in no event, no later than 24 hours after the occurrence of any such accident. Any accident or incident occurring directly or indirectly as a result of the Work which Contractor must report to a regulatory agency (e.g. OSHA, MSHA, TCEQ) must also be reported to Company immediately following notification to the regulatory agency.

6. WORK SITE PERMITS AND LICENSES

6.1 Subject to the following two paragraphs, Contractor will obtain, prior to the commencement of the Work, and provide to Company upon request, all permits, licenses and governmental authorizations, at its sole expense, required for the performance of the Work. Contractor will be solely responsible for maintaining compliance with such permits, licenses and governmental authorizations.

6.2 In the event that a storm water discharge permit is required for the performance of the Work, (i) Contractor will be responsible for filing a Notice of Intent with respect to the Work, in addition to any Notice of Intent that Company may be required to file, and (ii) Contractor will coordinate with

Company in the preparation and execution of a Storm Water Pollution Prevention Plan for the Work Site.

6.3 In the event that the performance of the Work involves the handling or abatement of asbestos-containing materials, Contractor will coordinate with Company in the preparation and filing of all required notification forms.

7. ACCESS. Should Contractor desire access to the Work Site over any land not controlled by Company, it will, at its sole expense, obtain all proper permits or written permission necessary for that access.

8. COMPANY FACILITIES. Contractor will not use Company's sanitary facilities, changehouses, shops, parks, storage buildings, tools, equipment or other facilities unless so directed by Company. Contractor will not discharge, without Company's prior written authorization, any product or waste used or generated in connection with the Work through any (i) Company-permitted outfall, (ii) Company-owned or operated pollution control equipment, or (iii) storm or sanitary sewer located at or in the vicinity of the Work Site. Any request for authorization to discharge will include, at a minimum, either a copy of the Material Safety Data Sheet for the product or a written description of the waste, including a list of the constituents of the waste and the relative concentrations thereof.

9. ENVIRONMENTAL

9.1 In the event that Contractor discovers during the performance of the Work any substance at the Work Site that is not the subject of the Work or has not otherwise been identified by Company for Contractor, which substance Contractor has reason to believe is or may be a Hazardous Substance that (i) has been or may be released or spilled into the soil, surface water, or groundwater or in a building or structure, or (ii) consists of asbestos-containing materials, lead-based paint, batteries, thermostats, lighting equipment, or equipment containing polychlorinated biphenyls, Contractor will immediately stop Work and notify Company of the discovery. Contractor will not resume the Work until receiving authorization from Company to do so.

9.2 The term "Hazardous Substance" means any product, waste, emission or substance defined, listed or designated as a hazardous or toxic substance, hazardous waste, hazardous material or pollutant by or pursuant to any Environmental Law and includes, but is not limited to, any petroleum-based product, substance or waste, including any additives associated therewith, pesticides, fertilizers, solvents, polychlorinated biphenyls, mercury, lead, lead-based paint, asbestos-containing material or explosives.

9.3 Contractor will immediately notify Company in the event of a spill or release of any material which Contractor knows or has reason to believe is a Hazardous Substance, whether onto the ground, into any body of water, a storm or sanitary sewer, or the air, or anywhere on property owned or controlled by Company, including within any building or structure. Contractor will be solely responsible, as may be required by applicable Environmental Laws, for, in consultation with Company, (i) notifying the appropriate governmental agencies of such spill or release caused or permitted by the acts or omissions of Contractor and (ii) for the cleanup and remediation of such spill or release.

10. PROTECTION OF HIGHWAYS AND RAILROADS. Contractor will make suitable arrangements with governmental authorities and railroads for the construction of all structures, whether underneath or over roads, railroads or rights-of-way to protect the public from accident or delay. Contractor will repair, at its

own expense, to the satisfaction of the governmental authorities or other owners, all roads, railroads and bridges that may be damaged by, or given undue wear due to the Work.

11. CLEANING UP

11.1 Contractor will at all times keep the Work Site free of waste materials or rubbish caused by the Work. After completing the Work, Contractor will remove all its waste materials, rubbish, tools, supplies, equipment and surplus materials from and about the Work Site.

11.2 If Contractor fails to keep the Work Site clean or to clean up after completing the Work, Company may do so and charge all costs of cleaning up to Contractor. Those costs may be deducted from the final payment to Contractor.

12. COLLATERAL WORK. Company and other contractors may be working at the Work Site. Company reserves the right to coordinate the performance of Contractor's Work with the work of others. Contractor will cooperate with and will not delay, impede or otherwise impair the work of others. Company does not guarantee Contractor continuous uninterrupted access to the Work Site, but will provide such access as good construction practices will allow, considering the other activities in the area.

13. ALCOHOLIC BEVERAGES, DRUGS AND WEAPONS. Contractor will inform all members of Contractor Group who may be involved in the performance of any Work of the following Company rules relating to alcoholic beverages, drugs and weapons, with which all personnel are expected to comply:

13.1 Bringing, attempting to bring, possessing, using or being under the influence of intoxicants, drugs, or narcotics while on any Company Property, including but not limited to parking areas, is prohibited. Possessing alcoholic beverages in sealed containers is permitted, however, in designated parking areas.

13.2 Prescription or over-the-counter medications that could affect the performance of safety-sensitive work are allowed on Company Property only if they have been previously cleared by Contractor. Contractor must confirm that the medication and dosage do not impair an individual's ability to perform safety-sensitive work before clearing the individual to perform such work while under the influence of the medication.

13.3 Bringing, attempting to bring, possessing or using firearms, whether classified as legal or illegal, while on any Company Property, including but not limited to buildings, parking areas, recreation facilities, equipment and vehicles, is prohibited, unless otherwise required by applicable law. Use or possession of firearms for specific situations is permitted if approved by function or higher level management of Company.

13.4 Off-the-job involvement with intoxicants, illegal drugs, or illegal narcotics that adversely affects Company's business, to include impairing the individual's ability to perform his job or the public trust in the safe operation of Company, is prohibited.

13.5 Any conduct on any Company Property which is in violation of any state or federal law or regulation is considered a violation of these rules and a breach of any agreement to which these policies are attached.

13.6 In order to enforce these rules, all individuals with access to any Company Property as well as the vehicles, offices, lockers and any personal belongings of such individuals on any Company Property are subject to search by Company and its agents, to include security representatives appointed or employed by Company. Individuals may be required to take a blood, urinalysis or Breathalyzer test, or submit to other recognized investigatory tests or procedures as are deemed appropriate or necessary by Company in the investigation of a violation of these rules.

14. TITLE AND RIGHT. Nothing in the Agreement will vest Contractor with any right of property in materials used after they have been attached to or incorporated into the Work, nor materials for which Contractor has received full or partial payment. All those materials, upon being so attached, incorporated or paid for, will become the property of Company. Any gravel, sand, stone, minerals, timber or other materials excavated, uncovered, developed or obtained in the Work, or on any land belonging to Company may be used, in the performance of the Work, provided such materials meet the requirements of this Agreement. Any objects or natural materials or animals excavated or exposed that may have historical significance or constitute a threatened or endangered species must be brought to the attention of Company.

15. PROTECTION AGAINST LIENS AND ENCUMBRANCES

15.1 Contractor will not at any time permit any lien, attachment or other encumbrance ("**Encumbrance**") by any person or persons whosoever or by reason of any claim or demand against Contractor to be placed or remain on the property of Company, including, but not limited to, the Work Site upon which Work is being performed or equipment and materials that are being furnished. To prevent an Encumbrance from being placed on the property of Company, Contractor will furnish during the progress of any Work, as requested from time to time, verified statements showing Contractor's total outstanding indebtedness in connection with the Work.

15.2 If Contractor allows any indebtedness to accrue to subcontractors or others and fails to pay or discharge that indebtedness within five (5) days after demand, then Company may withhold any money due Contractor until that indebtedness is paid or pay the indebtedness and apply that amount against the money due Contractor.

15.3 If Contractor allows any Encumbrances, whether valid or invalid to be placed on the property of Company, any and all claims or demands for payment to Contractor will be denied by Company until the Encumbrance is removed. If the Encumbrance is not removed immediately, Company may pay that claim or demand and deduct the amount paid, together with all related expenses, including attorneys' fees, from any further payment due Contractor, or at Company's election, Contractor will, upon demand, reimburse Company for the amount paid and all related expenses. Any payment made in good faith by Company will be binding on Contractor.

16. TERMINATION FOR DEFAULT

16.1 If a petition in bankruptcy should be filed by Contractor, or if Contractor should make a general assignment for the benefit of creditors, or if a receiver should be appointed due to the insolvency of Contractor, or if Contractor should refuse or fail to supply enough properly skilled workmen or proper equipment, materials or services or should fail to make prompt payment to subcontractors, or to pay promptly for materials or labor, or disregard laws, ordinances or the instruction of Company's Contract Coordinator, or if Contractor should refuse or fail to abide by the SOW Construction Schedule or otherwise violate any provisions of the Agreement or SOW, then Company, upon a

determination by Company's Contract Coordinator that sufficient cause exists to justify such action, may, without prejudice to any other right or remedy available to it after giving Contractor seven (7) days' written notice, terminate the Agreement or the SOW and take possession of the Work Site. In the event of such a termination, Company may use all or part of Contractor's equipment and materials and may finish the Work by whatever method Company may deem expedient. In such event, Contractor will not be entitled to receive any further payment hereunder until the Work is finished. If the unpaid balance of the SOW fees will exceed the expense of finishing the Work, including compensation of Company's Contract Coordinator, other Company personnel, third party engineering companies, or other contractors for additional services, such excess will be paid to Contractor. If the expense of finishing the Work will exceed such unpaid balance, Contractor will pay the difference to Company within fifteen (15) days of receiving an invoice for same. The expenses incurred by Company herein, and the damage incurred through Contractor's default, will be determined by Company's Contract Coordinator, in its sole discretion, and such determination will be binding as between the parties.

16.2 In the event of a termination under the provisions of this Section 3, Contractor will transfer and assign to Company, in accordance with Company's instructions, all Work, all construction records, reports, permits, data and information, other materials (including all Company-supplied materials), supplies, Work in progress and other goods for which Contractor is entitled to receive reimbursement hereunder, and any and all plans, drawings, sketches, specifications, and information in connection with the Work, and will take such action as may be necessary to secure Company, at Company's sole election, the rights of Contractor under any or all orders and subcontracts made in connection with the Work.

16.3 In the event that Company so directs or authorizes, Contractor will sell at a price approved by Company, or retain at a mutually agreeable price, any such materials, supplies, Work in progress, or other goods as referred to in the preceding paragraph. In any event, Company will receive any and all records, plans, drawings, data, permits, specifications, sketches, reports, or other information relating to the Work. The proceeds of any such sale or the agreed price will be paid or credited to Company in such manner as Company may direct so as to reduce the amount payable by Company under this Section 3.

APPENDIX D
COVID-19 SITE ENTRY GUIDELINES

COVID-19 Vistra Site Entry Guidelines – *Effective: June 17, 2021*
These guidelines are applicable to ALL PERSONNEL entering Vistra work sites.

To enter a Vistra work site, each person must answer the following three questions with a "no" answer *and* pass the required temperature testing *unless* they display their Vistra vaccination sticker on their employee badge or hardhat:

Site Entry Questions:

1. In the past 10 days, have you tested positive for COVID-19 or are you currently waiting on test results?

2. In the past 10 days, have you been within six feet of someone, where masks were not worn, who:
    a. has tested positive for COVID-19,
    b. is known to be waiting on test results for COVID-19, or
    c. is under a quarantine order?

3. In the past 10 days, have you or someone who has been within six feet of you where masks were not worn had:
    a. flu-like symptoms,
    b. a deep, dry cough,
    c. recent shortness of breath or difficulty breathing,
    d. new loss of taste or smell, and/or
    e. fever of 100 degrees or above?

Temperature Testing:

You must register a temperature between 96- and 100-degrees Fahrenheit as described in the temperature procedures. (see next page for testing procedures)

- If your temperature is below 96 degrees, retest with a different device.
- If your temperature is 100-degrees Fahrenheit or above, retest on another device preferably an ear thermometer, if your temperature still registers 100-degrees Fahrenheit or above you may not enter the site.

Clearance to enter the site:

- If you have answered **"no"** to all three questions ***and*** passed the temperature test, you may enter the site.
- ***If you have an approved Vistra vaccination sticker, you are cleared to enter the site without the temperature test or answering COVID screening questions.***
- If you passed the temperature test ***and*** answered "Yes" to any of the questions, but have been cleared through VistraTravelerSafety (HR clearance) to enter the Vistra work site for that instance of exposure, testing, or symptoms, you may enter the site.

Anyone *not* cleared to enter the work site must immediately leave the work site and notify their supervisor who will notify HR at VistraTravelerSafety@vistracorp.com for next steps.

Any symptomatic employee, unvaccinated employee exposed to COVID-19 or any employee tested for COVID-19 as described above must be cleared through VistraTravelerSafety prior to returning to work.

Required Temperature Testing Procedures:

All persons entering the site without a Vistra vaccination sticker, who have cleared all questions above, will also submit to temperature testing or self-administer a temperature test as required by the facility management. If a self-administered test is required, then a member of the management team or their designee will witness the testing; however, where that is not practicable, each person must attest that they are only entering the site premises because they have passed the screening questions and temperature test required for entry. Also:

a. Hats may cause false high temperatures and should not be worn for five minutes immediately preceding a forehead temperature test.
b. Each person is responsible for ensuring all self-testing materials and areas touched during testing are sanitized.
c. All personnel should maintain a **distance of at least six feet** from other people during this process or wear required masks.

Temperature Testing Requirements:

1. **All persons entering the site without a Vistra vaccination sticker must register a temperature between 96- and 100-degrees Fahrenheit. Any such person who has a temperature not within that range or who triggers an alarm on a thermal camera** must **retest with a different device**, preferably an **ear thermometer**, if available. If the second test registers a temperature of 100 degrees or above:
    a. That person **may not enter** the Vistra work site and must notify their supervisor, who will notify HR at VistraTravelerSafety@vistracorp.com for next steps.
    b. If there is significant inconsistency between the two tests, repeat another temperature test and use the two closest readings.
2. **Anyone who registers a temperature between 96- and 100-degrees Fahrenheit** may proceed to their work site.
    - **If temperature is below 96 degrees, wait a few minutes and retest with a different device.**

Control rooms and communal areas:

All persons entering the site without a Vistra vaccination sticker should maintain at least six-feet distance from other people as much as possible and should wear face coverings when six-feet distance is not feasible. No one should gather in communal areas (including the temperature-testing area) without a Vistra vaccination sticker. Only operators are allowed in control rooms without plant manager approval.

Vistra Vaccination Sticker protocols:

All persons with a valid Vistra vaccination sticker do not have to socially distance or wear masks while at the site. They will also not be required to quarantine as a part of COVID-19 exposures unless exhibiting COVID-19 symptoms. To be eligible for these protocols, each person must have their approved Vistra vaccination sticker easily visible at all times while at work. If someone who has applied for a Vistra vaccination sticker believes they have specific health conditions that may affect the ability to have a full immune response to the vaccination, please consult your health provider prior to working without a mask.

Any symptomatic employee, unvaccinated employee exposed to COVID-19 or any employee tested for COVID-19 as described above must be cleared through VistraTravelerSafety prior to returning to work.

APPENDIX E
SAFETY DATA SHEETS

DYNEGY

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	ASTM Bottom Ash
Synonyms:	Ash; Ashes; Ash residues; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Coal Fly Ash; Pozzolan; Waste solids.
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Relevant Identified Uses:	Component of wallboard, concrete, roofing material, bricks, cement kiln feed.
Uses Advised Against:	None known.

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Dynegy, Inc.
Street Address:	601 Travis Street, Suite 1400
City, State and Zip Code:	Houston, TX 77002
Customer Service Telephone:	800-633-4704

Section 2
Hazards Identification

2.1 Classification of the Substance

GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):

- Eye Irritant, Category 2A
- STOT-SE, Category 3 (Respiratory Irritation)
- Carcinogen, Category 1A
- STOT-RE, Category 1 (Lungs)
- Toxic to Reproduction, Category 2

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	**DANGER**
Hazard Statement(s):	*Causes serious eye irritation.* *May cause respiratory irritation.* *May cause damage to lungs after repeated/prolonged exposure via inhalation.* *May cause cancer of the lung.* *Suspected of damaging fertility or the unborn child.*
Precautionary Statement(s):	*Obtain special instructions before use.* *Do not handle until all safety precautions have been read and understood.* *Avoid breathing dust.* *Wash thoroughly after handling.* *Do not eat drink or smoke when using this product.* *Wear protective gloves/protective clothing/eye protection/face protection.* *Use outdoors or in a well-ventilated area.* *If exposed or concerned: Get medical advice/attention.* *Store in a secure area.* *Dispose of product in accordance with local/national regulations.*

** Fly ash and other coal combustion products (CCPs) are UVCB substances (unknown or variable composition or biological). Various CCPs, noted as ashes/ash residuals; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Waste solids, ashes under TSCA are defined as: "The residuum from the burning of a combination of carbonaceous materials. The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." Ashes including fly ash and fluidized bed combustion ash are identified by CAS number 68131-74-8. The exact composition of the ash is dependent on the fuel source and flue additives composed of many constituents. The classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.*

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [Yes] **Other:** **(ACGIH)** [Yes]

Section 3
Composition/Information on Ingredients

Substance	***CAS No.***	***Percentage (%)***	***GHS Classification***
Crystalline Silica	*14808-60-7*	*20 - 40%*	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Silica, crystalline respirable (RCS)	*14808-60-7*	***See Footnote 1***	*Repeat Dose STOT, Category 1* *Carcinogen. Category 1A*
Aluminosilicates[2]	***Various, see Footnote 2***	*10 - 60%*	*Single Exposure STOT, Category 3*
Calcium oxide (CaO)	*1305-78-8*	*10 - 30%*	*Skin Irritant, Category 2* *Eye Irritant, Category 1* *Single Exposure STOT, Category 3*
Iron oxide	*1309-37-1*	*1 - 10%*	*Not Classified*
Manganese dioxide (MnO_2)	*1313-13-9*	*<2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Magnesium oxide	*1309-48-4*	*2 - 10%*	*Not Classified*
Phosphorus pentoxide (P_2O_5)	*1314-56-3*	*≤2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Sodium oxide	*1313-59-3*	*1 - 10%*	*Not Classified*
Potassium oxide (K_2O)	*12136-45-7*	*≤1%*	*Skin Irritant Category 2* *Eye Irritant Category 2B*
Titanium dioxide (TiO_2)	*13463-67-7*	*<3%*	*Not Classified*
Bromide salt (calcium)	*7789-41-5*	***See Footnote 3***	*Toxic to Reproduction Category 2*

[1] *The percentage of respirable crystalline silica has not been determined. Therefore, a GHS classification of Carcinogen 1A has been assigned.*

[2] *Aluminosilicates (CAS# 1327-36-2) may be in the form of mullite (CAS# 1302-93-8); aluminosilicate glass; pozzolans (CAS# 71243-67-9); or calcium aluminosilicates such as tricalcium aluminate (C3A), or calcium sulfoaluminate (C4A3S). The form is dependent on the source of the coal and or the process used to create the CCP. Pulverized coal combustion would be more likely to create high levels of pozzolans. Aluminosilicates may have inclusions of calcium, titanium, iron, potassium, phosphorus, magnesium and other metal oxides.*

[3] *Analytical data are not available to demonstrate that the concentration of bromide salt is <0.1%; therefore, a GHS classification of Toxic to Reproduction Category 2 has been assigned.*

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse copiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute Effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.

Chronic Effects: Chronic exposure may cause lung damage from repeated exposure. Prolonged inhalation of respirable crystalline silica above certain concentrations may cause lung diseases, including silicosis and lung cancer. Repeated exposure to dusts containing inorganic bromide salts may affect fertility and/or result in effects to the unborn child.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing. Get medical advice if inhalation occurs and respiratory symptoms persist.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising from the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.2.2 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental Precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Calcium oxide		5	2	2	2
Particulates Not Otherwise Regulated	Total	15	15	10	10
	Respirable	5	5	3	5
Respirable Crystalline Silica	Respirable	0.05	0.05	0.025	0.05
Manganese dioxide (as manganese compounds)	Total	5 (Ceiling)	1 3 (STEL)	0.1	0.2
	Respirable	-	-	0.02	-

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless[1]	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C) (in water): 8 - 11	**Specific gravity or relative density:** 2.2 – 2.9
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point and boiling range (°C): Not applicable	**Partition coefficient: n-octane/water:** Not determined
Flash point (°C): Not determined	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

[1] The use of urea or aqueous ammonia injected into the flue gas to reduce nitrogen oxides (NOx) emissions may result in the presence of ammonium sulfate or ammonium bisulfate in the ash at less than 0.1%. When ash containing these substances becomes wet under high pH (>9), free ammonia gas may be released resulting in objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces.

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is an inert, inorganic material primarily composed of elemental oxides.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is a relatively stable, inert material; however, when ash containing ammonia becomes wet under high pH (>9), free ammonia gas may be released resulting in an objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces. Polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Does not meet the classification criteria but may cause slight skin irritation. Product dust can dry the skin which can result in irritation.
Eye damage/irritation	Causes serious eye irritation. Positive scores for conjunctiva irritation and chemosis in 2/3 animals based on average of 24, 48 and 72-hour scores with irritation clearing within 21 days; no corneal or iritis effects observed.
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer.
Germ cell mutagenicity	Not mutagenic in in-vitro and in-vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by OSHA, NTP, ACGIH and IARC.
Reproductive toxicity	No developmental toxicity was observed in available animal studies. Reproductive studies on CCPs showed either no reproductive effects, or some effects on male and female reproductive organs and parameters but without a clear dose response. Inorganic bromide salts have been shown to have adverse effects on reproductive parameters in some animal studies.
STOT-SE	CCPs when present as a nuisance dust may result in respiratory irritation.
STOT-RE	In a 180-day inhalation study with fly ash dust, no effects were observed at the highest dose tested. NOEC = 4.2 mg/m^3; it is not possible to assess the level at which toxicologically significant effects may occur. Repeated inhalation exposures to high levels of respirable crystalline silica may result in lung damage (i.e., silicosis).
Aspiration Hazard	Not applicable based product form.

Section 12
Ecological Information

12.1 Toxicity

Fly Ash (CAS# 68131-74-8)	
Toxicity to Fish	LC50 > 100 mg/L
Toxicity to Aquatic Invertebrates	Data indicates that the test substance is not toxic to *Daphnia magna* (EC50 undetermined)
Toxicity to Aquatic Algae and Plants	EC50 = 10 mg/L
Calcium oxide CAS# 1305-78-8	
Toxicity to Fish	LC50 = 50.6 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Invertebrates	EC50 = 49.1 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Algae and Plants	NOEC =48 mg/L @ 72 hours based on $Ca(OH)_2$ The initial pH of the test medium was not directly related to the biologically relevant effects. The formation of precipitates is likely the result of the reaction between CO_2 dissolved in the medium.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

This material does not contain any compounds that would bioaccumulate up the food chain.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

This material does not contain any compounds classified as “persistent, bioaccumulative or toxic” nor as “very persistent/very bioaccumulative”.

12.6 Other Adverse Effects

None known.

Section 13
Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate industrial hygiene practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65

  The following substances are known to the State of California to be carcinogens and/or reproductive toxicants:

  - Respirable crystalline silica
  - Titanium dioxide

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Ammonium bisulfate	7803-63-6	No	Yes	No	No
Ammonium sulfate	7783-20-2	Yes	No	Yes	No
Calcium oxide	1305-78-8	Yes	Yes	Yes	No
Iron oxide	1309-37-1	Yes	Yes	Yes	No
Magnesium oxide	1309-48-4	No	Yes	No	No
Phosphorus pentoxide (or phosphorus oxide)	1314-56-3	Yes	Yes	Yes	No
Potassium oxide	12136-45-7	No	Yes	No	No
Silica-crystalline (SiO_2), quartz	14808-60-7	Yes	Yes	Yes	No
Sodium oxide	1313-59-3	No	Yes	No	No
Titanium dioxide	13463-67-7	Yes	Yes	Yes	Yes

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: February 23, 2018

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- CA: California
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFR: Code of Federal Regulations
- EPA: Environmental Protection Agency
- GHS: Globally Harmonized System of Classification and Labelling
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit
- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological
- U.S.: United States
- U.S. DOT: United States of Department of Transportation

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	2*	**Flammability:**	0	**Physical Hazards:**	0	**Personal protection:****	

** Chronic Health Effects*
*** Appropriate personal protection is defined by the activity to be performed.*
See Section 8 for additional information.

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

DYNEGY

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	ASTM Class C Fly Ash
Synonyms:	Coal Fly Ash, Pozzolan
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Relevant Identified Uses:	Component of wallboard, concrete, roofing material, bricks, cement kiln feed.
Uses Advised Against:	None known.

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Dynegy, Inc.
Street Address:	601 Travis Street, Suite 1400
City, State and Zip Code:	Houston, TX 77002
Customer Service Telephone:	800-633-4704

Section 2
Hazards Identification

2.1 Classification of the Substance

GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):

- Eye Irritant, Category 2A
- STOT-SE, Category 3 (Respiratory Irritation)
- Carcinogen, Category 1A
- STOT-RE, Category 1 (Lungs)
- Toxic to Reproduction, Category 2

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	**DANGER**
Hazard Statement(s):	*Causes serious eye irritation.* *May cause damage to lungs after repeated/prolonged exposure via inhalation.* *May cause respiratory irritation.* *May cause cancer of the lung.* *Suspected of damaging fertility or the unborn child.*
Precautionary Statement(s):	*Obtain special instructions before use.* *Do not handle until all safety precautions have been read and understood.* *Avoid breathing dust.* *Wear protective gloves/protective clothing/eye protection/face protection.* *Wash thoroughly after handling.* *Do not eat drink or smoke when using this product.* *Use outdoors or in a well-ventilated area.* *If exposed or concerned: Get medical advice/attention.* *Store in a secure area.* *Dispose of product in accordance with local/national regulations.*

** Fly ash and other coal combustion products (CCPs) are UVCB substances (unknown or variable composition or biological). Various CCPs, noted as ashes/ash residuals; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Waste solids, ashes under TSCA are defined as: "The residuum from the burning of a combination of carbonaceous materials. The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." Ashes including fly ash and fluidized bed combustion ash are identified by CAS number 68131-74-8. The exact composition of the ash is dependent on the fuel source and flue additives composed of many constituents. The*

classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [Yes] **Other:** **(ACGIH)** [Yes]

Section 3
Composition/Information on Ingredients

Substance	***CAS No.***	***Percentage (%)***	***GHS Classification***
Crystalline Silica	*14808-60-7*	*30 - 60%*	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Silica, crystalline respirable (RCS)	*14808-60-7*	***See Footnote 1***	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Aluminosilicates	*71243-67-9* *1327-36-2*	*30 - 60%*	*Single Exposure STOT, Category 3*
Iron oxide	*1309-37-1*	*1 - 10%*	*Not Classified*
Calcium oxide (CaO)	*1305-78-8*	*20 - 30%*	*Skin Irritant, Category 2* *Eye Irritant, Category 1* *Single Exposure STOT, Category 3*
Magnesium oxide	*1309-48-4*	*2 - 10%*	*Not Classified*
Phosphorus pentoxide (P_2O_5)	*1314-56-3*	*≤2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Sodium oxide	*1313-59-3*	*1-8%*	*Not Classified*
Potassium oxide (K_2O)	*12136-45-7*	*≤1%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Titanium dioxide (TiO_2)	*13463-67-7*	*<3%*	*Not Classified*
Bromide salt (calcium)	*7789-41-5*	***See Footnote 2***	*Toxic to Reproduction, Category 2*

Footnote 1: *The percentage of respirable crystalline silica has not been determined. Therefore, a GHS classification of Carcinogen, Category 1A has been assigned.*

Footnote 2: *Analytical data are not available to demonstrate that the concentration of bromide salt is <0.1%; therefore, a GHS classification of Toxic to Reproduction, Category 2 has been assigned.*

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse copiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute Effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.

Chronic Effects: Chronic exposure may cause lung damage from repeated exposure. Prolonged inhalation of respirable crystalline silica above certain concentrations may cause lung diseases, including silicosis and lung cancer. Repeated exposure to dusts containing inorganic bromide salts may affect fertility and/or result in effects to the unborn child.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing. Get medical advice if inhalation occurs and respiratory symptoms persist.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising from the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.2.2 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental Precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Calcium oxide		5	2	2	2
Particulates Not Otherwise Regulated	Total	15	15	10	10
	Respirable	5	5	3	5
Respirable Crystalline Silica	Respirable Crystalline Silica	0.05	0.05	0.025	0.05
Titanium dioxide	Total	15	2.4 (fine) 0.3 (ultrafine)	10	10
Manganese dioxide (as manganese compounds)	Total	5 (Ceiling)	1 3 (STEL)	0.1	0.2
	Respirable	-	-	0.02	-

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless[1]	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C) (in water): Not Determined	**Specific gravity or relative density:** 2.2 – 2.9
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point/boiling range (°C): NA	**Partition coefficient: n-octane/water:** NA
Flash point (°C): Not determined	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

[1] The use of urea or aqueous ammonia injected into the flue gas to reduce nitrogen oxides (NOx) emissions may result in the presence of ammonium sulfate or ammonium bisulfate in the ash at less than 0.1%. When ash containing these substances becomes wet under high pH (>9), free ammonia gas may be released resulting in objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces.

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is an inert, inorganic material primarily composed of elemental oxides.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is a relatively stable, inert material; however, when ash containing ammonia becomes wet under high pH (>9), free ammonia gas may be released resulting in an objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces. Polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Does not meet the classification criteria but may cause slight skin irritation. Product dust can dry the skin which can result in irritation.
Eye damage/irritation	Causes serious eye irritation. Positive scores for conjunctiva irritation and chemosis in 2/3 animals based on average of 24, 48 and 72-hour scores with irritation clearing within 21 days; No corneal or iritis effects observed.
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer.
Germ cell mutagenicity	Not mutagenic in in-vitro and in-vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by OSHA, NTP, ACGIH and IARC.
Reproductive toxicity	No developmental toxicity was observed in available animal studies. Reproductive studies on CCPs showed either no reproductive effects, or some effects on male and female reproductive organs and parameters but without a clear dose response. Inorganic bromide salts have been shown to have adverse effects on reproductive parameters in some animal studies.
STOT-SE	CCPs when present as a nuisance dust may result in respiratory irritation.
STOT-RE	In a 180-day inhalation study with fly ash dust, no effects were observed at the highest dose tested. NOEC = 4.2 mg/m^3; it is not possible to assess the level at which toxicologically significant effects may occur. Repeated inhalation exposures to high levels of respirable crystalline silica may result in lung damage (i.e., silicosis).
Aspiration Hazard	Not applicable based product form.

Section 12
Ecological Information

12.1 Toxicity

Fly Ash C (CAS# 68131-74-8)	
Toxicity to Fish	LC50 > 100 mg/L
Toxicity to Aquatic Invertebrates	Data indicates that the test substance is not toxic to *Daphnia magna* (EC50 undetermined).
Toxicity to Aquatic Algae and Plants	EC50 = 10 mg/L

Calcium oxide CAS# 1305-78-8	
Toxicity to Fish	LC50 = 50.6 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Invertebrates	EC50 = 49.1 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Algae and Plants	NOEC =48 mg/L @ 72 hours based on $Ca(OH)_2$ The initial pH of the test medium was not directly related to the biologically relevant effects. The formation of precipitates is likely the result of the reaction between CO_2 dissolved in the medium.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

This material does not contain any compounds that would bioaccumulate up the food chain.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

This material does not contain any compounds classified as “persistent, bioaccumulative or toxic” nor as “very persistent/very bioaccumulative”.

12.6 Other Adverse Effects

None known.

Section 13

Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate industrial hygiene practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65.

  The following substances are known to the State of California to be carcinogens and/or reproductive toxicants:

  - Respirable crystalline silica

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Ammonium bisulfate	7803-63-6	No	Yes	No	No
Ammonium sulfate	7783-20-2	Yes	No	Yes	No
Calcium oxide	1305-78-8	Yes	Yes	Yes	No
Iron oxide	1309-37-1	Yes	Yes	Yes	No
Magnesium oxide	1309-48-4	No	Yes	No	No
Manganese oxide-as manganese compounds	1313-13-9; Various	No	No	Yes	Yes
Phosphorus pentoxide (or phosphorus oxide)	1314-56-3	Yes	Yes	Yes	No
Potassium oxide	12136-45-7	No	Yes	No	No
Silica-crystalline (SiO2), quartz	14808-60-7	Yes	Yes	Yes	No
Sodium oxide	1313-59-3	No	Yes	No	No
Titanium dioxide	13463-67-7	Yes	Yes	Yes	Yes

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: February 23, 2018

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- CA: California
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFR: Code of Federal Regulations
- EPA: Environmental Protection Agency

- GHS: Globally Harmonized System of Classification and Labelling
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit
- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological
- U.S.: United States
- U.S. DOT: United States of Department of Transportation

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	2*	**Flammability:**	0	**Physical Hazards:**	0	**Personal protection:****	

** Chronic Health Effects*
*** Appropriate personal protection is defined by the activity to be performed.*
See Section 8 for additional information.

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

ATTACHMENT T

October 2021

Phil Morris
Electric Energy, Inc.
Luminant
1500 Eastport Plaza Drive
Collinsville, IL 62234

May 19, 2021

Mr. Darin LeCrone, P.E.
Manager, Industrial Unit
Bureau of Water, Division of Water Pollution Control, Permits Section
Illinois Environmental Protection Agency
1021 North Grand Avenue, East
Springfield, IL 62794-9276

Re: CCR Surface Impoundment Category Designation and Justification for Electric Energy, Inc.

Dear Mr. LeCrone:

Pursuant to 35 I.A.C. 845.700(c), Electric Energy, Inc. (EEI) submits the information necessary to categorize the CCR surface impoundment located at the Joppa Power Plant. The following parameters were used in assessing and justifying each assigned category.

- Category 1 – *Impacts to existing potable water supply well or impacts to groundwater quality within the setback of an existing potable water supply well.*
  - This review includes an assessment of potable water wells within 2,500 feet of CCR surface impoundments to determine whether any potential impacts are occurring within the setback zone of any community water supply well established under the Illinois Groundwater Protection Act.
  - This information was developed during the Part 845 rulemaking and is summarized in Attachment 1, Table 2: Impacts to Potable Water Supply.
- Category 2 – *Imminent threat to human health or the environment or have been designated by IEPA under (g)(5)*
  - The surface impoundment at the Joppa Power Plant does not pose an imminent threat to human health or the environment. There are no known conditions at or around the facility where someone or something may be exposed to contaminant concentrations reasonably expected to cause harm
- Category 3 – *Located in areas of environmental justice ("EJ") concern*
  - EJ areas were evaluated using the EJ mapping link from IEPA's webpage located at https://www2.illinois.gov/epa/topics/environmental-justice. Per the IEPA mapping tool, the EJ Status thresholds were determined as twice the state averages for Minority and Low Income consistent with 35 IAC 845.700(g)(6).
  - An EJ map denoting the facilities with impoundments is located in Attachment 2.

- Category 4-7
    - Category 4 - Inactive CCR surface impoundments that have an exceedance of the groundwater protection standards in Section 845.600
    - Category 5 - Existing CCR surface impoundments that have exceedances of the groundwater protection standards in Section 845.600
    - Category 6 - Inactive CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600.
    - Category 7 – Existing CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600

Based on the information above, category designations have been assigned. The category designations for each CCR impoundment are shown in Attachment 1, Table 1: Category Designations.

If you have any questions regarding this submittal, please contact Phil Morris at 618-343-7794 or phil.morris@vistracorp.com.

Sincerely,

Phil Morris
Senior Environmental Director

Attachments

Attachment 1

Table 1: Category Designation

Facility	Pond Description	Classifications	Potable Water Supply Impacts (Category 1)	Human Health or Environment Threat (Category 2)	Located within Environmental Justice Areas[1] (Category 3)	Standards Exceedances[2] (Categories 4,5,6,7)	Impoundment Category 845.700(g)
Joppa	East Ash Pond	Existing	No	No	No	Yes	5

[1] See Attachment 2 Environmental Justice Area Map

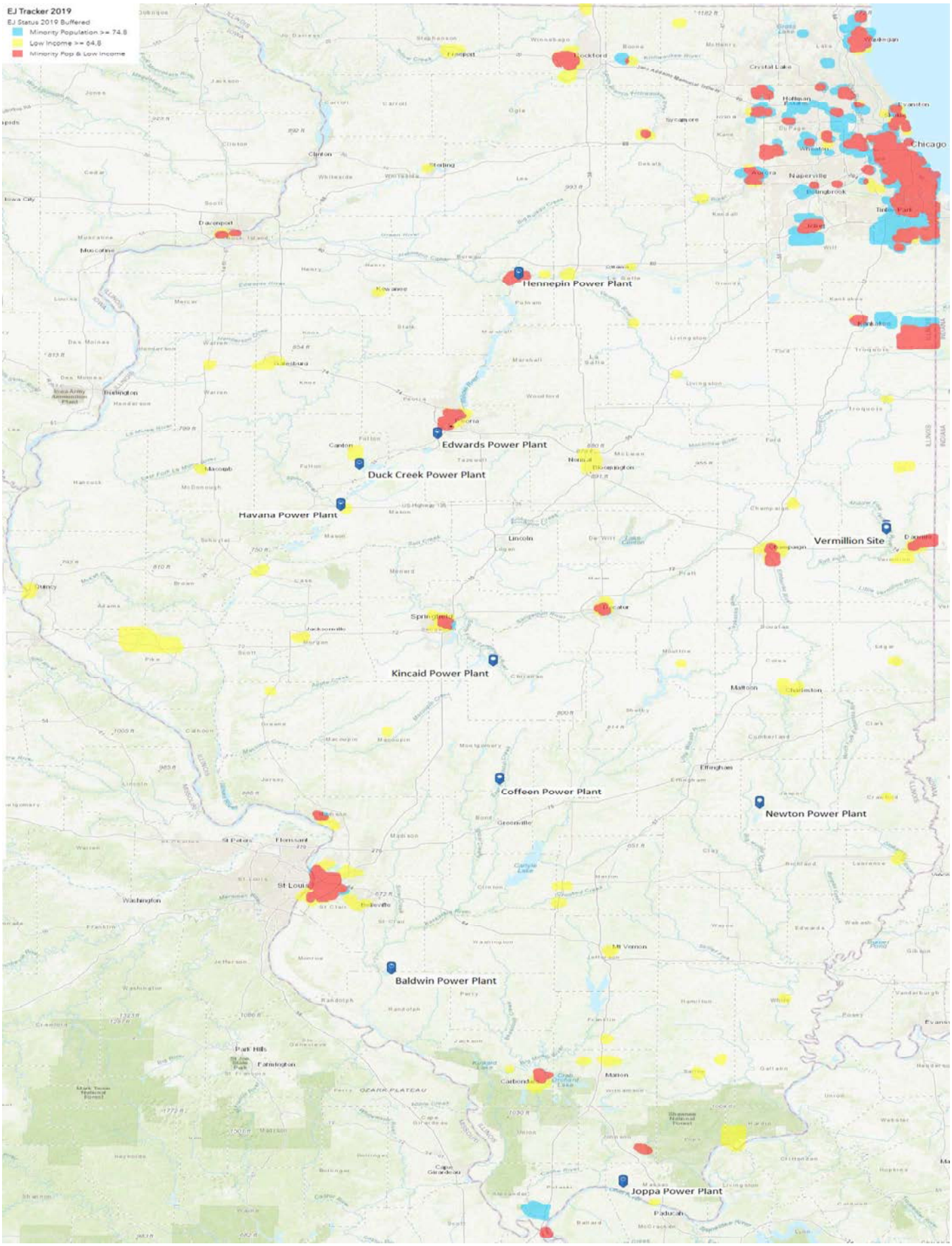
[2] Ground water analyses for purposes of categories 4-7, assumptions have been made based on current groundwater data. However, since sampling and analysis is ongoing and subject to IEPA review and approval, IPGC reserves the right to update its category designations for Categories 4-7.

Table 2: Impacts to Potable Water Supply

Site Name	Private and Semi-Private Wells	Non-Community Water Supply (CWS) Wells	Non-CWS Surface Water Intakes	Community Water Supply Wells	CWS Surface Water Intakes
Joppa	**Present, but not at risk** Forty-six (46) water wells were identified and 23 are located potentially downgradient of the site. However, only one (1) well is likely to be present and potentially used for drinking water. Based on Ramboll's review of groundwater data from the eastern portion of the site, it is unlikely that well P018 is at risk from coal ash constituents.	Absent	Absent	**Present, but not at risk** Two CWS wells were identified; however, they are unlikely to be at risk because of their hydrogeologic location relative to the power plant and/or their abandoned status.	Absent

R001272

Attachment 2: EJ Mapping Denoting Facilities with Impoundments



ATTACHMENT U

October 2021

Geosyntec consultants

1 McBride and Son Center Drive, Suite 202
Chesterfield, MO 63005
PH 636-812-0800
www.geosyntec.com

October 11, 2021

Electric Energy, Inc.
2100 Portland Road
Joppa, Illinois 62953

Subject: USEPA CCR Rule and IEPA Part 845 Rule Applicability Cross-Reference
2021 USEPA CCR Rule Periodic Certification Report
East Ash Pond, Joppa Power Plant, Joppa, Illinois

At the request of Electric Energy Incorporated (EEI), Geosyntec Consultants (Geosyntec) has prepared this letter to document how the attached 2021 United States Environmental Protection Agency (USEPA) CCR Rule Periodic Certification Report (Report) was prepared in accordance with both the Federal USEPA CCR Rule[1] and the state-specific Illinois Environmental Protection Agency (IEPA) Part 845 Rule[2]. Specific sections of the report and the applicable sections of the USEPA CCR Rule and Illinois Part 845 Rule are cross-referenced in **Table 1**. A certification from a Qualified Professional Engineer for each of the CCR Rule sections listed in **Table 1** is provided in Section 9 of the attached Report. This certification statement is also applicable to each section of the Part 845 Rule listed in **Table 1.**

Table 1 – USEPA CCR Rule and Illinois Part 845 Rule Cross-Reference

Report Section	USEPA CCR Rule		Illinois Part 845 Rule	
3	§257.73 (a)(2)	Hazard Potential Classification	845.440	Hazard Potential Classification Assessment[3]
4	§257.73 (c)(1)	History of Construction	845.220(a)	Design and Construction Plans (Construction History)
5	§257.73 (d)(1)	Structural Stability Assessment	845.450 (a) and (c)	Structural Stability Assessment
6	§257.73 (e)(1)	Safety Factor Assessment	845.460 (a-b)	Safety Factor Assessment
7	§257.82 (a)(1-3)	Adequacy of Inflow Design Control System Plan	845.510(a), (c)(1), (c)(3)	Hydrologic and Hydraulic Capacity Requirements / Inflow Design Flood Control System Plan
	§257.82 (b)	Discharge from CCR Unit	845.510(b)	Discharge from CCR Surface Impoundment

[1] United Stated Environmental Protection Agency, 2015. *40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule.*
[2] State of Illinois, Joint Committee on Administrative Rule, Administrative Code (2021). *Title 35: Environmental Protection, Subtitle G: Waste Disposal, Chapter I: Pollution Control Board, Subchapter j: Coal Combustion Waste Surface Impoundment, Part 845 Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments.*
[3] "Significant" and "High" hazard, per the CCR Rule[1], are equivalent to Class II and Class I hazard potential, respectively, per Part 845[2].

CLOSING

This letter has been prepared to demonstrate that the content and Qualified Professional Engineer Certification of the 2021 Periodic USEPA CCR Rule Certification Report fulfills the corresponding requirements of Part 845 of Illinois Administrative Code listed in **Table 1**.

Sincerely,

Lucas P. Carr, P.E.
Senior Engineer

John Seymour, P.E.
Senior Principal

2021 USEPA CCR RULE PERIODIC CERTIFICATION REPORT §257.73(a)(2), (c), (d[1]), (e) and §257.82 EAST ASH POND Joppa Power Plant Joppa, Illinois

Submitted to

Electric Energy, Inc.

2100 Portland Road
Joppa, Illinois 62953

Submitted by

Geosyntec consultants

engineers | scientists | innovators

1 McBride and Son Center Drive, Suite 202
Chesterfield, Missouri 63005

October 11, 2021

[1] Except for §257.73(d)(1)(vi).

TABLE OF CONTENTS

Executive Summary 1
SECTION 1 Introduction and Background 3
1.1 EAP Description 4
1.2 Report Objectives 6
SECTION 2 Comparision of Initial and Peroidic Site Conditions 8
2.1 Overview 8
2.2 Review of Annual Inspection Reports 8
2.3 Review of Instrumentation Data 8
2.4 Comparison of Initial to Periodic Surveys 9
2.5 Comparison of Initial to Periodic Aerial Photography 10
2.6 Comparison of Initial to Periodic Site Visits 10
2.7 Interview with Power Plant Staff 10
SECTION 3 Hazard Potential Classification - §257.73(a)(2) 13
3.1 Overview of Initial HPC 13
3.2 Review of Initial HPC 13
3.3 Summary of Site Changes Affecting the Initial HPC 14
3.4 Periodic HPC 14
SECTION 4 History of Construction Report - §257.73(c) 15
4.1 Overview of Initial HoC 15
4.2 Summary of Site Changes Affecting the Initial HoC 15
SECTION 5 Structural Stability Assessment - §257.73(d) 17
5.1 Overview of Initial SSA 17
5.2 Review of Initial SSA 17
5.3 Summary of Site Changes Affecting Initial SSA 18
5.4 Periodic SSA 18
SECTION 6 Safety Factor Assessment - §257.73(e)(1) 20
6.1 Overview of Initial SFA 20
6.2 Review of Initial SFA 20
6.3 Summary of Site Changes Affecting the Initial SFA 21
6.4 Periodic SFA 21
SECTION 7 Inflow Design Flood Control System Plan - §257.82 23
7.1 Overview of Initial IDF 23
7.2 Review of Initial IDF 23
7.3 Summary of Site Changes Affecting the Initial IDF 25
7.4 Periodic IDF 25

SECTION 8 Conclusions 27
SECTION 9 Certification Statement 28
SECTION 10 References 29

LIST OF FIGURES

Figure 1 Site Location Map
Figure 2 Site Plan

LIST OF TABLES

Table 1 Periodic Certification Summary
Table 2 Initial to Periodic Survey Comparison
Table 3 Factors of Safety from Periodic SFA
Table 4 Water Levels from Periodic IDF

LIST OF DRAWINGS

Drawing 1 Initial to Periodic Survey Comparison
Drawing 2 Survey Comparison Isopach
Drawing 3 Initial to Periodic Aerial Imagery Comparison

LIST OF ATTACHMENTS

Attachment A EAP Piezometer Data Plots
Attachment B EAP Site Visit Photolog
Attachment C Periodic History of Construction Report Update Letter
Attachment D Periodic Structural Stability and Safety Factor Assessment Analyses
Attachment E Periodic Inflow Design Flood Control System Plan Analyses

EXECUTIVE SUMMARY

This Periodic United States Environmental Protection Agency (USEPA) Coal Combustion Residuals (CCR) Rule [1] certification report (Periodic Certification Report) for the East Ash Pond (EAP)[2] at the Joppa Power Plant (JPP), also referred to as Joppa Power Station, has been prepared in accordance with Rule 40, Code of Federal Regulations (CFR) §257. herein referred to as the "CCR Rule" [1]. The CCR Rule requires that initial certifications for existing CCR surface impoundment, completed in 2016 and subsequently posted on the Electric Energy, Incorporated (EEI) CCR Website ([2], [3], [4], [5], [6]) be updated on a five-year basis.

The initial certification reports developed in 2016 were independently reviewed by Geosyntec ([2], [3], [4], [5], [6], [7], [8]). Additionally, field observations, interviews with plant staff, and evaluations were performed to compare conditions in 2021 at the EAP relative to the 2016 initial certifications. These tasks determined that updates are not required for the Initial Hazard Potential Classification. However, due to changes at the site and technical review comments, updates were required and were performed for the:

- History of Construction Report,
- Initial Structural Stability Assessment,
- Initial Safety Factor Assessment, and
- Initial Inflow Design Flood Control System Plan.

Geosyntec's evaluations of the initial certification reports and updated analyses identified that the EAP meets all requirements for hazard potential classification, history of construction reporting, structural stability, safety factor assessment, and hydrologic and hydraulic control, with the exception of the structural integrity of hydraulic structures (§257.73(d)(1)(vi)), which was certified by others. **Table 1** provides a summary of the initial 2016 certifications and the 2021 periodic certifications.

[2] The EAP is also referred to as ID Number W1270100004-02, East Ash Pond 2 by the Illinois Environmental Protection Agency (IEPA); CCR unit ID 401 by EEI; and IL50714 within the National Inventory of Dams (NID) maintained by the Illinois Department of Natural Resources (IDNR). Within this document it is referred to as the EAP.

Table 1 – Periodic Certification Summary

Section	CCR Rule Reference	Requirement Summary	2016 Initial Certification		2021 Periodic Certification	
			Requirement Met?	Comments	Requirement Met?	Comments
Hazard Potential Classification						
3	§257.73(a)(2)	Document hazard potential classification	Yes	The East Ash Pond was determined to have a High hazard potential classification [2].	Yes	Updates were not determined to be necessary. Geosyntec recommends retaining the High hazard potential classification.
History of Construction						
4	§257.73(c)(1)	Compile a history of construction	Yes	A history of Construction report was prepared for the EAP [3].	Yes	A letter listing updates to the History of Construction report is provided in **Attachment C**.
Structural Stability Assessment						
5	§257.73(d)(1)(i)	Stable foundations and abutments	Yes	Foundations and abutments were found to be stable [8].	Yes	Foundations and abutments were found to be stable after performing updated slope stability analyses.
	§257.73(d)(1)(ii)	Adequate slope protection	Yes	Slope protection was adequate [8].	Yes	No changes were identified that may affect this requirement.
	§257.73(d)(1)(iii)	Sufficiency of dike compaction	Yes	Dike compaction was sufficient for expected ranges in loading conditions [8].	Yes	Dike compaction was found to be sufficient after performing updated slope stability analyses.
	§257.73(d)(1)(iv)	Presence and condition of slope vegetation	Yes	Vegetation was present on exterior slopes and is maintained. Interior slopes had alternate protection (geomembrane liner) [8].	Yes	No changes were identified that may affect this requirement.
	§257.73(d)(1)(v)(A) and (B)	Adequacy of spillway design and management	Yes	Spillways were adequately designed and constructed and were expected to adequately manage flow during probable maximum flood (PMF) [8].	Yes	Spillways were found to be adequately designed and constructed and are expected to adequately manager flow during the PMF, after performing updated hydrologic and hydraulic analyses.
	§257.73(d)(1)(vi)	Structural integrity of hydraulic structures	No	Requirement could not be certified in 2016 due to inability to complete a CCTV inspection of the 26-inch diameter south outlet pipe due to water-filled pipe portions. AECOM recommended inspecting this pipe as soon as feasible to address the issue [8].	Periodic certification of §257.73(d)(1)(vi) was performed independently Luminant in 2020 [9].	
	§257.73(d)(1)(vii)	Stability of downstream slopes inundated by water body.	Not Applicable	Inundation of exterior slopes was not expected; this requirement was not applicable [8].	Yes	No changes were identified that may affect this requirement.
Safety Factor Assessment						
6	§257.73(e)(1)(i)	Maximum storage pool safety factor must be at least 1.50	Yes	Safety factors were calculated to be 1.59 and higher [8].	Yes	Safety factors from updated slope stability analyses were calculated to be 1.53 and higher.
	§257.73(e)(1)(ii)	Maximum surcharge pool safety factor must be at least 1.40	Yes	Safety factors were calculated to be 1.57 and higher [8].	Yes	No changes were identified that may affect this requirement.
	§257.73(e)(1)(iii)	Seismic safety factor must be at least 1.00	Yes	Safety factors were calculated to be 1.01 and higher [8].	Yes	Safety factors from updated slope stability analyses were calculated to be 1.00 and higher.
	§257.73(e)(1)(iv)	For dike construction of soils that have susceptible to liquefaction, safety factor must be at least 1.20	Not Applicable	Dike soils were not susceptible to liquefaction. This requirement was not applicable [8].	Not Applicable	No changes were identified that may affect this requirement.
Inflow Design Flood Control System Plan						
7	§257.82(a)(1), (2), (3)	Adequacy of inflow design control system plan.	Yes	Flood control system adequately managed inflow and peak discharge during the PMP, 24-hour, Inflow Design Flood [8].	Yes	The flood control system was found to adequately manage inflow and peak discharge during the PMP, 24-hour, Inflow Design Flood, after performing updated hydrologic and hydraulic analyses.
	§257.82(b)	Discharge from CCR Unit	Yes	Discharge from the CCR Unit is routed through a NPDES-permitted outfall during both normal and PMP, 24-hour Inflow Design Flood conditions [8].	Yes	Discharge from the CCR Unit is routed through a NPDES-permitted outfall during both normal and PMP, 24-hour Inflow Design Flood conditions, after performing updated hydrologic and hydraulic analyses.

SECTION 1

INTRODUCTION AND BACKGROUND

This Periodic United States Environmental Protection Agency (USPA) Coal Combustion Residual (CCR) Rule [1] Certification Report was prepared by Geosyntec Consultants (Geosyntec) for Electric Energy Incorporated (EEI) to document the periodic certification of the East Ash Pond (EAP) at the Joppa Power Plant, also known as the Joppa Power Station, (JOP), located at 2100 Portland Road in Joppa, Illinois, 62953. The location of JPP is provided in **Figure 1**, and a site plan showing the location of the EAP is provided in **Figure 2**.

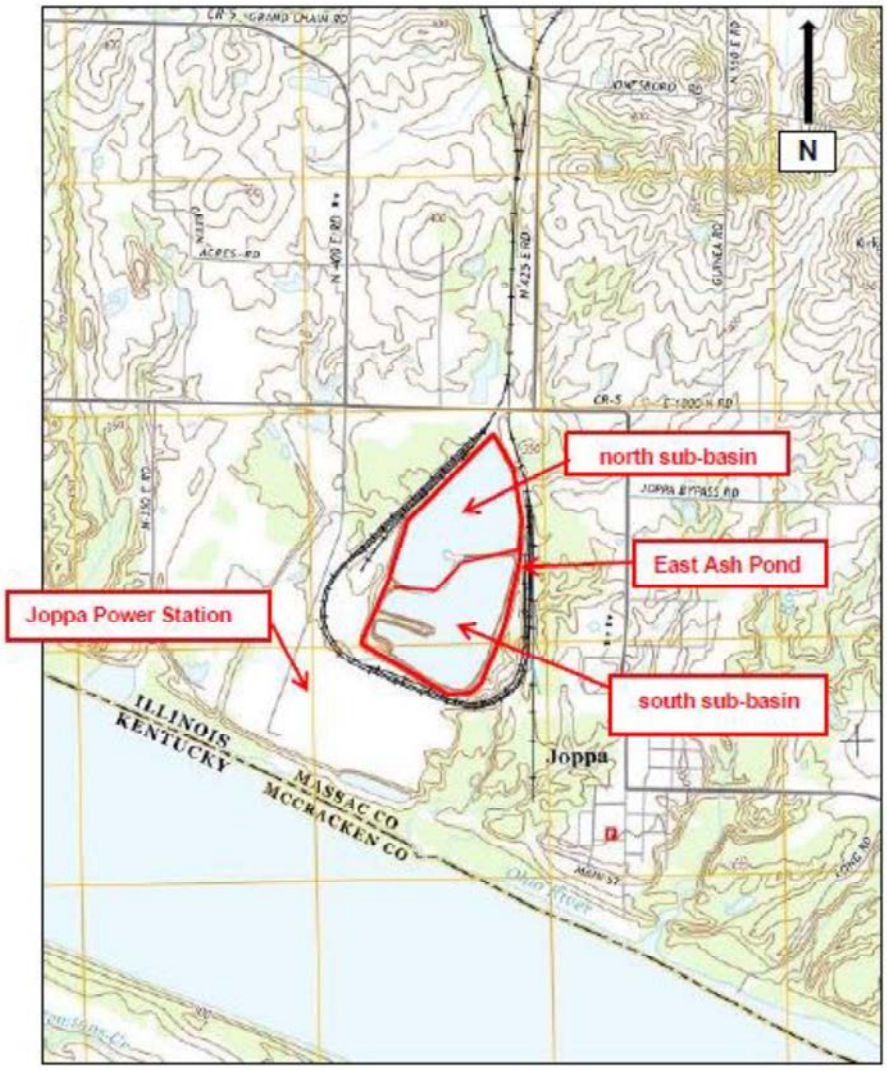


Figure 1 – Joppa Power Plant Location Map (from AECOM, 2016)

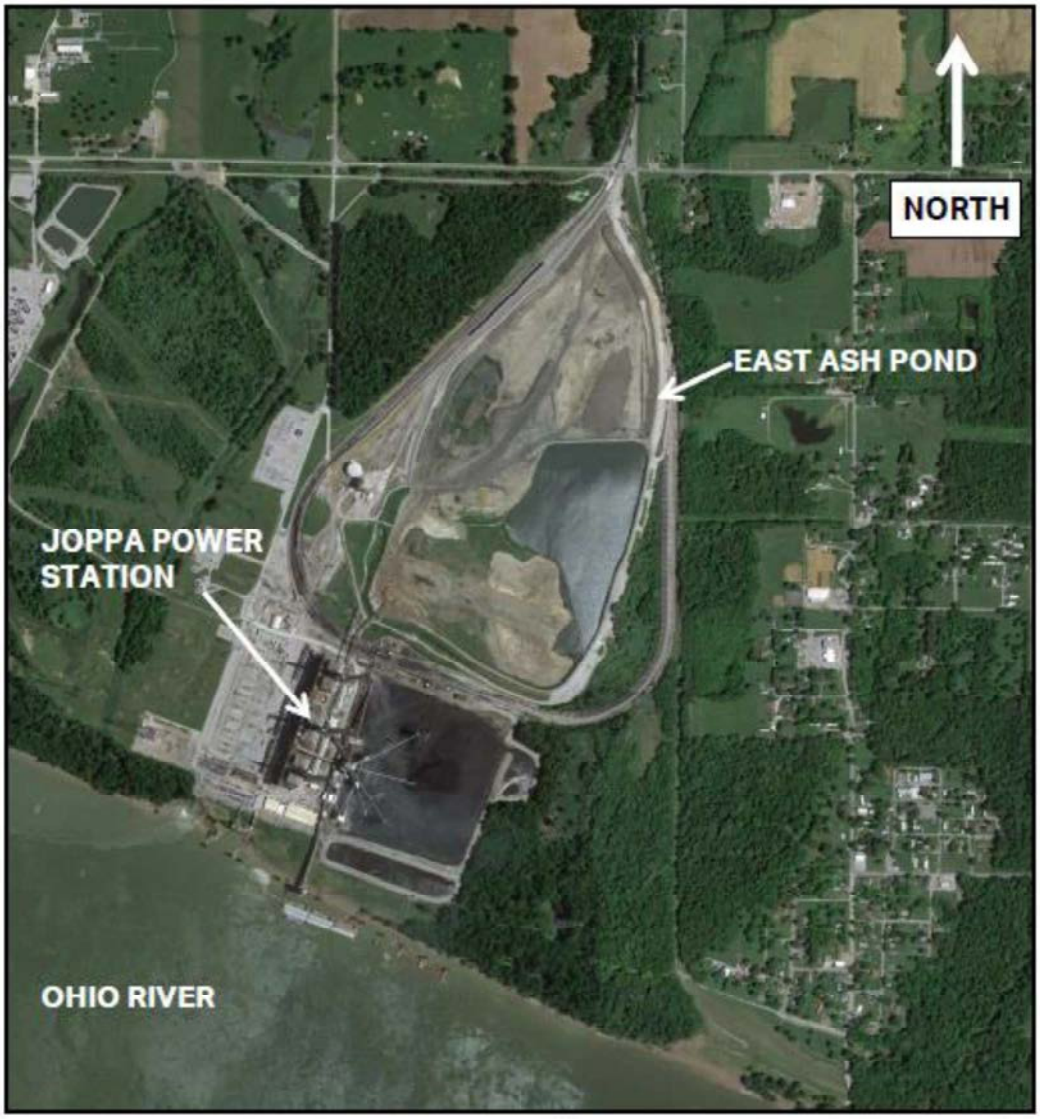


Figure 2 – Joppa Power Plant Site Plan (from AECOM, 2016)

1.1 EAP Description

The East Ash Pond serves as the sole wet ash impoundment basin for the Joppa Power Plant and contains materials such as bottom ash, fly ash and other non-CCR waste streams from the Joppa Power Plant. The East Ash Pond receives sluiced CCRs from the power plant which discharges into the southwest corner of the south sub-basin. A third-party recycling company recovers acceptable fly ash and bottom ash for beneficial reuse, and unacceptable materials are left in the East Ash Pond [8].

Only the south sub-basin includes a free-water pool under normal operating conditions. The north sub-basin is mostly filled with CCR materials and free water is limited to the interior drainage channel that occasionally flows from the south sub-basin through an overflow pipe. Outflow from

the north sub-basin of the East Ash Pond is discharged to the effluent control tank, which is a concrete basin used for water quality mixing purposes located at the northern toe of the East Ash Pond dike. Water discharged from the effluent control tank is via a concrete weir is conveyed approximately 650 feet southward to the Ohio River at the site's NPDES-permitted outfall [8].

Outflow from the south sub-basin of the East Ash Pond is discharged directly to the mixing tank through a 24-inch vertical ductile iron tee (invert elevation 372.7 feet[3]) located on the east side of the impoundment. Flow enters the tee from the bottom of the structure, although the tee is also open on the top and includes a corrugated metal skimmer that allows for additional flow to enter the tee during high water conditions. The 24-inch diameter tee is connected to the end of a horizontal 26-inch high-density polyethylene (HDPE) pipe that penetrates the East Ash Pond embankment before dropping in elevation and transporting discharge water approximately 900 feet northward into the 48-inch RCP spillway pipe for the north sub-basin. The south and north sub-basins are connected with a 36-inch corrugated HDPE pipe (invert elevation 373.2 feet) that allows for flow between the two basins during stormwater conditions when the pool level in the south sub-basin exceeds the El. 373.2 ft normal level [8].

In 2016, an approximately 800-foot-long zone of foundation of the East Ash Pond was improved using deep-mixing method (DMM) ground improvement technology and buttressing. This zone, located at the southeast corner of the East Ash Pond dike, was installed to improve the seismic factor of safety within a zone of liquefaction-susceptible sluiced fly ash over which the East Ash Pond dike was originally constructed. The zone was installed at and partially underneath the downstream toe of the East Ash Pond embankment, and consisted of the placement of columns, arranged into transverse shear walls, consisting of native embankment and foundation soil and CCRs mechanically mixed with Portland cement to improve the shear strength within the foundation soils at the East Ash Pond. The zone was designed and constructed to improve seismic and post-earthquake (i.e., "liquefaction" or "post-liquefaction") slope stability to meet the criteria listed in §257.73(e) of the CCR Rule [1]. Sluiced fly ash was not identified within the foundation of the East Ash Pond in any other areas than where the DMM was installed [8].

An engineered liner system is not present beneath the East Ash Pond. The surface area of the impoundment is approximately 111 acres, and the embankment portion of the East Ash Pond has a total length of approximately 8,950 feet and a maximum height above the exterior grade of 43 feet. The embankment was constructed as a homogenous earthen structure with well-compacted clayey fill. The exterior slopes are graded at a slope of approximately 1.5H:1V and predominately covered in crushed stone or vegetation. The interior slopes are graded at a s approximately 1.5H:1V and are covered with either vegetation or mechanically stacked CCRs. Embankment crest width ranges from approximately 15 to 35 feet, and the crest is covered with a gravel access road. As currently operated, the normal pool of the East Ash Pond was El. 373.5 feet in the south sub-basin, as controlled by the 36-inch diameter HDPE pipe connecting the north and south sub-basins, the

[3] All elevations in this report are in the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted.

invert of the 24-inch ductile iron pipe tee spillway structure is El. 372.7, and process flow volumes [10]. The north sub-basin does not have a free water pool during normal conditions and only includes the 36-inch overflow structure and open stormwater collection channel.

Initial certifications for the EAP for Hazard Potential Classification (§257.73(a)(2)), History of Construction (§257.73(c)), Structural Stability Assessment (§257.73(d)), Safety Factor Assessment (§257.73(e)(1)), and Inflow Design Flood Control System Plan (§257.82) were completed by Stantec and AECOM in 2016 and 2017 and subsequently posted to EEI's CCR Website ([2], [3], [4], [5], [6]). Additional documentation for the initial certifications included a detailed operating record reports containing calculations and other information prepared for the hazard potential classification by Stantec [7] and for the structural stability assessment, safety factor assessment, and inflow design flood control system plan by AECOM [8]. These operating record reports were not posted to EEI's CCR Website.

1.2 Report Objectives

These following objectives are associated with this report:

- Compare site conditions from 2015/2016, when the initial certifications were developed, to site conditions in 2020/2021, when data for the periodic certification was obtained, and evaluate if updates are required to the:
    - §257.73(a)(2) Hazard Potential Classification [2];
    - §257.73(c) History of Construction [3];
    - §257.73(d) Structural Stability Assessment [4];
    - §257.73(e) Safety Factor Assessment [5], and/or
    - §257.82 Inflow Design Flood Control System Plan [6].
- Independently review the Hazard Potential Classification ([2], [7]), Structural Stability Assessment ([4], [8]), Safety Factor Assessment ([5], [8]), and Inflow Design Flood Control System Plan ([6], [8]) reports to determine if updates may be required based on technical considerations.
    - The History of Construction report [3] was not independently reviewed for technical considerations, as this report contained historical information primarily developed prior to promulgation of the CCR Rule [1] for the CCR units at JOP, and did not include calculations or other information used to certify performance and/or integrity of the impoundments under §257.73(a)(2), §257.73(c)-(e), or §257.82.

- Confirm that the EAP meets all of the requirements associated with §257.73(a)(2), (c), (d), (e), and §257.82, or, if the EAP does not meet all requirements, provide recommendations for compliance with these sections of the CCR Rule [1].

SECTION 2

COMPARISION OF INITIAL AND PEROIDIC SITE CONDITIONS

2.1 Overview

This section describes the comparison of conditions at the EAP between the start of the initial CCR certification program in 2015 and 2016 (initial conditions) and subsequent collection of periodic certification site data in 2020 and 2021 (periodic conditions).

2.2 Review of Annual Inspection Reports

Annual onsite inspections for the EAP were performed between 2016 and 2020 ([11], [12], [13], [14], [15]) and were certified by a licensed professional engineer in accordance with §257.83(b). Each inspection report stated the following information, relative to the previous inspection:

- A statement that no changes in geometry of the impounding structure were observed since the previous inspection;
- Information on maximum recorded instrumentation readings and water levels;
- Approximate volumes of impounded water and CCR at the time of inspection;
- A statement that no appearances of actual or potential structural weakness or other disruptive conditions were observed; and
- A statement that no other changes which may have affected the stability or operation of the impounding structure were observed.

In summary, the reports did not indicate any significant changes to the EAP between 2015 and 2020. No signs of instability, structural weakness, or changes which may have affected the operation or stability of the EAP were noted in the inspection reports.

2.3 Review of Instrumentation Data

Twenty-three piezometers, JOP-P001 through JOP-P023, are present at the EAP and are monitored monthly by EEI. Data collected between August 6, 2015 and May 6, 2021 were provided to Geosyntec. Geosyntec reviewed the piezometer data to evaluate if significant fluctuations, partially increases in phreatic levels, may have occurred between development of the initial structural stability and factor of safety certifications ([8], [4], [5]) and May 6, 2021. Available piezometer readings are plotted in **Attachment A**.

In summary, only minor changes in phreatic conditions were observed in the available piezometric data. Phreatic levels typically varied by 2 to 5 ft, although levels for JOP-P007, JOP-P014, and

JOP-P020 exhibited consistent seasonal variations of approximately 10 to 20 ft. These changes do not indicate significantly different phreatic levels than those utilized for the initial structural stability and factor of safety certifications ([8], [4], [5]).

2.4 Comparison of Initial to Periodic Surveys

The initial survey of the EAP, conducted by Weaver Consultants (Weaver) in 2015 [16], was compared to the periodic survey of the EAP, conducted by IngenAE, LLC (IngenAE) in 2020 [10], using AutoCAD Civil3D 2021 software. This comparison quantified changes in the volume of CCR placed within the EAP and considered volumetric changes above and below the starting water surface elevation (SWSE) used for the 2016 §257.82 inflow design flood control plan hydraulic analysis ([6], [8]). Potential changes to embankment geometry were also evaluated. This comparison is presented in a plan view in **Drawing 1** and in an isopach map denoting changes in ground surface elevation in **Drawing 2**. A summary of the water elevations and changes in CCR volumes is provided in **Table 2**.

Table 2 – Initial to Periodic Survey Comparison

Initial Surveyed Pool Elevation (ft)	372.7
Periodic Surveyed Pool Elevation (ft)	373.5
Initial §257.82 Starting Water Surface Elevation (SWSE) (ft)	373.2
Total Change in CCR Volume, North and South Sub-Basins (CY)	+38,674 (fill)
Change in CCR Volume Above SWSE, North Sub-Basin (CY)	+77,554 (fill)
Change in CCR Volume Above SWSE, South Sub-Basin (CY)	+18,182 (fill)
Change in Volume Below SWSE, North Sub-Basin (CY)	+1,661 (fill)
Change in Volume Below SWSE, South Sub-Basin (CY)	-58,677 (cut)

The comparison indicated that approximately 39,000 CY (net cut and fill) of CCR was placed in the EAP between the initial and periodic surveys. However, this comparison also indicated approximately 59,000 CY of cut below the SWSE in the south sub-basin. As CCR was unlikely to have been removed below the SWSE, this apparent cut may be due to differences in bathymetric survey equipment and/or survey data processing between bathymetry measured by the initial and periodic surveys, rather than an actual change in volume.

The comparison also indicated a total placement of CCR above the SWSE of approximately 78,000 CY in the north sub-basin and 18,000 CY in the south sub-basin. thereby leading to a potential for the peak water surface elevation (PWSE) to increase during the inflow design PMP flood event. Furthermore, the comparison indicated that the water surface elevation (WSE) in the south-sub basin was approximately 0.3 ft higher than the SWSE from the 2016 IDF ([6], [8]), thereby also leading to a potential for the PWSE to increase during the inflow design PMP flood event.

No significant changes to embankment geometry appeared to have occurred between the initial and periodic surveys, outside of embankment buttressing and armoring associated with construction of the DMM zone in 2016 [8].

2.5 Comparison of Initial to Periodic Aerial Photography

Initial aerial photographs of the EAP collected by Weaver in 2015 [16] were compared to periodic aerial photographs collected by IngenAE in 2020 [10] to visually evaluate if potential site changes (i.e., changes to the embankment, outlet structures, limits of CCR, other appurtenances) may have occurred. A comparison of these aerial photographs is provided in **Drawing 3**. The following changes were noted in the comparison:

- Standing water was no longer present in the north sub-basin, and
- Embankment buttressing and armoring associated with the construction of the DMM zone in 2016 [8] were also apparent.

2.6 Comparison of Initial to Periodic Site Visits

An initial site visit to the EAP was conducted by AECOM in 2015 and documented with a Site Visit Summary and corresponding photographs [17]. A periodic site visit was conducted by Geosyntec on May 26, 2021, with Mr. Lucas P. Carr, P.E. and Mr. Pourya Kargar conducting the site visit. The site visit was intended to evaluate potential changes at the site since the initial certifications were prepared (i.e., modification to the embankment, outlet structures or other appurtenances, limits of CCR, maintenance programs, repairs), in addition to performing visual observations of the EAP to evaluate if the structural stability requirements (§257.73(d)) were still met. The stie visit included walking the perimeter of the EAP, visually observing conditions, recording filed notes, and collecting photographs. The site visit is documented in a photographic log provided in **Attachment B**. A summary of significant findings from the periodic site visit is provided below:

- No new development was observed in the vicinity of the EAP, although the observation was limited to the portions of the vicinity visible on foot from the crest of the EAP dikes.
- No signs of structural instability or erosion were observed during the site visit.
- Embankment buttressing and armoring associated with the construction of the DMM zone in 2016 [8] were observed.

2.7 Interview with Power Plant Staff

An interview with Mr. Bruce Parker and Mr. Roger Faughn of JPP was conducted by Mr. Lucas P. Carr of Geosyntec on May 26, 2021. Mr. Parker had been employed at JPP for 32 years as the manager of environmental and chemistry, with the responsibility of managing the EAP from an environmental standpoint. Mr. Faughn had been employed by JPP for one year and is part of the JPP environmental group, with the responsibility of supporting EAP environmental compliance. The interview included a discussion of potential changes that may have occurred at the EAP since

development of the initial certifications ([2], [3], [4], [5], [6]). A summary of the interview is provided below.

- Were any construction projects completed for the EAP since 2015, and, if so, can you please describe the work, reason for the work, and provide any design drawings and/or details available?
    - The DMM zone was installed in 2016.
    - Wet spots were noted on the road at the east side of the embankment in 2020 and were evaluated by both EEI and Hanson Professional Services (Hanson). The wetness was addressed by over-excavating an approximately 100-ft long area, putting down (from bottom to top) filter fabric, sand, filter fabric, and then gravel, based on a repair plan developed by Hanson ([18], [19]). The area has since been dry.
- Were there any changes to the purpose or operation of the EAP since 2015?
    - No changes have occurred.
- Were there any changes to the to the instrumentation program and/or physical instruments for the EAP between 2015 and 2021, and, if so, are records available?
    - Several piezometers have been abandoned since 2015 due to access difficulties or problems with the instrument no longer functioning. These piezometers are marked as abandoned in the monthly piezometer reading spreadsheet maintained by EEI.
- Have area-capacity curves for the EAP been prepared since 2015?
    - No known curves have been prepared.
- Were there any changes to spillways and/or diversion features for the EAP completed since 2015, and, if so, are records available?
    - No known changes have occurred.
- Were there any changes to construction specifications, surveillance, maintenance, and repair procedures for the EAP since 2015, and, if so, are records available?
    - No changes have occurred.
- Were there any instances of dike and/or structural instability for the EAP since 2015, and, if so, are records available?

- No known instances of dike and/or structural instability have occurred.

SECTION 3

HAZARD POTENTIAL CLASSIFICATION - §257.73(a)(2)

3.1 Overview of Initial HPC

The Initial Hazard Potential Classification (Initial HPC) was prepared by Stantec Consulting Services, Inc. (Stantec) in 2016 ([2], [7]), following the requirements of §257.73(a)(2). The Initial HPC included the following information:

- Performing six breach analyses using HEC-RAS Version 5.0.1 software [20], using pool levels estimated within the EAP during the probable Maximum Precipitation (PMP) rainfall event, for multiple locations around the east, south, and west embankments of the EAP.

- Evaluating potential effects of flooding in multiple areas, including breach flood wave velocities and/or flood depths, for areas north, east, west, and south of the EAP.

- While a breach map is not included in the Initial HPC, it is included within the §257.73(a)(3) Initial Emergency Action Plan prepared by Stantec [21].

The breach analysis concluded that a breach of the EAP could impact multiple occupied structures on the north, east, west, and south of the EAP, with maximum flood depths of greater than 2 ft and velocities of greater than 5 ft/sec. Based on the finding of impacts to occupied structures, a breach of the EAP represented a probable threat to human life. The Initial HPC therefore recommended a "High" hazard potential classification for the EAP [2].

3.2 Review of Initial HPC

Geosyntec performed a review of the Initial HPC ([2], [7]), in terms of technical approach, input parameters, and assessment of the results. The review included the following tasks:

- Reviewing the rainfall depths utilized in the breach analysis for appropriateness,

- Reviewing breach assessment inputs for appropriateness,

- Reviewing the selected HPC for appropriateness based on the results of the breach analysis, including flow velocities and depths, and

- Reviewing the HPC vs. applicable requirements of the CCR Rule.

No significant technical issues were noted within the technical review, although a detailed review (e.g., check) of the calculations was not performed.

3.3 Summary of Site Changes Affecting the Initial HPC

Geosyntec did not identify any changes at the site that may affect the HPC. No new structures, infrastructure, frequently occupied facilities/areas, or waterways were present in the probable breach area indicated in the Initial EmAP [21], although Geosyntec's evaluation of new structures was limited to visual observations completed from the dike crest during the site visit and a review of available aerial imagery provided by EEI ([16], [10]). Additionally, no significant changes to the topography within the EAP nor in the probable breach area were identified.

3.4 Periodic HPC

Geosyntec recommends retaining the "High" hazard potential classification for the EAP, per §257.73(a)(2), based on a the lack of site changes potentially affecting the Initial HPC occurring since the Initial HPC was developed, as described in **Section 3.3**, and the lack of significant review comments, as described in **Section 3.2**. Updates to the Initial HPC reports ([2], [7]) are not recommended at this time.

SECTION 4

HISTORY OF CONSTRUCTION REPORT - §257.73(c)

4.1 Overview of Initial HoC

The Initial History of Construction report (Initial HoC) was prepared by AECOM in 2016 [3], following the requirements of §257.73(c), and included information on the EAP at JOP. The Initial HoC included the following information for the CCR surface impoundment:

- The name and address of the owner/operator,
- Location maps,
- A statement of purpose,
- The names and size of the surrounding watershed,
- A description of the foundation and abutment materials,
- Available design and engineering drawings,
- A summary of instrumentation,
- Area capacity curves for the north and south sub-basins,
- Information on spillway structures,
- A statement that construction specifications are not reasonably and readily available,
- A statement that an operations and maintenance plan is currently being prepared; and
- A summary of eight separate surficial movements that occurred along the downstream slope of the perimeter embankment, followed by a statement that other historical structural instability had not occurred at the CCR surface impoundment.

4.2 Summary of Site Changes Affecting the Initial HoC

Several significant changes were identified at the site that occurred after development of the initial HoC report [4] and are described below:

- A state identification number (ID) of W1270100004-02 was assigned to the EAP by the Illinois Environmental Protection Agency (IEPA).

- A wet area was observed at the eastern toe of the perimeter dike and was repaired by excavating the area and backfill it with geotextile, sand, and crushed stone in 2020, in accordance with a memo and design prepared by Hanson ([18], [19]).

- Several piezometers were abandoned or have become inaccessible between 2015 and 2020. These piezometers are no longer being monitored.

- Revised area-capacity curves and spillway design calculations for the EAP were prepared as part of the periodic Inflow Design Flood Control System Plan, as described in **Section 6.3**.

A letter documenting changes to the HoC report is provided in **Attachment C**.

SECTION 5

STRUCTURAL STABILITY ASSESSMENT - §257.73(d)

5.1 Overview of Initial SSA

The Initial Structural Stability Assessment (Initial SSA) was prepared by AECOM in 2016 ([4], [8]), following the requirements of §257.73(d)(1), and included the following evaluations:

- Stability of dike foundations, dike abutments, slope protection, dike compaction, and slope vegetation,
- Spillway stability including capacity, structural stability and integrity; and
- Downstream slope stability under sudden drawdown conditions for an adjacent, downstream water body.

The Initial SSA concluded that all EAP met all structural stability requirements for §257.73(d)(1)(i)-(v) and (vii), but recommended inspection of the 26-inch diameter HDPE spillway pipe to verify that the EAP meets the structural stability and structural integrity criteria for hydraulic outfall structures, per §257.73(d)(1)(vi). A complete inspection of the pipe was not performed in 2015 or 2016 due to the pipe being full of water as necessary for plant operations.

The Initial SSA referenced the results of the Initial Structural Factor Assessment (Initial SFA), to demonstrate stability of the stability of foundations and abutments (§257.73(d)(1)(i)) sufficiency of dike compaction (§257.73(d)(1)(iii)) portions of the SSA criteria. This included stating that slope stability analyses for slip surfaces passing through the foundation met or exceeded the criteria listed in §257.73(e)(1), for the stability of foundations and abutments. For the sufficiency of dike compaction, this included stating that slope stability analyses for slip surfaces passing through the dike also met or exceeded the §257.73(e)(1) criteria.

A periodic certification of the structural stability and structural integrity for hydraulic outfall structures (§257.73(d)(1)(vi)) was performed by Luminant in 2020 [9]. This certification independently determined that the criteria was met due to the condition of the spillway pipes and the soil types within the embankment. Therefore, the review and certification of §257.73(d)(1)(vi) is not included within the scope of this report.

5.2 Review of Initial SSA

Geosyntec performed a review of the Initial SSA ([4], [8]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing photographs collected in 2015 and used to demonstrate compliance with §257.73(d)(1)(i)-(vii).

- Reviewing geotechnical calculations used to demonstrate the stability of foundations, per §257.73(d)(1)(i) and sufficiency of dike compaction, per §257.73(d)(1)(iii), in terms of supporting geotechnical investigation and testing data, input parameters, analysis methodology, selection of critical cross-sections, and loading conditions.

- Review of the methodology used to demonstrate that a downstream water body that could induce a sudden drawdown condition, per §257.73(d)(1)(vii), is not present.

- Reviewing the contents vs. the applicable CCR Rule requirements [1].

No significant technical issues were noted within the technical review of the Initial SSA. A detailed review (e.g., check) of the calculations was not performed.

5.3 Summary of Site Changes Affecting Initial SSA

Several changes at the site that occurred after development of the Initial SSA were identified. These changes required updates to the Initial SSA and are described below:

- The Initial SSA utilized the results of the Initial Inflow Design Flood Control System Plan (IDF) to demonstrate compliance with the adequacy of spillway design and management (§257.73(d)(1)(v)(A)-(B)). The Initial IDF was subsequently updated to develop a Periodic IDF, based on site changes, as discussed in **Section 7**.

- The Initial SFA utilized the results of the Initial Safety Factor Assessment (SFA), in addition to separate slope stability analyses to evaluate the effects of foundation liquefaction and cyclic softening, to demonstrate compliance with the stability of foundations and abutments (§257.73(d)(1)(i)) and sufficiency of dike compaction (§257.73(d)(1)(iii)). The Initial SFA was subsequently updated to develop a Periodic SFA, based on site changes, as discussed in **Section 6**.

5.4 Periodic SSA

The Periodic SFA (**Section 6**) indicates that foundations and abutments are stable and dike compaction is sufficient for expected ranges in loading conditions, as slope stability factors of safety were found to meet or exceed the requirements of §257.73(e)(1), including for static maximums storage pool conditions and post-earthquake loading conditions assessing the consequences of liquefaction and cyclic softening in the foundation soils. Therefore, the requirements of §257.73(d)(1)(i) and §257.73(d)(1)(iii) are met for the Periodic SSA.

The Periodic IDF (**Section 7**) indicates that spillways are adequately designed and constructed to adequately manage flow during the PMF flood, as the spillways can adequately manage flow

during peak discharge from the PMP storm event without overtopping of the embankments. Therefore, the requirements of §257.73(d)(1)(v)(A)-(B) are met for the Periodic SSA.

Certification of §257.73(d)(1)(vi) was performed independently by Luminant [9].

SECTION 6

SAFETY FACTOR ASSESSMENT - §257.73(e)(1)

6.1 Overview of Initial SFA

The Initial Safety Factor Assessment (Initial SFA) was prepared by AECOM in 2016 ([5], [8]), following the requirements of §257.73(e)(1). The Initial SFA included the following information:

- A geotechnical investigation program with in-situ and laboratory testing;
- An assessment of the potential for liquefaction in the dike and foundations soils;
- The development of six slope stability cross-sections for limit equilibrium stability analysis using GeoStudio SLOPE/W software;
- The analysis of each cross-section for maximums storage pool, maximum surcharge pool, seismic, and post-earthquake (i.e., liquefaction) location conditions;
- Calculations used to design the DMM zone installed in 2016; and
- Simplified seismic deformation analyses to estimate seismically-induced deformations occurring after an earthquake event.

The Initial SFA concluded that the EAP met all safety factor requirements, per §257.73(e), as all calculated safety factors were equal to or higher than the minimum required values.

6.2 Review of Initial SFA

Geosyntec performed a review of the Initial SFA ([5], [8]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing geotechnical calculations used to demonstrate the acceptable safety factors, per §257.73(e)(1), in terms of:
    - Completeness and adequacy of supporting geotechnical investigation and testing data;
    - Completeness and approach of liquefaction triggering assessments; and
    - Input parameters, analysis methodology, selection of critical cross-sections, and loading conditions utilized for slope stability analyses.

- Phreatic conditions based on piezometric data collected between August 6, 2015 and May 6, 2021, as discussed in **Section 2.3**.

No significant technical issues were noted within the technical review. A detailed review (e.g., check) of the calculations was not performed.

6.3 Summary of Site Changes Affecting the Initial SFA

Several changes at the site that occurred after the development of the Initial SFA ([5], [8]) were identified. These changes required updates to the Initial SFA and are described below:

- The normal pool elevation within the south sub-basin of the EAP increased from 373.2 ft to 373.5 ft, resulting in a 0.3 ft of additional water loading on the embankment dikes for the maximum storage pool and seismic loading conditions (§257.73(e)(1)(i) and (iii), relative the Initial SFA.

6.4 Periodic SFA

Geosyntec revised existing slope stability analyses associated with the Initial SFA ([5], [8]) for cross-sections adjacent to the south sub-basin of the EAP to account for the increase in normal pool loading, as described in **Section 6.3**. The following approach and input data were used to revise the analyses:

- Analyses were updated for cross-sections B-B and K-K, as they are directly adjacent to the south sub-basin and subjected to increased pool loading.
    - Water levels in the EAP for the maximum storage pool, seismic, and liquefaction slope stability analysis loading conditions were increased to El. 373.5 ft.
    - Section H-H is also near the south sub-basin, but not adjacent to the free water pool, as CCR is located directly behind the dike. The phreatic water level assumed in the slope stability analyses for the initial SFA was above El. 373.5 ft. Therefore, slope stability analyses for Section H-H were not updated.
    - The seismic deformation analysis performed in the Initial SFA for Section K-K utilized the Bray and Travasarou (2007) methodology [22], including a spreadsheet that was, at the time of the Initial SFA, posted on a website hosted by Prof. Bray [23]. This spreadsheet has since been updated following Bray and Macedo (2019) methodology [24], and the spreadsheet utilized for the initial IDF is no longer available on Prof. Bray's website. Therefore, the seismic deformation analyses were updated to use the currently available Bray and Macedo (2019) method and spreadsheet.

- All other analysis input data and settings form the Initial SFA ([5], [8]) were utilized, including, but not limited to, subsurface stratigraphy and soil strengths, phreatic conditions, ground surface geometry, software package and version, slip surface search routines and methods, and input data for the seismic analyses (i.e., acceleration, magnitudes, probability of exceedances, maximum tolerable deformation).

Factors of safety from the Periodic SFA (cross-sections B-B and K-K) and the Initial SFA (A-A, C-C, G-G, and H-H) are summarized in **Table 3** and confirm that the EAP meets the requirements of §257.73(e)(1). Slope stability analysis output associated with the Initial SFA is provided in **Attachment D**.

Table 3 – Factors of Safety from Periodic SFA

	Structural Stability Assessment (§257.73(d)) and Safety Factor Assessment (§257.73(e))				Structural Stability Assessment (§257.73(d))
Cross-Section	**Maximum Storage Pool §257.73(e)(1)(i) Minimum Required = 1.50**	**Maximum Surcharge Pool[1] §257.73(e)(1)(ii) Minimum Required = 1.40**	**Seismic §257.73(e)(1)(iii) Minimum Required = 1.00**	**Dike Liquefaction §257.73(e)(1)(iv) Minimum Required = 1.20**	**Foundation Liquefaction §257.73(d)(1)(i) Minimum Required = 1.20**
A-A[2]	1.83	1.83	1.05	N/A	1.63
B-B[3]	1.77	1.78	1.13	N/A	2.12
C-C[2]	1.77	1.71	1.26	N/A	N/A
G-G[2]	1.68	1.68	1.16	N/A	N/A
H-H[2]	1.72	1.70	1.04	N/A	1.39
K-K[3]	1.53*	1.57*	1.00*	N/A	1.22*

Notes:
[1]Maximum surcharge pool analyses were not updated as the Periodic IDF water levels did not increase above the Initial IDF water levels and water levels used within the Initial SFA analyses.
[2]Denotes cross-section where results from the Initial SFA are presented due to no observed changes relative to the Initial IDF.
[3]Denotes cross-section where changes are occurred, and results are presented from the Periodic SFA.
*Indicates critical cross-section (i.e., lowest calculated factor of safety out of the two cross-sections analyzed)
N/A – Loading condition is not applicable.

SECTION 7

INFLOW DESIGN FLOOD CONTROL SYSTEM PLAN - §257.82

7.1 Overview of Initial IDF

The Initial Inflow Design Flood Control System Plan (Initial IDF) was prepared by AECOM in 2016 ([6], [8]), following the requirements of §257.82. The Initial IDF included the following information:

- A hydraulic and hydrologic analysis, performed for the probable maximum flood event because of the hazard potential classification of "high", which corresponded to 36 inches of rainfall over a 24-hour period.
- The Initial IDF utilized a HydroCAD Version 10.0 model to evaluate spillway flows and pool level increases during the design flood, with a SWSE of 370 ft in the North Sub-Basin and 373.2 ft in the South Sub-Basin of the EAP.

The Initial IDF concluded that the EAP met the requirements of §257.82, as the peak water surface estimated by the HydroCAD model was El. 376.2 ft in the North Sub-Basin and El. 377.6 ft in the South Sub-Basin, relative to a minimum EAP dike crest elevation of 378.0 ft in both subbasins. Therefore, overtopping was not expected. The Initial IDF also evaluated the potential for discharge from the CCR unit and determined that discharge in violation of the existing NDPES for the EAP was not expected, as all discharge from the EAP during both normal and inflow design flood conditions was expected to be routed through the existing spillway and NDPES-permitted outfall.

7.2 Review of Initial IDF

Geosyntec performed a review of the Initial IDF ([6], [8]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing the return interval used vs. the hazard potential classification.
- Reviewing the rainfall depth and distribution for appropriateness.
- Performing a high-level review of the inputs to the hydrological modeling.
- Reviewing the hydrologic model parameters for spillway parameters, starting pool elevation, and storage vs. the reference data.
- Reviewing the overall Initial IDF vs. the applicable requirements of the CCR Rule [1].

Several review comments were identified during review of the Initial IDF. The comments are described below:

- The Initial IDF utilized the National Resource Conservation Service (NRCS) Type II rainfall distribution type [25]. Geosyntec recommend utilizing the NRCS 24-hour Emergency Spillway and Freeboard (ESFB) distribution [26] which is a distribution that NRCS utilizes in making determination and analysis of auxiliary spillway flow depth and duration, for the reasons listed below.
    - The ESFB rainfall distribution was determined by NRCS to be a more accurate representation of a 24-hour Probable Maximum Precipitation (PMP) event per a study applying different rainfall distributions to 24-hour PMP storm events for purposes of evaluating existing high-hazard dams east of the 105th meridian [26]:
        - *For the area east of the 105th meridian, the Type II and Type III patterns used with 24-hour PMP values consistently produces one-hour and two-hour intensities that far exceeded any known or documented rates…Because the Type II and Type III distributions over-predicted the maximum one-hour intensity for PMP events, they were excluded from further study.*
        - *The dimensionless conversion of the ESFB distribution from a 6-hour to a 24-hour pattern has been used with PMP events in a number of states where 24-hour storms are required as a part of the State's dam safety criteria and approval process……Although the ESFB Distribution and the World Curve distribution were developed from entirely independent data sources, the distributions are similar when compared on a volume-duration basis. The world curve supports the ESFB.*
        - *The World Curve Distribution is a valid basis for design of high hazard structures…It would seem logical to use the World Curve distribution for PMP size event.*
    - The NRCS study [26] determined that the NRCS ESFB is comparable to the World Curve. The World Curve is developed from worldwide maximum rainfall records and deemed by NRCS to be logical to use for a PMP size event and valid for design of high hazard structures.
    - The NRCS study [26] deemed the NRCS Type II (and III) distributions to overpredict PMP maximum 1-hr intensities, which typically control dam capacity design, and therefore were not considered further as a basis for rainfall distributions of PMP size events.

7.3 Summary of Site Changes Affecting the Initial IDF

Two changes at the site that occurred after development of the Initial IDF were identified. These changes required updates to the Initial IDF and are described below:

- Approximately 18,000 CY and 78,000 CY of CCR were placed above the SWSE utilized for the Initial IDF certification in the south and north sub-basins of the EAP, respectively, thereby altering the stage-storage curve for both sub-basins, relative to the Initial IDF.

- The surveyed water surface elevation (WSE) within the south sub-basin of the EAP was 373.5 ft in 2020 [10]; this is 0.3 ft higher than the SWSE used in the Initial IDF and 0.5 ft above the WSE surveyed in 2016 [16], thereby the SWSE utilized in the Initial IDF was no longer consistent with conditions observed in 2020.

7.4 Periodic IDF

Geosyntec revised the HydroCAD model associated with the Initial IDF to account for the revised rainfall distribution type, increase in SWSE, and additional CCR placement, as described in **Sections 7.2** and **7.3**. The following approach and input data were used for the revised analyses:

- Stage-storage (i.e., area-capacity) curves for both the north and south sub-basins of the EAP were updated based on the 2020 site survey [10].

    - A revised stage-volume curve for the EAP was prepared based on measuring the area of both north and south subbasins within the EAP at every one-foot increment of depth from an elevation just beneath the normal pool elevation (369.0 ft) to the perimeter dike embankment crest elevation (378.0 ft). This elevation-surface area curve was input to HydroCAD, which computed a stage-volume curve for the subbasins using the conic volume method. The survey showed a total overall loss of 78 ac-ft of storage volume from the EAP from 2016 to 2020.

- The SWSE within the south sub-basin of the EAP was updated from 373.2 ft to 373.5 ft to reflect the 2020 site survey [10].

- The rainfall distribution type was updated to the "Spillway Emergency" storm type provided by HydroCAD [23], which replicates the NRCS 24-hour ESFB distribution.

- All other input data and settings from the Initial IDF HydroCAD model were utilized, including, but not limited to software package and version, runoff method, analysis time span and analysis time step.

The results of the Updated IDF are summarized in **Table 4** and confirm that the EAP sill meets the requirements of §257.82(a)-(b), as the peak water surface elevation does not exceed the minimum perimeter dike crest elevations. Additionally, all discharge from the EAP is routed through the existing spillway system to the NPDES-permitted outfall, during both normal and IDF

conditions. Updated area-capacity curves and HydroCAD model output is provided in **Attachment E**.

Table 4 – Water Levels from Periodic IDF

	North Sub-Basin		South Sub-Basin		
Analysis	**Starting Water Surface Elevation (ft)**	**Peak Water Surface Elevation (ft)**	**Starting Water Surface Elevation (ft)**	**Peak Water Surface Elevation (ft)**	**Minimum Dike Crest Elevation (ft)**
Initial IDF	370.0	376.2	373.2	377.6	378.0
Periodic IDF	370.0	376.0	373.5	377.3	378.0
Initial to Periodic Change[1]	0.0	-0.2	+0.3	-0.3	

Notes:
[1]Postive change indicates increase in the WSE relative to the Initial IDF, negative change indicates decrease in the WSE, relative to the Initial IDF.

SECTION 8

CONCLUSIONS

The EAP at JPP was evaluated relative to the USEPA CCR Rule periodic assessment requirements for:

- Hazard potential classification (§257.73(a)(2)),
- History of Construction reporting (§257.73(d)),
- Structural stability assessment (§257.73(d)), with the exception of §257.73(d)(1)(vi) that was independently certified by Luminant [9],
- Safety factor assessment (§257.73(e)), and
- Inflow design flood control system planning (§257.82).

Based on the evaluations presented herein, the referenced requirements are satisfied.

SECTION 9

CERTIFICATION STATEMENT

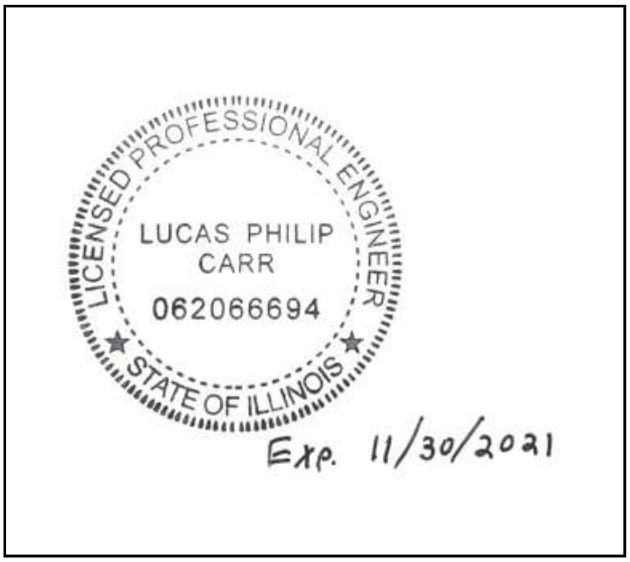
CCR Unit: Electric Energy Incorporated, Joppa Power Plant, East Ash Pond

I, Lucas P. Carr, 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 2021 USEPA CCR Rule Periodic Certification Report, has been prepared in accordance with the accepted practice of engineering. I certify, for the above-referenced CCR Unit, that the periodic assessment of the hazard potential classification, history of construction report, structural stability, safety factors, and inflow design flood control system planning, dated October 2021, were conducted in accordance with the requirements of 40 CFR §257.73(a)(2), (c), (d), (e), and §257.82, with the exception of §257.73(d)(1)(vi)) that was independently certified by others.

Lucas P. Carr

10/11/2021

Date



SECTION 10

REFERENCES

[1] United States Environmental Protection Agency, 40 CFR Parts 257 and 261; Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule, 2015.

[2] Stantec Consulting Services, Inc., "Initial Hazard Potential Classification Assessment, EPA Final CCR Rule, East Ash Pond, Joppa Power Station, Massac County, Illinois," Fenton, MO, October 12, 2016.

[3] AECOM, "History of Construction, USEPA Final CCR Rule, Joppa Power Station, Joppa, Illinois," October 2016.

[4] AECOM, "CCR Rule Report: Initial Structural Stability Assessment For East Ash Pond At Joppa Power Station," St. Louis, MO, October 2016.

[5] AECOM, "CCR Rule Report: Initial Safety Factor Assessment For East Ash Pond At Joppa Power Station," St. Louis, MO, October 2016.

[6] AECOM, "CCR Rule Report: Initial Inflow Design Flood Control System Plan For East Ash Pond At Joppa Power Station," St. Louis, MO, October 2016.

[7] Stantec Consulting Services, Inc., "Documentation of Initial Hazard Potential Classification Assessment, East Ash Pond, Joppa Power Station, Massac County, Illinois," October 12, 2016.

[8] AECOM, "CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Control System Plan for East Ash Pond at Joppa Power Station," St. Louis, MO, October 2016.

[9] Luminant, "East Ash Pond Structural Stability Assessment, Electric Energy Inc., Joppa Power Station," November 14, 2020.

[10] IngenAE, "Luminant, Dynegy Midwest Generation, LLC, Joppa Power Station, December 2020 Topography," Earth City, Missouri, May 20, 2021.

[11] D. Hoots, *Annual CCR Surface Impoundment Inspection Report (per 40 CFR 257.83(b)(2)), Joppa Power Station, East Ash Pond,* January 14, 2016.

[12] D. Hoots, *Annual CCR Surface Impoundment Inspection Report (per 40 CFR 257.83(b)(2)), Joppa Power Station, East Ash Pond,* January 12, 2017.

[13] J. Knutelski, *Annual Inspection by a Qualified Professional Engineer, 40 CFR §257.83(b), Electric Energy, Inc. - Joppa, East Ash Pond,* December 28, 2018.

[14] J. Knutelski, *Annual Inspection by a Qualified Professional Engineer, 40 CFR 257.83(b), Electric Energy, Inc. - Joppa, East Ash Pond,* January 8, 2020.

[15] J. Knutelski, *Annual Inspection by a Qualified Professional Engineer, 40 CFR §257.83(b), Electric Energy, Inc. - Joppa, East Ash Pond,* January 6, 2021.

[16] Weaver Consultants Group, "Dynegy, Collinsville, IL, 2015 - Joppa Existing Topography," Collinsville, IL, December 2015.

[17] AECOM, "Draft Initial Site Visit Summary, Dynegy CCR Compliance Program," June 18, 2015.

[18] Hanson Professional Services, Inc., "Report on reported seepage, Joppa active South Ash Pond, Dynegy IPH Joppa Power Station, Joppa, Illinois," Springfield, Illinois, January 10, 2020.

[19] Hanson Professional Services, Inc., "Blanket Drain, Joppa Active South Ash Pond, Joppa, Illinois, Revision 1," January 13, 2021.

[20] U.S. Army Corps of Engineers, Hydrologic Engineering Center, "Hydrologic Engineer Center River Analysis System (HEC-RAS) Software, Version 5.0.1," April 2016.

[21] Stantec Consulting Services, Inc, "Dynegy Midwestern Generation, LLC, Joppa Power Station, Joppa, Massac County, IL, Emergency Action Plan, East Ash Pond (NID # IL50714)," Fenton, MO, April 13, 2017.

[22] J. Bray and T. Travasarou, "Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements," *Journal of Geotechnical and Geoenvironmental Engineering,* vol. 133, no. 4, pp. 381-392, 2007.

[23] J. Bray, "Jonathan D. Bray | Civil and Environmental Engineering," University of California, Berkeley, [Online]. Available: https://ce.berkeley.edu/people/faculty/bray. [Accessed 26 August 2021].

[24] J. Bray and J. Macedo, "Procedure for Estimating Shear-Induced Seismic Slope Displacement for Shallow Crustal Earthquakes," *Journal of Geotechnical and Geoenvironmental Engineering,* vol. 145, no. 12, 2019.

[25] J.N. Moore and R.C. Riley, "Comparison of Temporal Rainfall Distributions for Near Probably Maximum Precipitation Storm Events for Dam Design," National Water Management Center, Natural Resources Conservation Service (NRCS), Little Rock, Arkansas.

[26] HydroCADTM Software Solutions, LLC. , *HydroCADTM Stormwater Modeling System, Version 10,* Chocorua, New Hampshire, 2016.

DRAWINGS

INITIAL SURVEY
12-01-2015 TOPOGRAPHY

PERIODIC SURVEY
03-09-2021 TOPOGRAPHY

NOTES:

1. THE INITIAL SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - JOPPA EXISTING TOPOGRAPHY", PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "LUMINANT, ELECTRIC ENERGY, INC., JOPPA POWER STATION, DECEMBER 2020 TOPOGRAPHY", PREPARED BY INGENAE, DATED MARCH 9, 2021.
3. ALL SURVEY DATA WAS COLLECTED IN THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) AND NORTH AMERICAN DATUM OF 1983 (NAD83) FOR VERTICAL AND HORIZONTAL COORDINATES, RESPECTIVELY.

0 500
SCALE IN FEET

INITIAL TO PERIODIC SURVEY COMPARISON
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

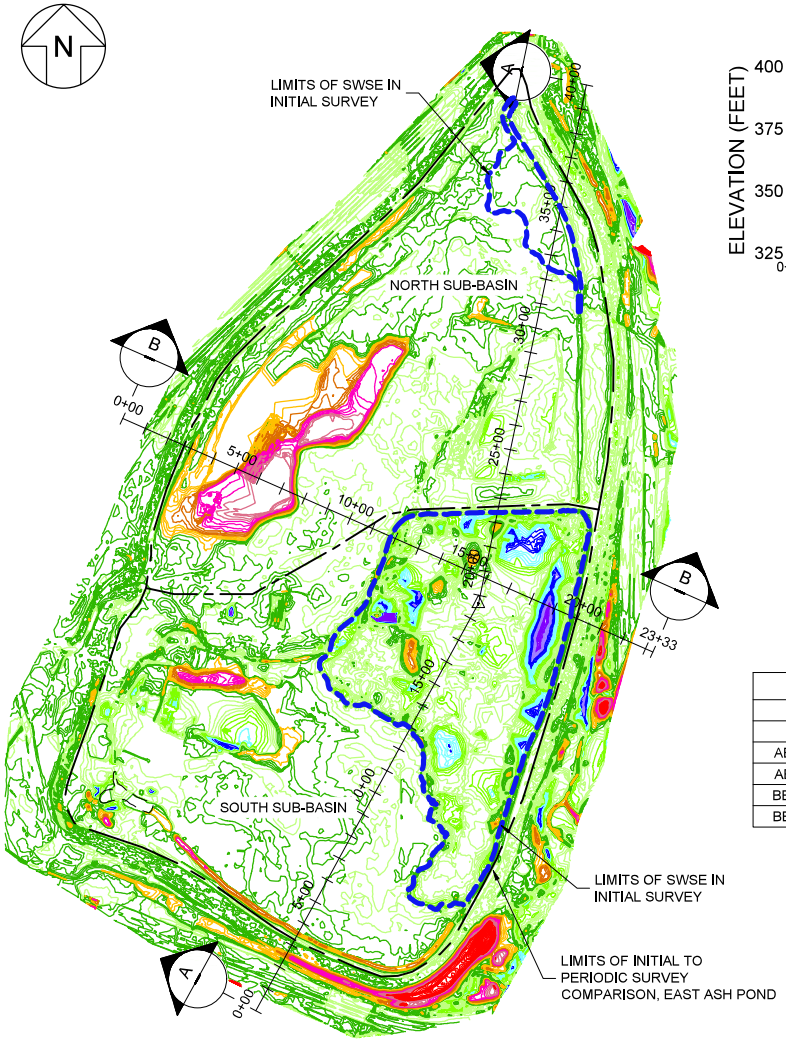
Geosyntec consultants

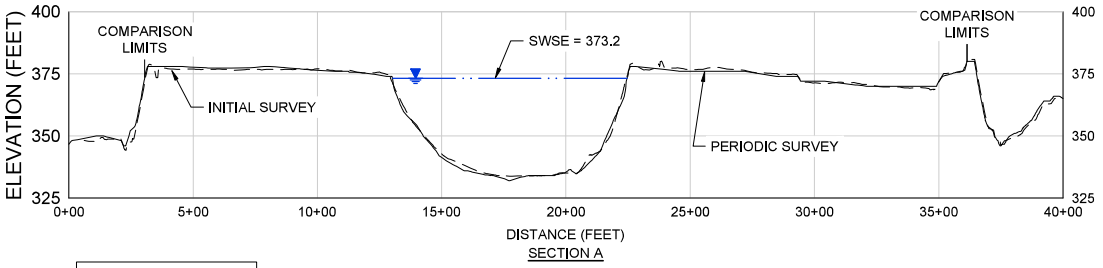
FIGURE
1

GLP8027.06 | MAY 2021

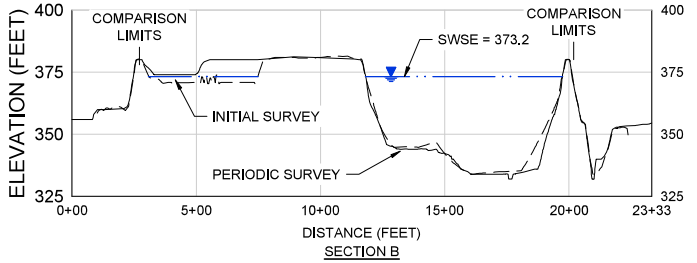
P:\CADD\PROJECTS\VISTRA PONDS\JOPPA\FIGURES\GLP8027006F01 - Last Saved by: KHaravec on 5/19/21

R001311





ISOPACH CONTOUR KEY		
COLOR	MIN ELEV	MAX ELEV
	-28	-10
	-10	-8
	-8	-6
	-6	-4
	-4	-2
	-2	0
	0	2
	2	4
	4	6
	6	8
	8	10
	10	34



INITIAL TO PERIODIC SURVEY COMPARISON SUMMARY			
	CUT	FILL	NET (CU. YD.)
EAST ASH POND	102,389	141,063	38,674 (FILL)
ABOVE SWSE - NORTH SUB-BASIN	21,085	98,639	77,554 (FILL)
ABOVE SWSE - SOUTH SUB-BASIN	17,252	35,435	18,182 (FILL)
BELOW SWSE - NORTH SUB-BASIN	192	1,853	1,661 (FILL)
BELOW SWSE - SOUTH SUB-BASIN	63,829	5,151	58,677 (CUT)

NOTES:

1. THE INITIAL SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - JOPPA EXISTING TOPOGRAPHY", PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "LUMINANT, ELECTRIC ENERGY, INC., JOPPA POWER STATION, DECEMBER 2020 TOPOGRAPHY", PREPARED BY INGENAE, DATED MARCH 9, 2021.
3. ALL SURVEY DATA WAS COLLECTED IN THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) AND NORTH AMERICAN DATUM OF 1983 (NAD83) FOR VERTICAL AND HORIZONTAL COORDINATES, RESPECTIVELY.
4. THE STARTING WATER SURFACE ELEVATION (SWSE) OF THE EAST ASH POND IS EL. 373.2 FT IN THE SOUTH SUB-BASIN AND 370.0 FT IN THE NORTH SUB-BASIN, AS NOTED IN THE REPORT TITLED "CCR CERTIFICATION REPORT: INITIAL STRUCTURAL STABILITY ASSESSMENT, INITIAL SAFETY FACTOR ASSESSMENT, AND INITIAL INFLOW DESIGN FLOOD CONTROL SYSTEM PLAN FOR EAST ASH POND AT JOPPA POWER STATION", PREPARED BY AECOM, DATED OCTOBER, 2016.

SURVEY COMPARISION ISOPACH
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

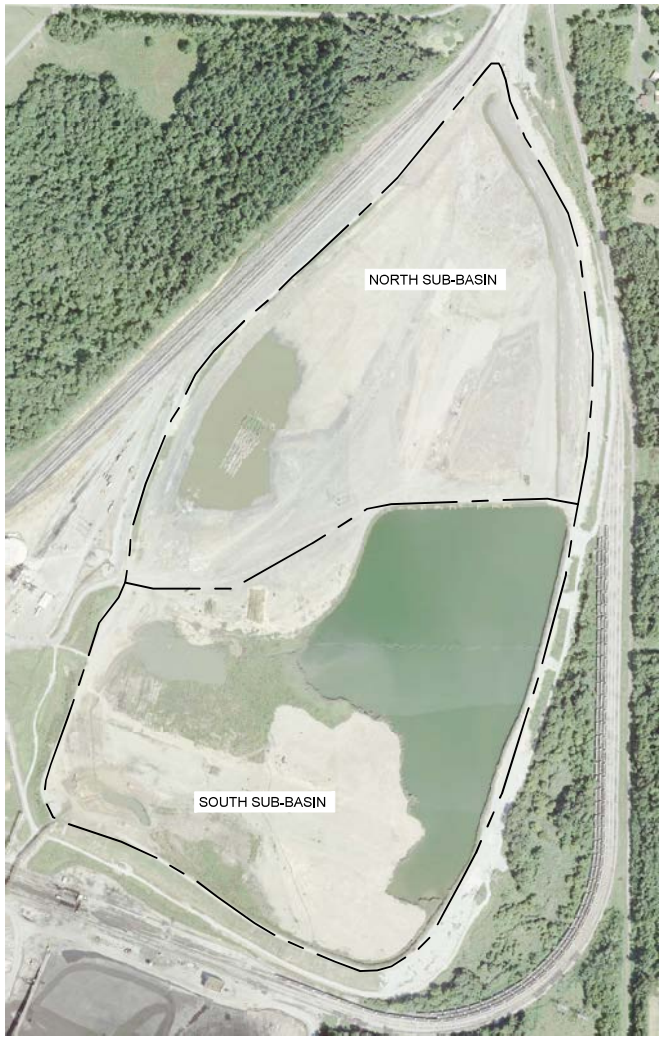
Geosyntec consultants

FIGURE 2

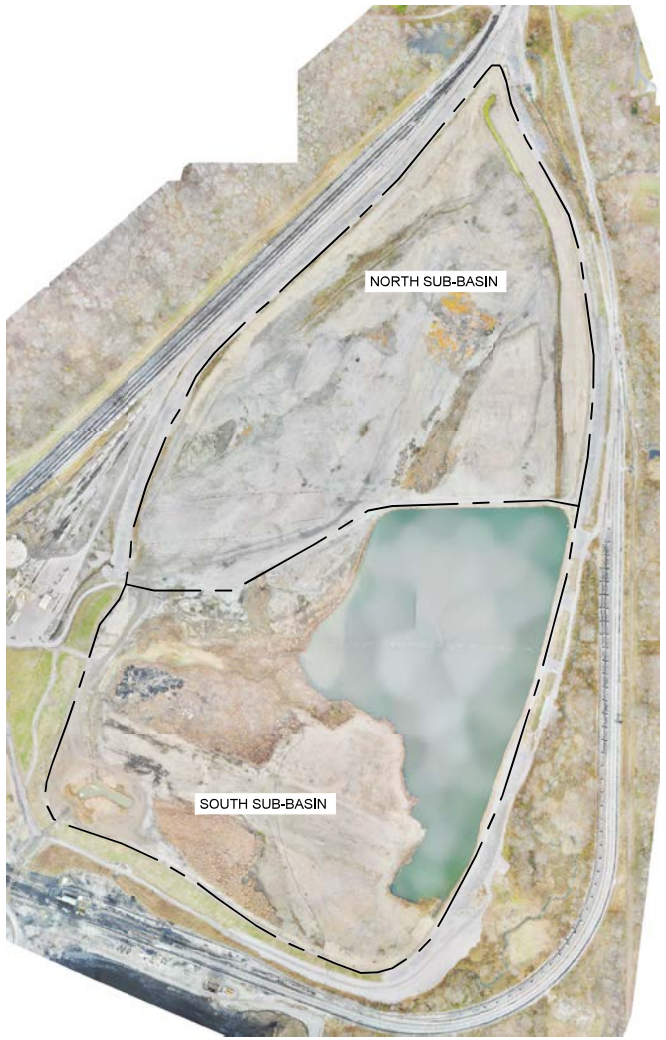
GLP8027.06 | MAY 2021

P:\CADD\PROJECTS\VISTRA POND\SUOPPA\FIGURES\ISOPACH - Last Saved by: KHanavec on 5/20/21

R001312



INITIAL AERIAL
12-01-2015 IMAGERY



PERIODIC AERIAL
03-09-2021 IMAGERY

NOTES:

1. THE INITIAL IMAGERY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - JOPPA EXISTING TOPOGRAPHY", PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC IMAGERY WAS TAKEN FROM THE DRAWING PACKAGE TITLED "LUMINANT, ELECTRIC ENERGY, INC., JOPPA POWER STATION, DECEMBER 2020 TOPOGRAPHY", PREPARED BY INGENAE, DATED MARCH 9, 2021.

0 500
SCALE IN FEET

INITIAL TO PERIODIC AERIAL IMAGERY
COMPARISON
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

Geosyntec consultants

DRAWING 3

GLP8027.06 | MAY 2021

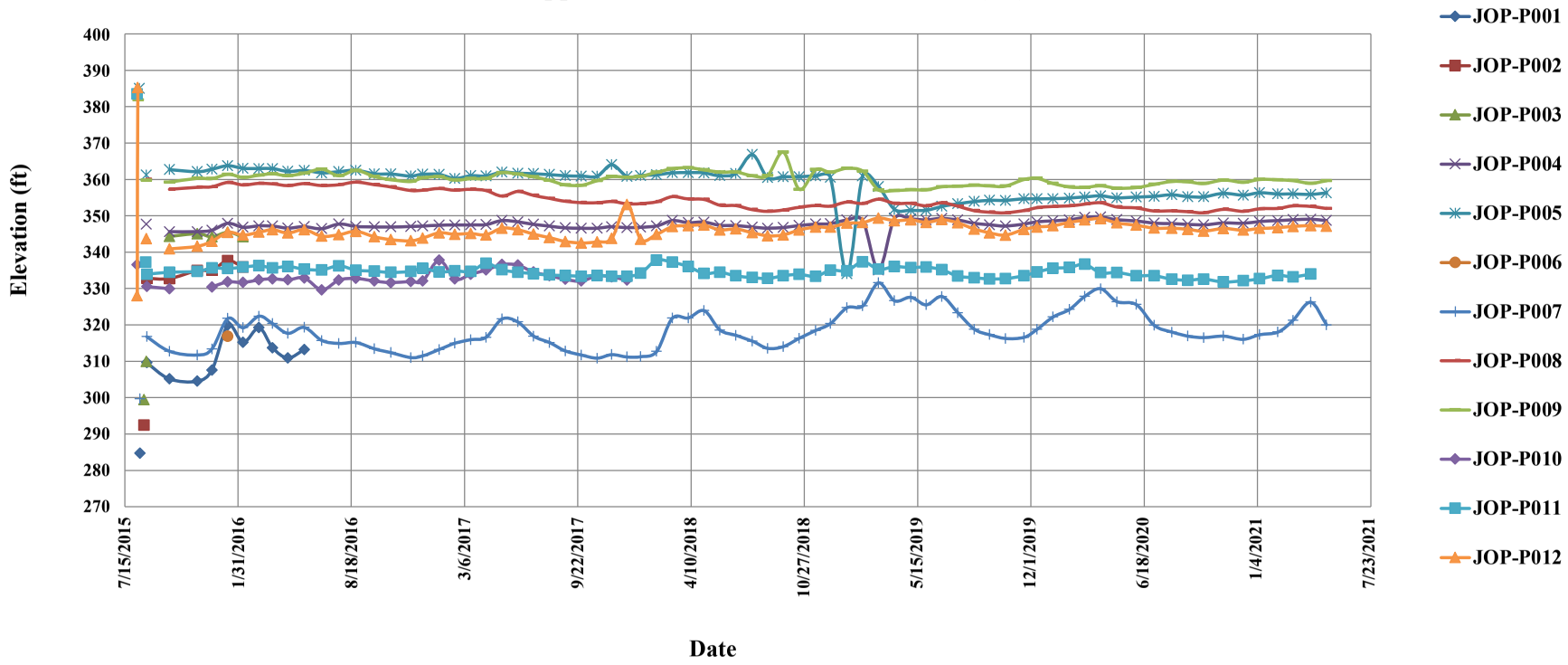
P:\CADD\PROJECTS\VISTRA PONDS\JOPPA\FIGURES\GLP802706F02 - Last Saved by: KHaravec on 5/24/21

R001313

ATTACHMENTS

Attachment A

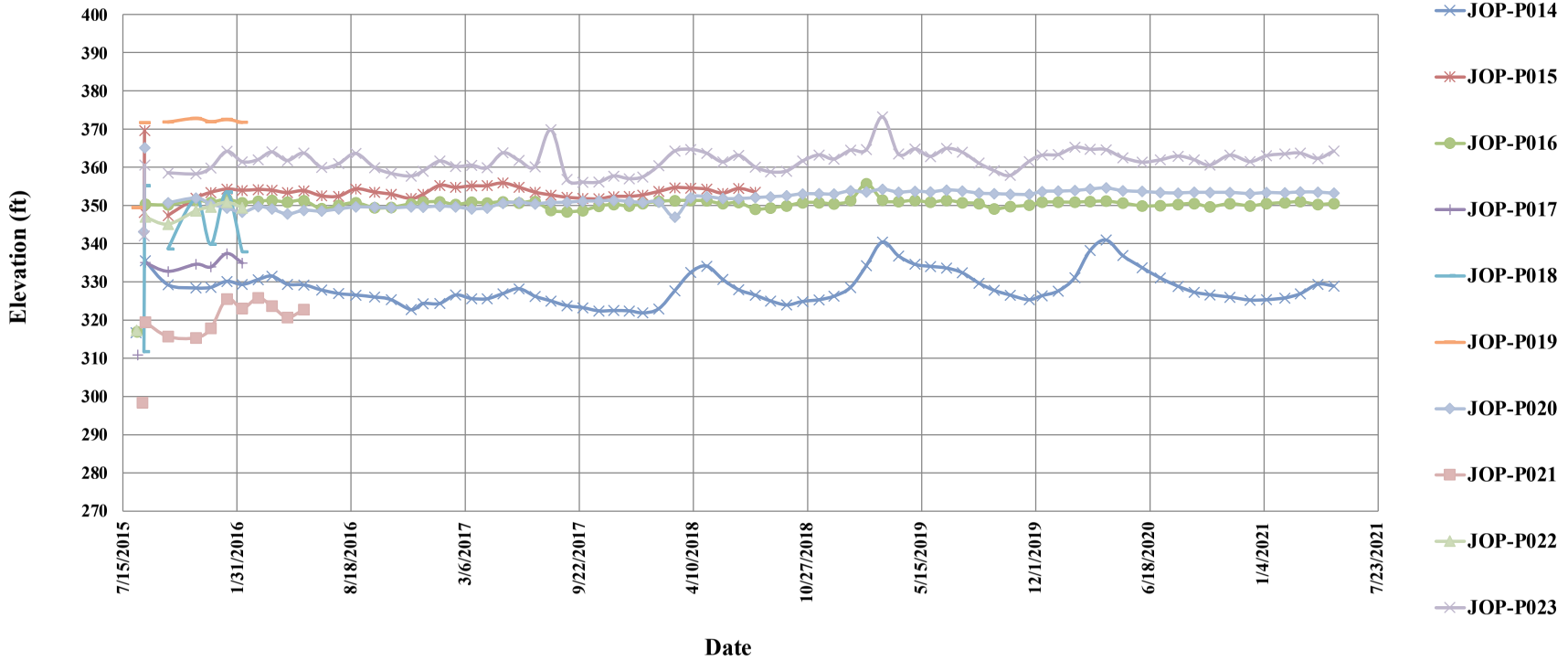
EAP Piezometer Data Plots



NOTES:
1. Piezometer data was taken from the spreadsheet titled "Joppa Piezo Measurements_20160109", provided by the Joppa Power Plant.

PIEZOMETER DATA PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS		
Geosyntec consultants		Figure A-1
GLP8027	5/20/2021	

R001316



NOTES:
1. Piezometer data was taken from the spreadsheet titled "Joppa Piezo Measurements_20160109", provided by the Joppa Power Plant.

PIEZOMETER DATA PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS	
Geosyntec consultants	Figure A-2
GLP8027	5/20/2021

R001317

Attachment B

EAP Site Visit Photolog

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc. **Project Number:** GLP8027

CCR Unit: East Ash Pond (EAP) **Site:** Joppa Power Plant

Photo: 01 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Overview of EAP perimeter dike.	

Photo: 02 **Date:** 05/26/2021 **Direction Facing:** NE **Comments:** Overview of perimeter slope protection	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 03 **Date:** 05/26/2021 **Direction Facing:** NE **Comments:** Overview of perimeter slope protection	
Photo: 04 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Overview of slope protection near 72" CMP inlet	

GEOSYNTEC CONSULTANTS	
Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 05 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Overview of perimeter slope protection. Material was dumped crushed stone and fines.	

Photo: 06 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Outfall structure mixing tank overview.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 07 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** Outfall structure mixing tank and weir overview.	

Photo: 08 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** Inlet for culvert leading to outfall structure. Note plugging with algae and debris. Geosytnec recommended cleaning of inlet as part of routine site maintenance.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc. **Project Number:** GLP8027

CCR Unit: East Ash Pond (EAP) **Site:** Joppa Power Plant

Photo: 09 **Date:** 05/26/2021 **Direction Facing:** SW **Comments:** Outfall discharge into the mixing basin.	
Photo: 10 **Date:** 05/26/2021 **Direction Facing:** S **Comments:** Overview of northeast embankment exterior and slope protection.	

GEOSYNTEC CONSULTANTS

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 11 **Date:** 05/26/2021 **Direction Facing:** SW **Comments:** Exterior embankment slope protection.	

Photo: 12 **Date:** 05/26/2021 **Direction Facing:** SE **Comments:** North EAP interior slope protection (vegetation and crushed stone).	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 13 **Date:** 05/26/2021 **Direction Facing:** SE **Comments:** North EAP exterior slope protection.	

Photo: 14 **Date:** 05/26/2021 **Direction Facing:** SE **Comments:** North EAP interior slope protection (crushed stone and vegetation).	

GEOSYNTEC CONSULTANTS	
Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 15 **Date:** 05/26/2021 **Direction Facing:** SW **Comments:** North EAP exterior slope.	

Photo: 16 **Date:** 05/26/2021 **Direction Facing:** S **Comments:** North EAP exterior slope.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 17 **Date:** 05/26/2021 **Direction Facing:** S **Comments:** Perimeter slope protection overview	

Photo: 18 **Date:** 05/26/2021 **Direction Facing:** S **Comments:** Perimeter slope protection overview	

GEOSYNTEC CONSULTANTS	
Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 19 **Date:** 05/26/2021 **Direction Facing:** SW **Comments:** Perimeter slope vegetation.	

Photo: 20 **Date:** 05/26/2021 **Direction Facing:** SW **Comments:** Perimeter slope vegetation	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 21 **Date:** 05/26/2021 **Direction Facing:** SE **Comments:** Sluice pipe discharge area.	

Photo: 22 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** South perimeter dike overview.	

GEOSYNTEC CONSULTANTS

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 23 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** South perimeter dike crest and exterior slope overview.	

Photo: 24 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** Overview of DMM area and slope protection.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 25 **Date:** 05/26/2021 **Direction Facing:** NE **Comments:** Overview of DMM area and slope protection.	

Photo: 26 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Overview of perimeter slope protection	

GEOSYNTEC CONSULTANTS	
Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 27 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Interior slope vegetation overview	
Photo: 28 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Perimeter slope protection and vegetation	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 29 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Culvert between north and south basins of EAP.	

Photo: 30 **Date:** 05/26/2021 **Direction Facing:** W **Comments:** Staff gauge installed within the EAP, on the handrails.	

GEOSYNTEC CONSULTANTS

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 31 **Date:** 05/26/2021 **Direction Facing:** SE **Comments:** Overview of DSM toe in area of reinforced soil slope (RSS).	
Photo: 32 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Inlet to 72" CMP at east dike toe.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Electric Energy Inc.	**Project Number:** GLP8027
CCR Unit: East Ash Pond (EAP)	**Site:** Joppa Power Plant

Photo: 33 **Date:** 05/26/2021 **Direction Facing:** N **Comments:** Another view of the inlet to the 72" CMP	

Photo: 34 **Date:** 05/26/2021 **Direction Facing:** E **Comments:** Outlet to 72" CMP. Some section loss observed at outlet. However, this pipe does not penetrate the dike of the EAP and is located downstream of the discharge of the EAP.	

Attachment C

Periodic History of Construction Report Update Letter

Geosyntec consultants

1 McBride and Son Center Drive, Suite 202
Chesterfield, MO 63005
PH 636-812-0800
www.geosyntec.com

October 11, 2021

Electric Energy, Inc.
2100 Portland Road
Joppa, Illinois 62953

Subject: Periodic History of Construction Report Update Letter
USEPA Final CCR Rule, 40 CFR §257.73(c)
Joppa Power Plant
Joppa, Illinois

At the request of Electric Energy, Inc. (EEI), Geosyntec Consultants (Geosyntec) has prepared this Letter to documents updates to the Initial History of Construction (HoC) report for the Joppa Power Plant (JPP), also known as the Joppa Power Station (JOP). The Initial HoC report was prepared by AECOM in October of 2016 [1] in accordance with 40 Code of Federal Regulations (CFR) §257.73(c) of the United States Environmental Protection Agency (USEPA) Coal Combustion Residuals Rule, known as the CCR Rule [2]. This letter also includes information required by Section 845.220(a)(1)(B) (Design and Construction Plans) of the state-specific Illinois Environmental Protection Agency (IEPA) Part 845 CCR Rule [3] that is not expressly required by §257.73(c).

BACKGROUND

The CCR Rule required that, by October 17, 2016, Initial HoC reports to be compiled for existing CCR surface impoundments with: (1) a height of five feet or more and a storage volume of 20 acre-feet or more, or (2) a height of 20 feet or more. The Initial HoC report was required to contain, to the extent feasible, the information specified in 40 CFR §257.73(c)(1)(i)-(xii). The Initial HoC report for JPP, which included the existing CCR surface impoundment, the East Ash Pond (EAP), was prepared and subsequently posted to EEI's CCR Website prior to October 17, 2016.

The CCR Rule requires that Initial HoC to be updated if there is a significant change to any information complied in the Initial HoC report, as listed below:

§ 257.73(c)(2): If there is a significant change to any information complied under paragraph (c)(1) of this section, the owner or operator of the CCR unit must update the relevant information and place it in the facility's operating record as required by § 257.105(f)(9).

EEI retained Geosyntec to review the Initial HoC report, review reasonably and readily available information for the EAP generated since the Initial HoC report was prepared, and perform a site visit to JPP to evaluate if significant changes may have occurred since the Initial HoC report was prepared. This Letter contains the results of Geosyntec's evaluation and documents significant changes that have occurred at the EAP and JPP, as they pertain the requirements of §257.73(c)(1)(i)-(xii)

UPDATES TO HISTORY OF CONSTRUCTION REPORT

Geosyntec's evaluation for the JPP EAP determined that no known significant changes requiring updates to the information in the Initial HoC report pertaining to §257.73(c)(1)(ii)-(vi) and (xi)-(xii) of the CCR Rule had occurred since the Initial HoC report was developed.

However, Geosyntec's evaluation determined that significant changes at the JPP EAP pertaining to §257.73(c)(1)(i) and (vii)-(x) of the CCR Rule had occurred since the Initial HoC report had been developed. Additionally, information how long the CCR surface impoundments have been operating and the types of CCR in the surface impoundments, as required by Section 845.220(a)(1)(B) of the Part 845 Rule were not included in the Initial HoC report, as this information is not required by the CCR Rule. Each change and the subsequent updates to the Initial HoC report is described within this section.

Section 845.220(a)(1)(B): A statement of … how long the CCR surface impoundment has been in operation, and the types of CCR that have been placed in the surface impoundment.

East Ash Pond

The EAP is in operation since 1973 for a total of approximately 48 years [4].

CCR placed in the EAP is being used to store and dispose of sluiced bottom ash, fly ash, and dredged material from the coal pile runoff pond [4].

§ 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.

A state identification numbers (IDs) for the EAP was assigned by the Illinois Environmental Protection Agency (IEPA). The ID is listed in **Table 1**.

Table 1 – IEPA ID Numbers

CCR Surface Impoundment	State ID
East Ash Pond (EAP)	W1270100004-02

§ 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.

A wet area was observed at the toe of the eastern perimeter dike of the EAP in 2020. The wet area was repaired with geotextile, sand, and crushed stone in 2020, based on engineering drawings. Drawings for this repair are provided in **Attachment A**.

§ 257.73(c)(1)(viii): A description of the type, purpose, and location of existing instrumentation.

Several piezometers were abandoned, have stopped working, or are no longer being read due health and safety concerns related with poor accessibility that have developed since 2016. These piezometers include:

- JOP-P001, JOP-P002, JOP-P003, JOP-P010, JOP-P015, JOP-P017, JOP-P018, JOP-P019, JOP-P021, JOP-P022, B1, and B2.

§ 257.73(c)(1)(ix): Area-capacity curves for the CCR unit.

Updated area-capacity curves were prepared for the north and south sub-basins of the EAP in 2021. These curves are provided in **Figures 1** and **2**.

Figure 1 – Area-Capacity Curve for East Ash Pond – North Sub-Basin

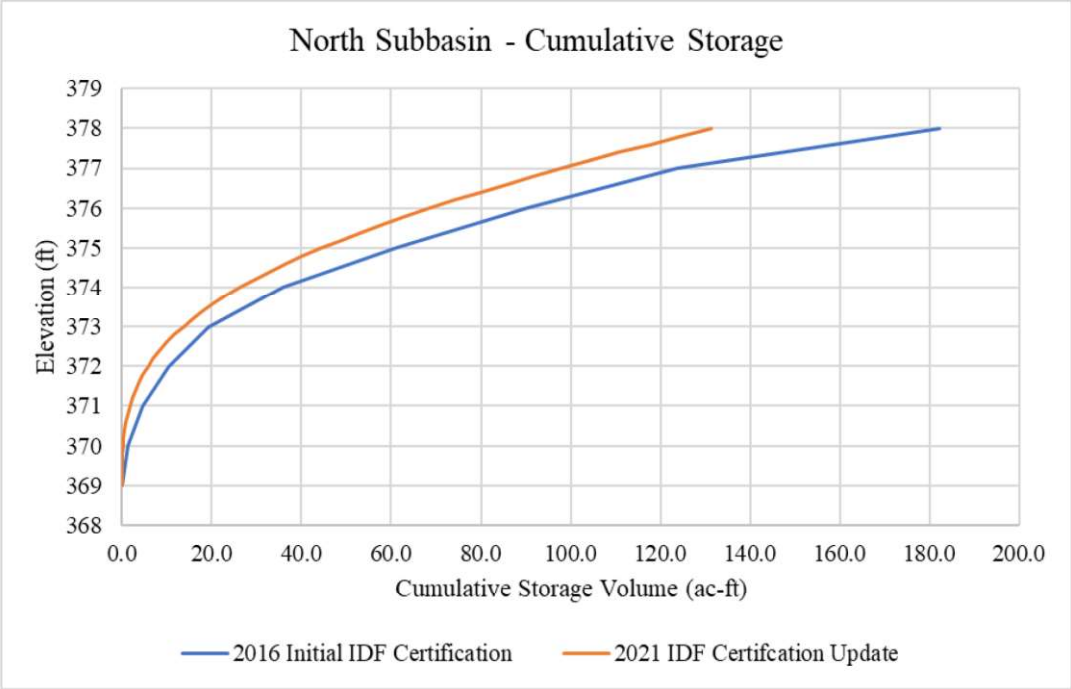
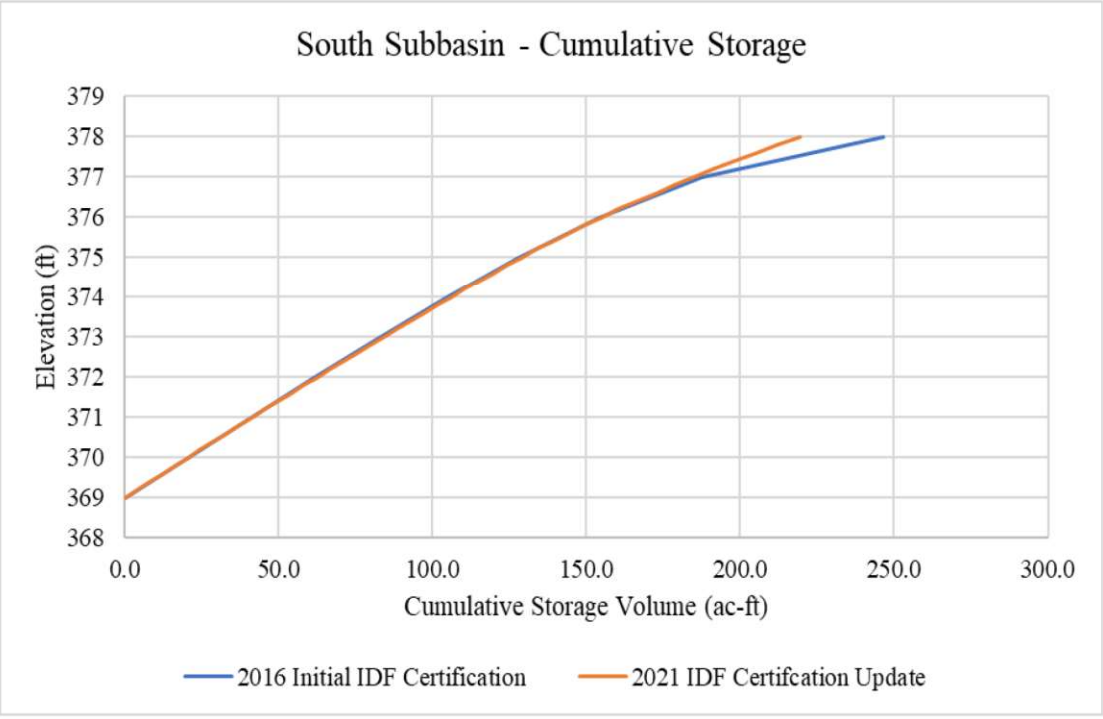


Figure 2 – Area-Capacity Curve for East Ash Pond – South Sub-Basin



§ 257.73(c)(1)(x): A description of each spillway and diversion design features and capacities and calculations used in their determination.

Updated discharge capacity calculations for the existing spillways were prepared in 2021 using HydroCAD 10 modeling software. The calculations indicate that the EAP has sufficient storage capacity and will not overtop the embankments during the Probable Maximum Precipitation (PMP), 24-hour, storm event. The results of the calculations are provided in **Table 2**.

Table 2 – Results of Updated Discharge Capacity Calculations

	North Sub-Basin	South Sub-Basin
Approximate Berm Minimum Elevation[1], ft	378.0	378.0
Approximate Emergency Spillway Elevation[1], ft	Not Applicable	Not Applicable
Starting Water Surface Elevation[1] (SWSE), ft	370.0	373.5
Peak Water Surface Elevation[1] (PWSE), ft	375.95	377.29
Time to Peak, hr	12.6	15.5
Surface Area[2], ac	26.8	33.6
Storage[3], ac-ft	67.3	99.4

Notes:
[1]Elevations are based on the NAVD88 datum
[2] Surface Area is defined as the water surface area at the PWSE
[3]Storage is defined as the volume between the SWSE and PWSE

CLOSING

This letter has been prepared to document Geosyntec's evaluation of changes that have occurred at the EAP at the JPP since the Initial HoC was developed, based on reasonably and readily available information provided by EEI, observed by Geosyntec during the site visit, or generated by Geosyntec as part of subsequent calculations.

Sincerely,

Lucas P. Carr, P.E.
Senior Engineer

John Seymour, P.E.
Senior Principal

REFERENCES

[1] AECOM, "History of Construction, USEPA 40 CFR § 257.73(c), Joppa Power Station, Joppa, Illinois," October 2016.

[2] United Stated Environmental Protection Agency, "40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule, 2015," 2015.

[3] Illinois Environmental Protection Agency, "35 Ill. Adm. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments," Springfield, IL, 2021.

[4] AECOM, "History of Construction, USEPA Final CCR Rule, 40 CFR § 257.73(c), Hennepin Power Station, Hennepin, Illinois," October 2016.

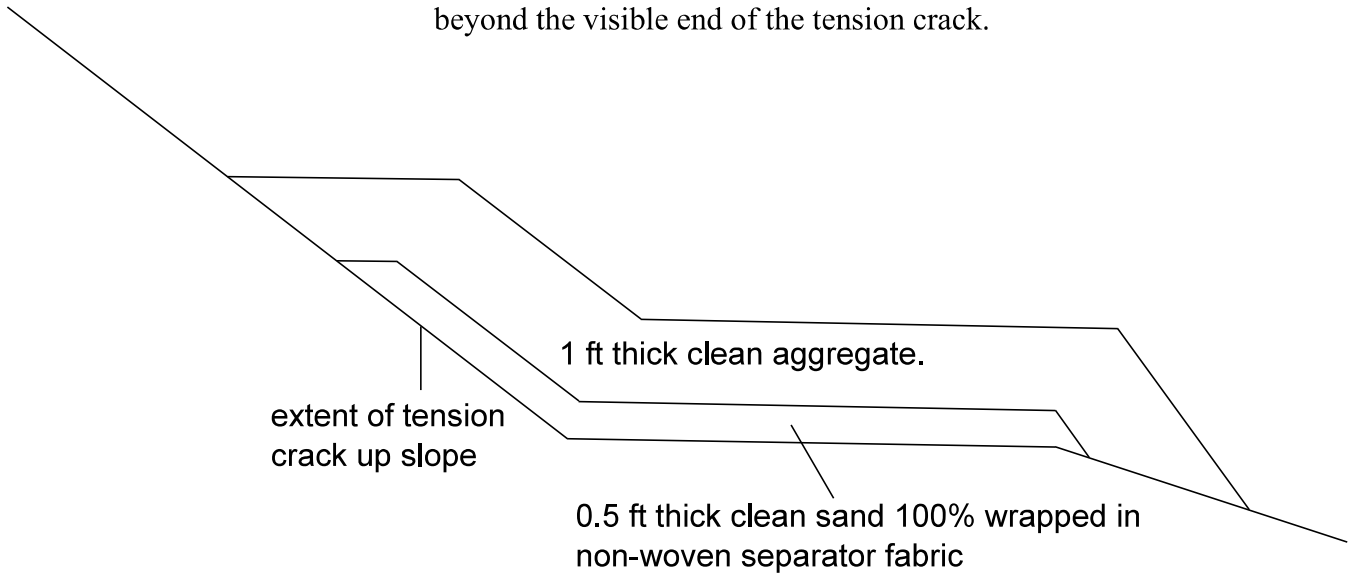
APPENDICES

Appendix A Drawings for 2020 EAP Wet Area Repair

Appendix A
Drawings for 2020 EAP Wet Area Repair

Revision 1
1/13/2020

Ends of Blanket Drain should extend a minimum of 10 feet beyond the visible end of the tension crack.



Revision 1
1/13/2020

Notes:

1) fill and roll the slope to repair rutting/erosion features
2) extend sand blanket 1 ft upslope from tension crack
3) separator fabric strength dependent on expected roadway traffic (recommend US Fabrics 160NW or equivalent)
4) clean sand = IDOT FA-1 or similar
5) clean aggregate = IDOT CA-1, CA-7 or similar

HANSON
Hanson Professional Service inc.

BLANKET DRAIN
JOPPA ACTIVE SOUTH ASH POND
JOPPA, ILLINOIS
JOB NO. 19E0122 FIGURE 1

R001344

Attachment D

Periodic Structural Stability and Safety Factor Assessment Analyses

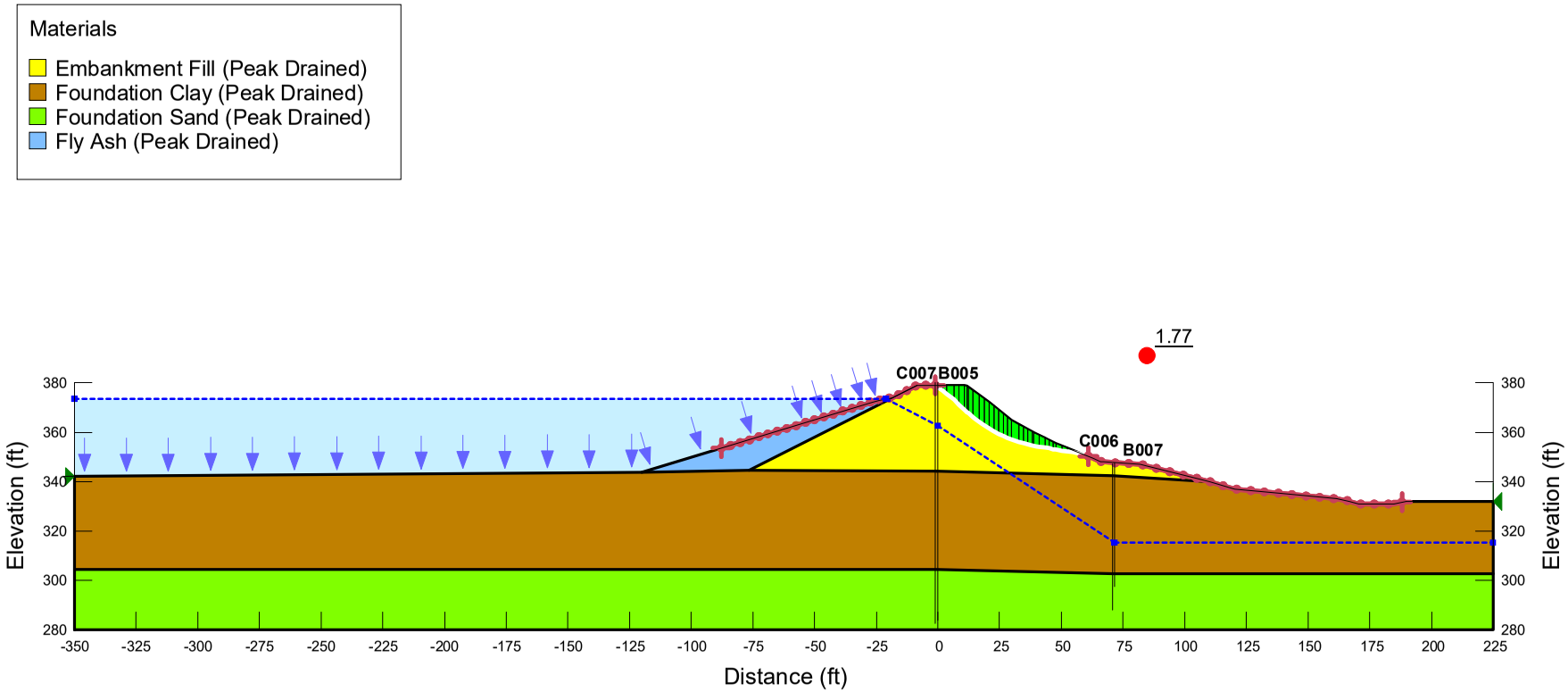
Computed By: VMCh Date: 8/25/2016
Checked By: ZJF Date: 8/25/2016
Modified By: PK Date: 8/25/2021
Checked By: PB Date: 8/25/2021

Joppa Section B
Long-Termed Drained Stability

Kind: SLOPE/W
Method: Spencer
F of S: 1.77

Section B Normal Pool

Name: Embankment Fill (Peak Drained) Unit Weight: 131 pcf Strength Function: Embankment Fill Peak Drained Piezometric Line: 1
Name: Foundation Clay (Peak Drained) Unit Weight: 128 pcf C-Horizontal: 0 psf C-Vertical: 0 psf Phi-Horizontal: 29 ° Phi-Vertical: 33 ° Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: Fly Ash (Peak Drained) Unit Weight: 106 pcf C-Horizontal: 0 psf C-Vertical: 0 psf Phi-Horizontal: 29 ° Phi-Vertical: 33 ° Piezometric Line: 1



\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_B_Drained_PK_08252021.gsz

R001346

Computed By: VMCh / AJW Date: 10/02/16
Checked By: ZJF / VMCh Date: 10/03/16
Modified By: PK Date: 08/25/21
Checked By: PB Date: 08/25/21

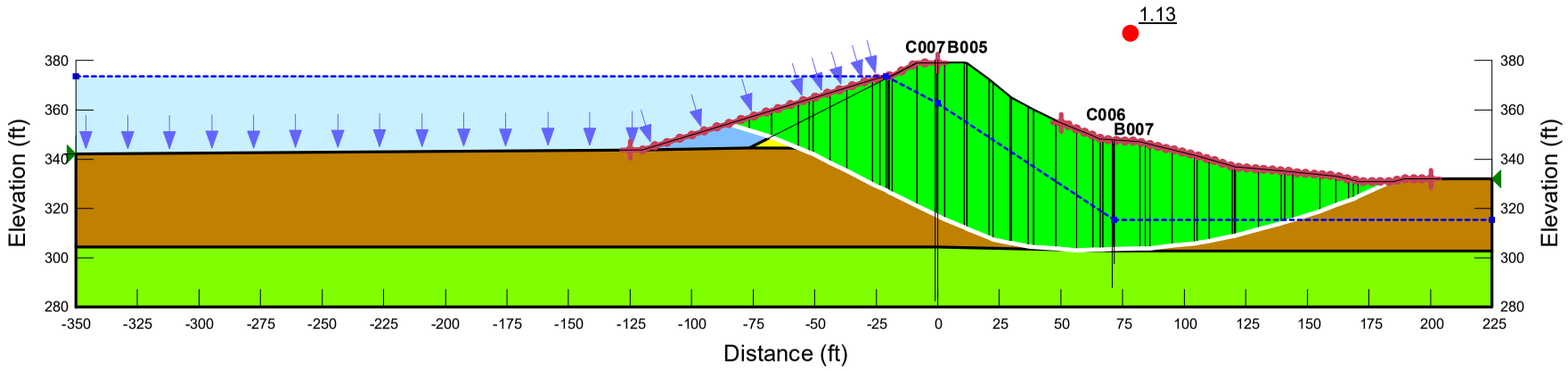
Joppa Section B
Seismic Slope Stability

Kind: SLOPE/W
Method: Spencer
F of S: 1.13

Section B Pseudostatic (kh)

Name: Embankment Fill (Peak Undrained) Unit Weight: 131 pcf Strength Function: Embankment Fill Peak Undrained Piezometric Line: 1
Name: Foundation Clay (Peak Undrained) Unit Weight: 128 pcf Strength Function: Foundation Clay Peak Undrained Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: Fly Ash (Peak Undrained) Unit Weight: 106 pcf Tau/Sigma Ratio: 0.44 Minimum Strength: 0 psf Piezometric Line: 1

Horizontal Seismic Coefficient:
kh = 0.275 g



\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_B_Undrained_PK_08252021.gsz

R001347

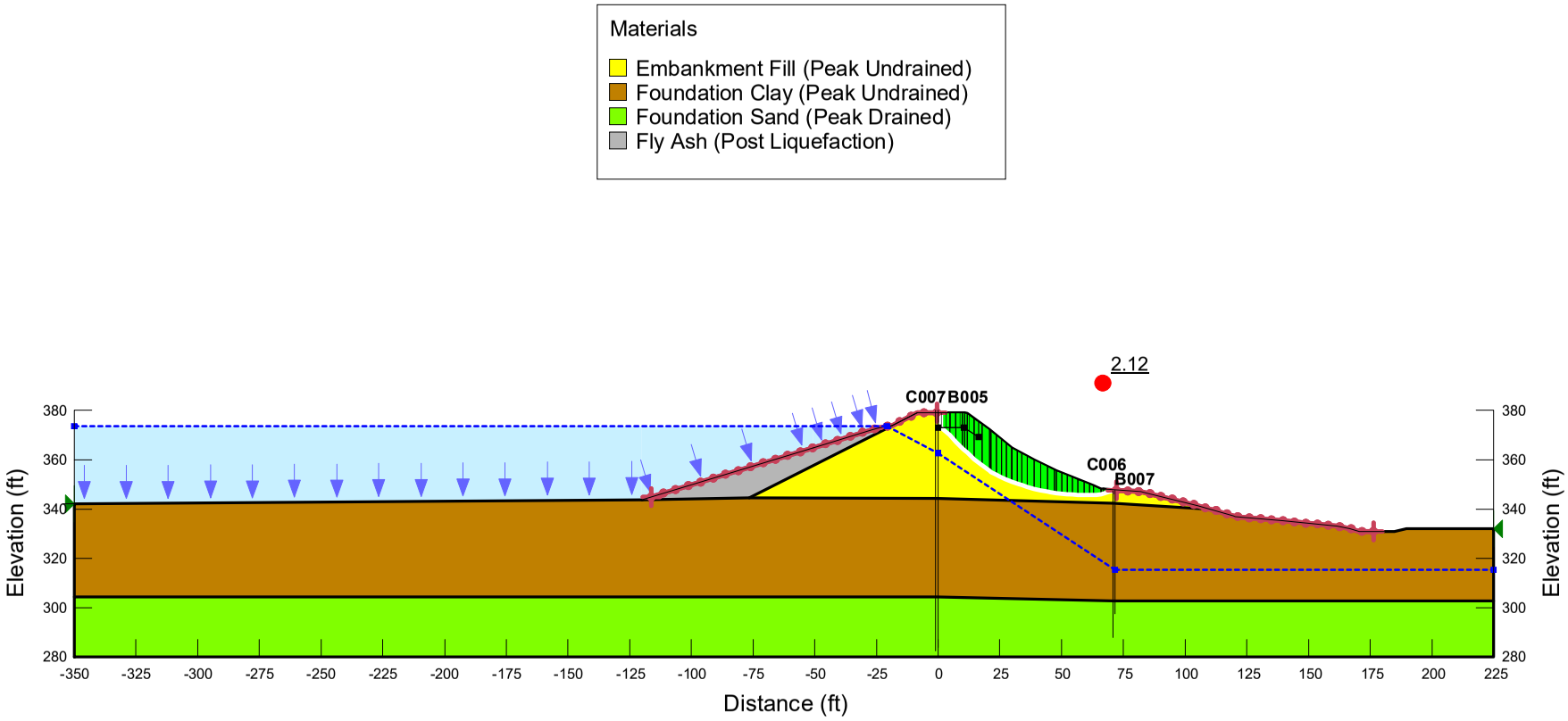
Computed By: VMCh / AJW Date: 10/02/16
Checked By: ZJF / VMCh Date: 10/03/16
Modified By: PK Date: 08/25/21
Checked By: PB Date: 08/25/21

Joppa Section B
Seismic Slope Stability

Kind: SLOPE/W
Method: Spencer
F of S: 2.12

Section B Post Earthquake

Name: Embankment Fill (Peak Undrained) Unit Weight: 131 pcf Strength Function: Embankment Fill Peak Undrained Piezometric Line: 1
Name: Foundation Clay (Peak Undrained) Unit Weight: 128 pcf Strength Function: Foundation Clay Peak Undrained Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: Fly Ash (Post Liquefaction) Unit Weight: 106 pcf Tau/Sigma Ratio: 0.07 Minimum Strength: 0 psf Piezometric Line: 1



\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_B_Undrained_PK_08252021.gsz

R001348

Computed By: LPC
Modified By: PK
Checked By: PB
Date: 8/25/2021

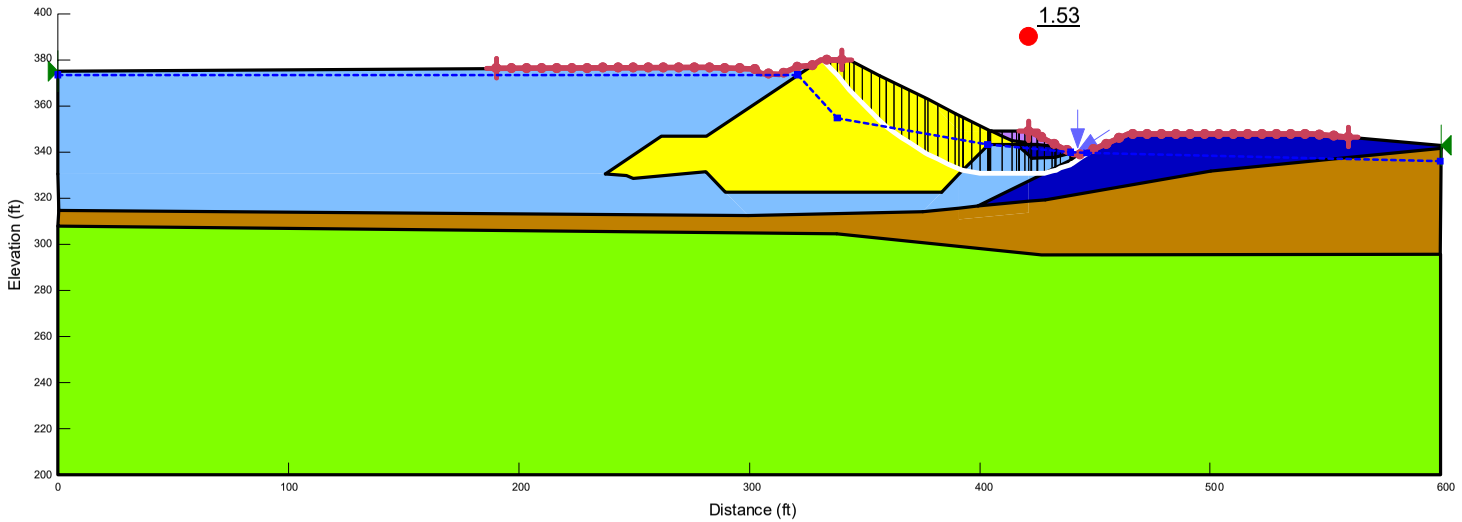
Joppa Section K DMM Design
Long-Termed Drained Stability

Name: Embankment Fill (Peak Drained) Unit Weight: 131 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: Foundation Clay (Peak Drained) Unit Weight: 128 pcf C-Horizontal: 0 psf C-Vertical: 0 psf Phi-Horizontal: 29 ° Phi-Vertical: 33 ° Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: Fly Ash (Peak Drained) Unit Weight: 106 pcf C-Horizontal: 0 psf C-Vertical: 0 psf Phi-Horizontal: 29 ° Phi-Vertical: 33 ° Piezometric Line: 1
Name: Toe Buttress (Peak Drained) Unit Weight: 125 pcf Cohesion': 0 psf Phi': 30 ° Piezometric Line: 1
Name: Soft NC Clay Unit Weight: 125 pcf Cohesion': 0 psf Phi': 25 ° Piezometric Line: 1

Materials
- Embankment Fill (Peak Drained)
- Foundation Clay (Peak Drained)
- Foundation Sand (Peak Drained)
- Fly Ash (Peak Drained)
- Toe Buttress (Peak Drained)
- Soft NC Clay

Section K Max Storage Pool

Kind: SLOPE/W
Method: Spencer
F of S: 1.53



\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_K_Ash_DMM_Remediation_Drained_PK_08252021.gsz

R001349

Joppa Section K DMM Design

Computed By: LPC
Modified By: PK
Checked By: PB
Date: 8/25/2021

Name: Embankment Fill (Peak Undrained) Unit Weight: 131 pcf Strength Function: Embankment Fill Peak Undrained Piezometric Line: 1
Name: Foundation Clay (Peak Undrained) Unit Weight: 128 pcf Strength Function: Foundation Clay Peak Undrained Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: DMM - Embankment Unit Weight: 131 pcf Cohesion Spatial Fn: Embankment Fill DMM Phi': 0 ° Piezometric Line: 1
Name: Fly Ash (Peak Undrained) Unit Weight: 106 pcf Tau/Sigma Ratio: 0.44 Minimum Strength: 0 psf Piezometric Line: 1
Name: Toe Buttress (Peak Undrained) Unit Weight: 125 pcf Cohesion': 1,500 psf Phi': 0 ° Piezometric Line: 1
Name: DMM - Ash Unit Weight: 106 pcf Cohesion Spatial Fn: Ash DMM Phi': 0 ° Piezometric Line: 1
Name: DMM - Foundation Unit Weight: 128 pcf Cohesion Spatial Fn: Foundation DMM Phi': 0 ° Piezometric Line: 1
Name: Soft NC Clay Unit Weight: 125 pcf Tau/Sigma Ratio: 0.23 Minimum Strength: 500 psf Piezometric Line: 1
Name: DMM - Soft Clay Unit Weight: 125 pcf Cohesion': 3,448 psf Phi': 0 ° Piezometric Line: 1

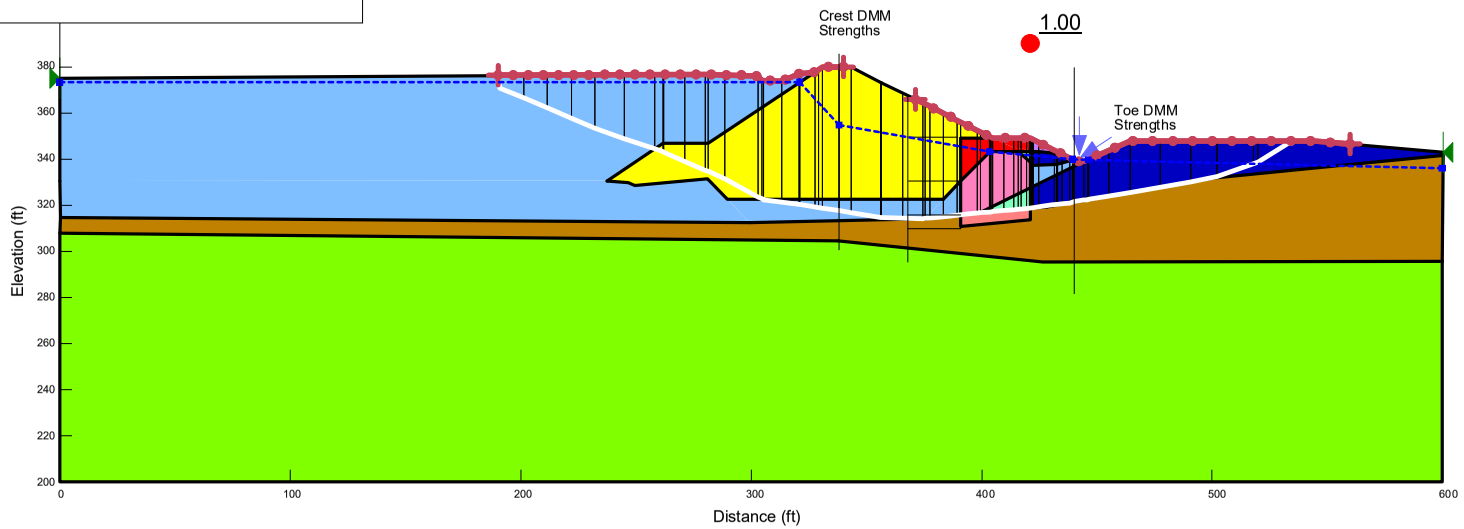
Materials

- Embankment Fill (Peak Undrained)
- Foundation Clay (Peak Undrained)
- Foundation Sand (Peak Drained)
- DMM - Embankment
- Fly Ash (Peak Undrained)
- Toe Buttress (Peak Undrained)
- DMM - Ash
- DMM - Foundation
- Soft NC Clay
- DMM - Soft Clay

Section K Pseudostatic

Kind: SLOPE/W
Method: Spencer
F of S: 1.00

Pseudostatic Seismic Yield
ky = 0.243 g



\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_K_Ash_DMM_Remediation_PK_08252021.gsz

R001350

Procedure for Estimating Shear-Induced Seismic Slope Displacement for Shallow Crustal Earthquakes

by Jonathan D. Bray and Jorge Macedo, UC Berkeley and Georgia Tech

Procedure for Estimating Shear-Induced Seismic Slope Displacement for Shallow Crustal Earthquakes, ASCE JGGE, 2019, 145(12), doi: 10.1061/(ASCE)GT.1943-5

SEE NOTES BELOW FOR GUIDANCE IN THE USE OF SPREADSHEET

Input Parameters			
Case	Deterministic-Pseudoprobabilistic (EQ8&9)		*** Select Ordinary or Pulse or Combined Equations**
Yield Coefficient (k_y) [(a)]	0.24		**(a) Based on pseudostatic analysis**
Initial Fundamental Period (T_s) [(b)]	0.15	seconds	**(b) 1D: T_s=4H/V_s 2D: T_s=2.6H/V_s**
Degraded Period (1.3T_s)	0.20	seconds	**(c) Input the Spectral Acceleration (g) at the base of the sliding mass assuming there is no material above it.**
Moment Magnitude (M_w)	7.6		
Spectral Acceleration (S_a(1.3T_s)) [(c)]	1.23	g	
PGV Information	Both Ordinary & Pulse Motions		**(d) PGV (cm/s) is required for near-fault pulse motions & for EQ9 when PGV > 115 cm/s; it is estimated at the base of sliding mass assuming no material above it.**
Peak Ground Velocity (PGV) [(d)]	1.0	cm/s	
Percentile (if Pulse ground Motion) [(e)]	Both Ordinary & Pulse Motions		
Additional Input Parameters			**(e) If Pulse motion the percentile is given as either D100 or D50. D100 should be used for fault-normal direction**
Probability of Exceedance #1 (P1)	84	%	
Probability of Exceedance #2 (P2)	50	%	
Probability of Exceedance #3 (P3)	16	%	
Displacement Threshold (d_threshold)	91.44	cm	

Intermediate Calculated Parameters			
Non-Zero Seismic Displacement Est (D)	14.2	cm	eq. (3) or (5) or (7) or (9)
Standard Deviation of Non-Zero Seismic D	0.736		

Results			
Probability of Negligible Displ. (P(D=0))	**0.01**		eq. (2) or (4) or (6) or (8)
D1	**6.7**	**cm**	calc. using eq. (11)
D2	**14.2**	**cm**	calc. using eq. (11)
D3	**29.5**	**cm**	calc. using eq. (11)
P(D>d_threshold)	**0.01**		eq. (11)

Notes

1. Values highlighted in blue are input parameters, and results are presented in the table with the yellow heading.
2. Probability of Exceedance is the desired probability of exceeding a particular displacement value.
3. Displacements D1, D2, and D3 correspond to P1, P2, and P3, respectively.
   (e.g., the probability of exceeding displacement D1 is P1 and it is referred to as the (100% - P1) percentile value.
4. The 16%, 50%, and 84% percentile displacement values at selected k_y values are shown to the right.
5. Calculated seismic displacements are due to deviatoric deformation only (add in volumetrically induced movement).
6. k_y may range between 0.01 and 0.8, T_s between 0 and 2 s, S_a between 0.002 and 4.5 g, M_w between 5.5 and 8.2
7. Rigid slope is assumed for T_s < 0.05 s, i.e. T_s = 0.0. If Ts is just less than 0.05 s, set T_s = 0.050 s
8. When a value for D is not calculated, D is < 0.5 cm
9. k_y should be estimated with a slope stability program; the simplified equations shown below provide approximate values.
10. Examples of how T_s is estimated are shown below.
11. V_s = weighted avg. shear wave velocity for the sliding mass, e.g., for 2 layers, V_s = [(h1)(V_s1) + (h2)(V_s2)]/(h1 + h2)

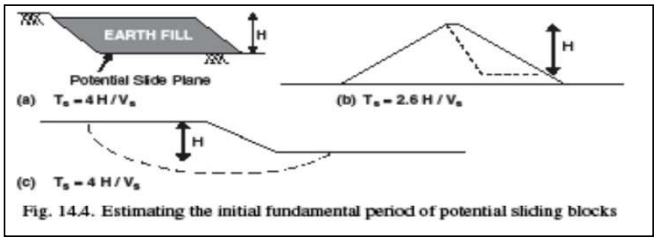


Fig. 14.4. Estimating the initial fundamental period of potential sliding blocks

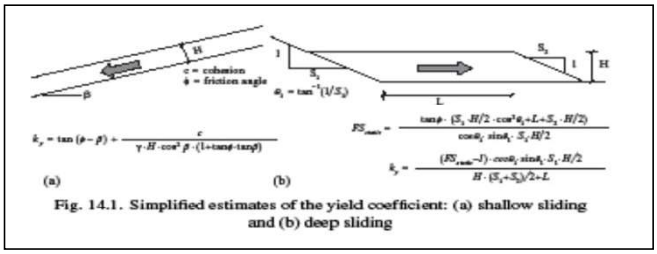


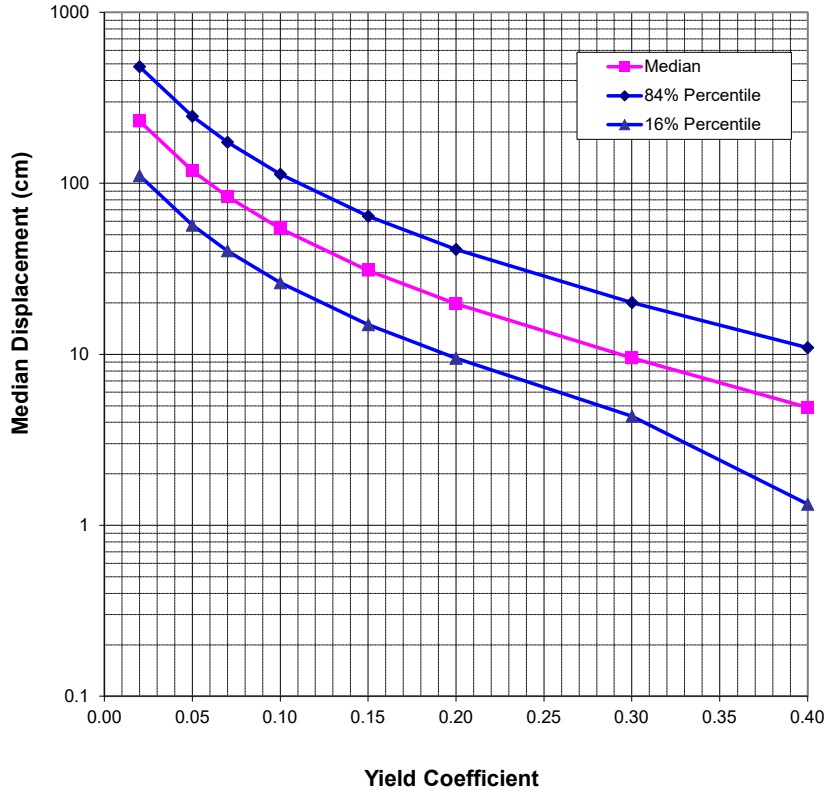
Fig. 14.1. Simplified estimates of the yield coefficient: (a) shallow sliding and (b) deep sliding

Figures from Bray, J.D. (2007) "Chapter 14: Simplified Seismic Slope Displacement Procedures," Earthquake Geotechnical Engineering, 4th Inter. Conf. on Earthquake Geotechnical Engineering - Invited Lectures, in Geotechnical, Geological, and Earthquake Engineering Series, Vol. 6, Pitilakis, Kyriazis D., Ed., Springer, Vol. 6, pp. 327-353.

5606.0002143

Dependence on k_y

k_y	P(D="0")	D (cm)	Dmedian (cm)	D-84% (cm)	D-16% (cm)
0.020	0.000	231.2	231.2	480.8	111.2
0.05	0.000	118.6	118.6	246.6	57.0
0.07	0.000	83.7	83.7	174.0	40.3
0.1	0.000	54.4	54.4	113.2	26.2
0.15	0.000	31.0	31.0	64.4	14.9
0.2	0.001	19.8	19.7	41.0	9.5
0.3	0.029	9.8	9.5	20.1	4.3
0.4	0.139	5.7	4.87	10.93	1.33



Joppa Section K DMM Design

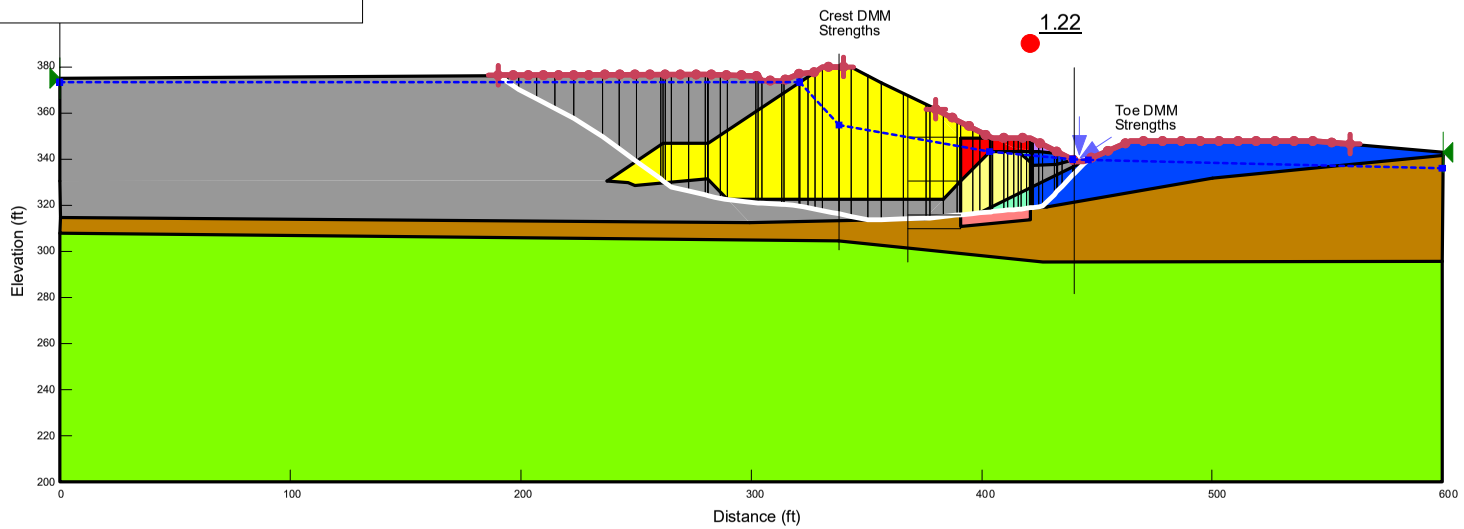
Computed By: LPC
Modified By: PK
Checked By: PB
Date: 8/25/2021

Name: Embankment Fill (Peak Undrained) Unit Weight: 131 pcf Strength Function: Embankment Fill Peak Undrained Piezometric Line: 1
Name: Foundation Clay (Peak Undrained) Unit Weight: 128 pcf Strength Function: Foundation Clay Peak Undrained Piezometric Line: 1
Name: Fly Ash (Post-Liquefaction) Unit Weight: 106 pcf Tau/Sigma Ratio: 0.07 Minimum Strength: 0 psf Piezometric Line: 1
Name: Foundation Sand (Peak Drained) Unit Weight: 128 pcf Cohesion': 0 psf Phi': 35 ° Piezometric Line: 1
Name: DMM - Embankment Unit Weight: 131 pcf Cohesion Spatial Fn: Embankment Fill DMM Phi': 0 ° Piezometric Line: 1
Name: Toe Buttress (Peak Undrained) Unit Weight: 125 pcf Cohesion': 1,500 psf Phi': 0 ° Piezometric Line: 1
Name: DMM - Foundation Unit Weight: 128 pcf Cohesion Spatial Fn: Foundation DMM Phi': 0 ° Piezometric Line: 1
Name: DMM - Ash (Post-EQ) Unit Weight: 106 pcf Cohesion Spatial Fn: Ash DMM - Post-EQ Phi': 0 ° Piezometric Line: 1
Name: Soft NC Clay - Softened Unit Weight: 125 pcf Tau/Sigma Ratio: 0.184 Minimum Strength: 400 psf Piezometric Line: 1
Name: DMM - Soft Clay Unit Weight: 125 pcf Cohesion': 3,448 psf Phi': 0 ° Piezometric Line: 1

Materials
- Embankment Fill (Peak Undrained)
- Foundation Clay (Peak Undrained)
- Fly Ash (Post-Liquefaction)
- Foundation Sand (Peak Drained)
- DMM - Embankment
- Toe Buttress (Peak Undrained)
- DMM - Foundation
- DMM - Ash (Post-EQ)
- Soft NC Clay - Softened
- DMM - Soft Clay

Section K Post-EQ

Kind: SLOPE/W
Method: Spencer
F of S: 1.22

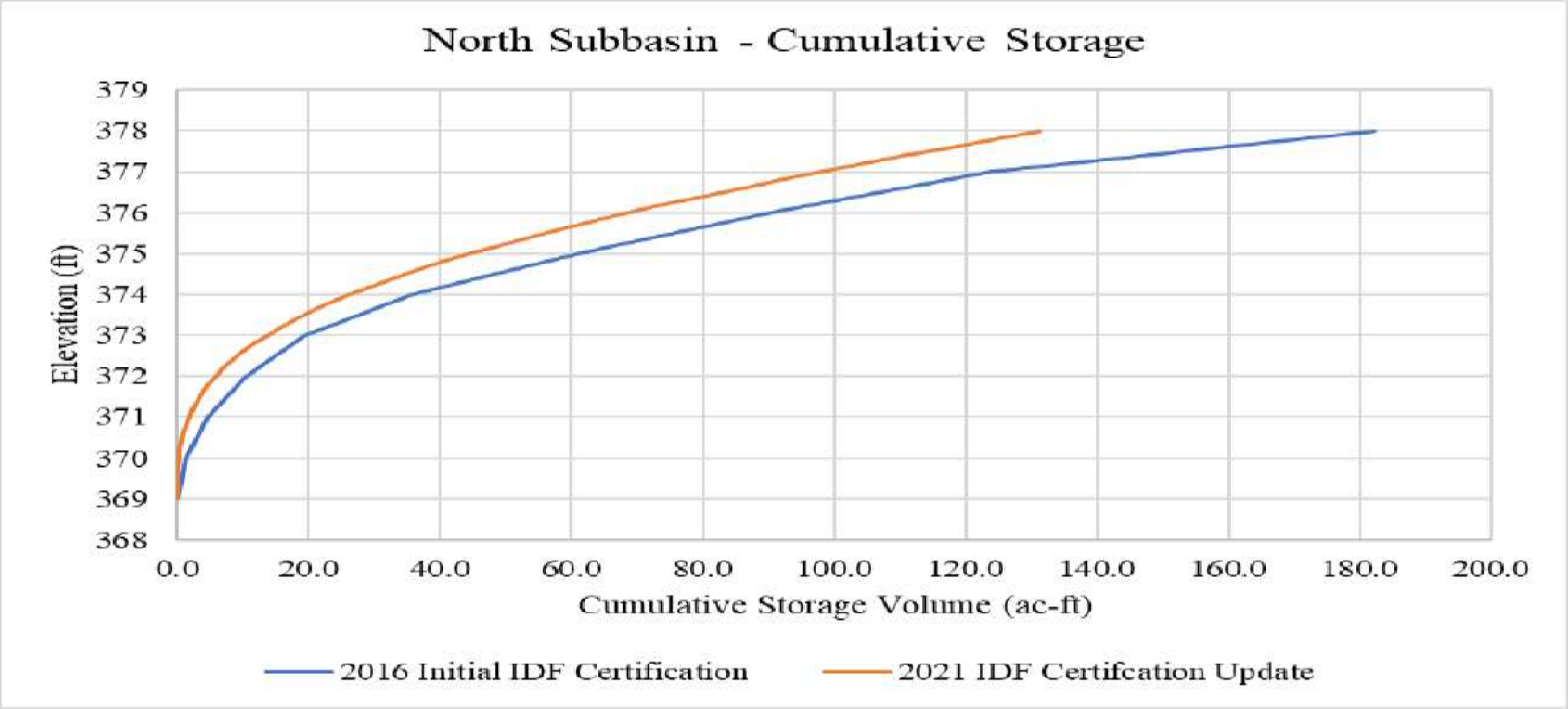


\\STLOUISMO-01\Data\Company\Projects_post_2014\GLP8027_CCR_ReCert\500_Technical\506_JOP\506d_Periodic_Report\EAP\Revised SFA\2016_AECOM_Files\JOP_Section_K_Ash_DMM_Remediation_PK_08252021.gsz

R001353

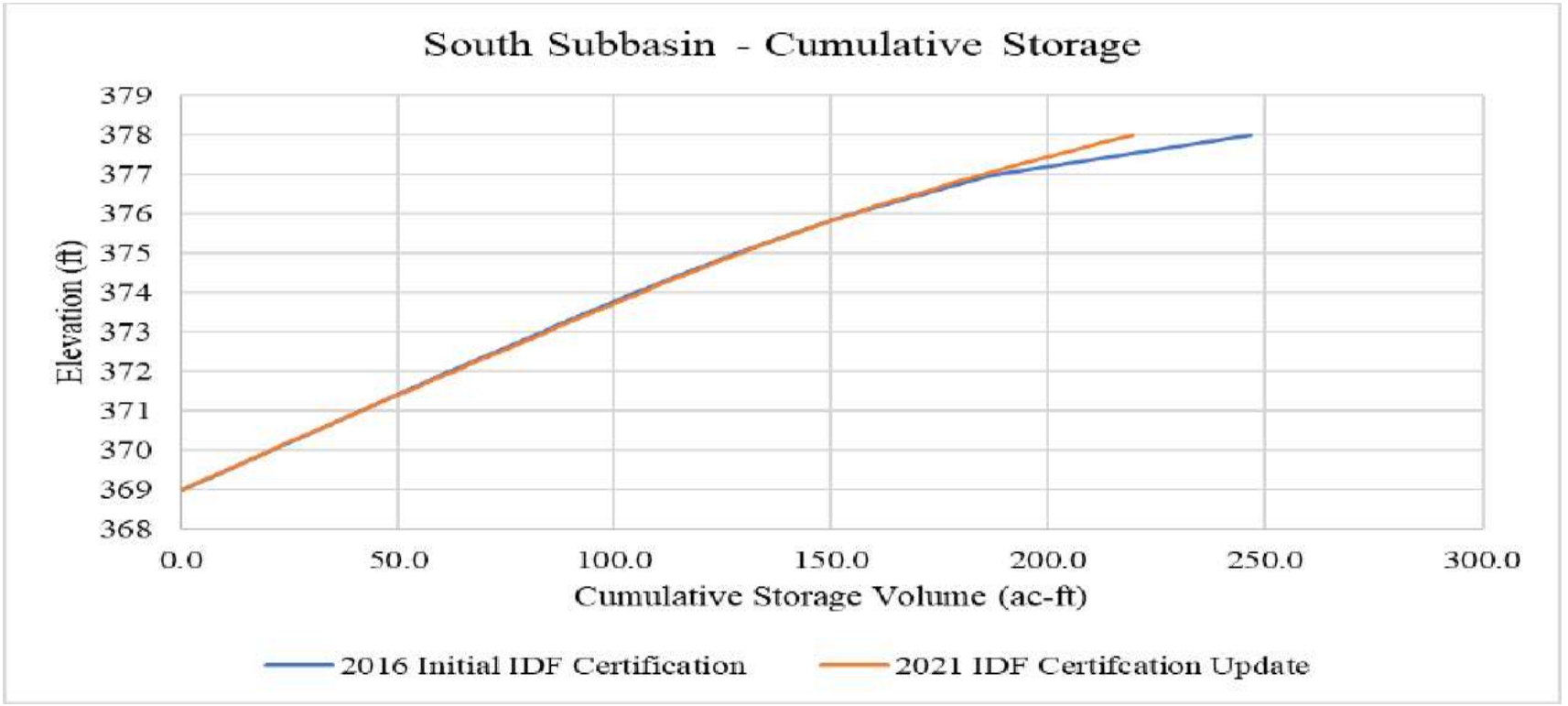
Attachment E

Periodic Inflow Design Flood Control System Plan Analyses



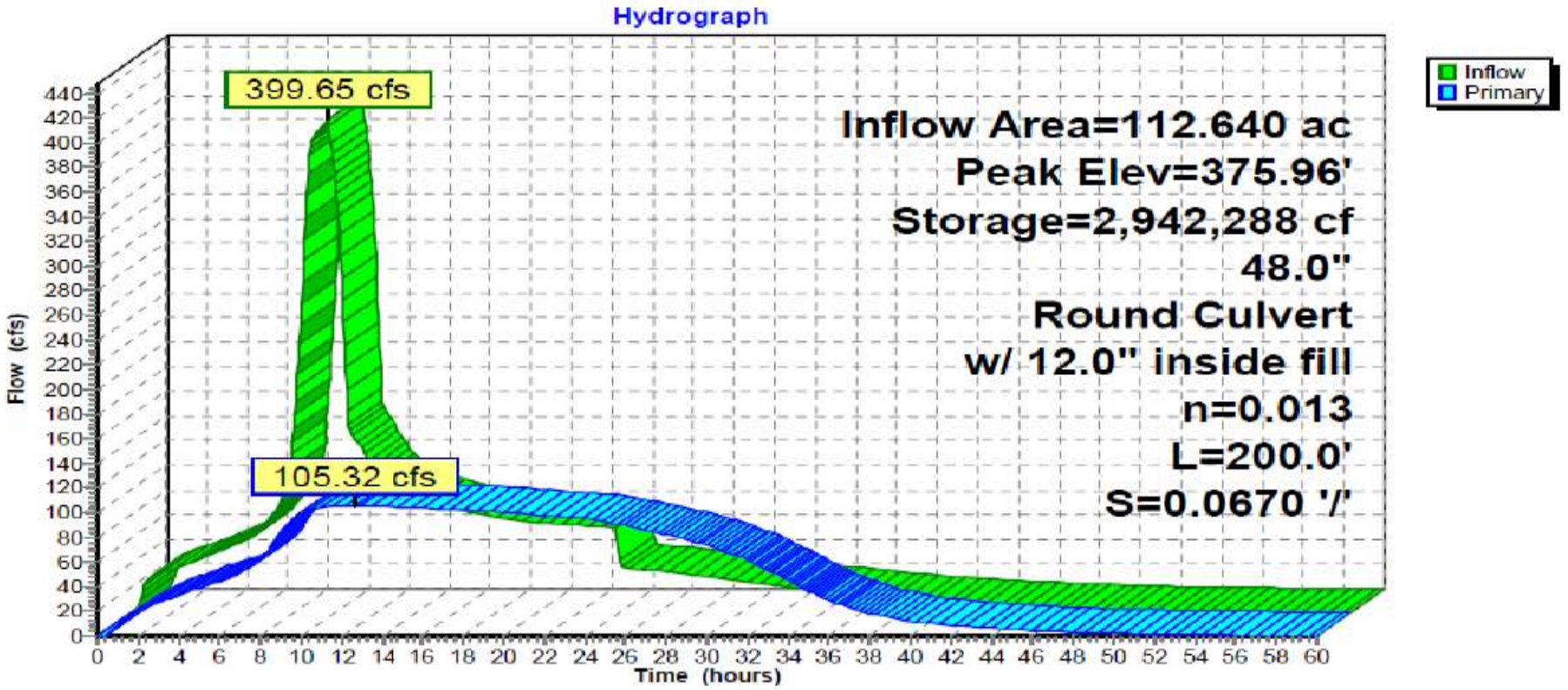
NORTH SUBBASIN - CUMULATIVE STORAGE PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS		
Geosyntec consultants		Figure E-1
GLP8027	8/24/2021	

R001355



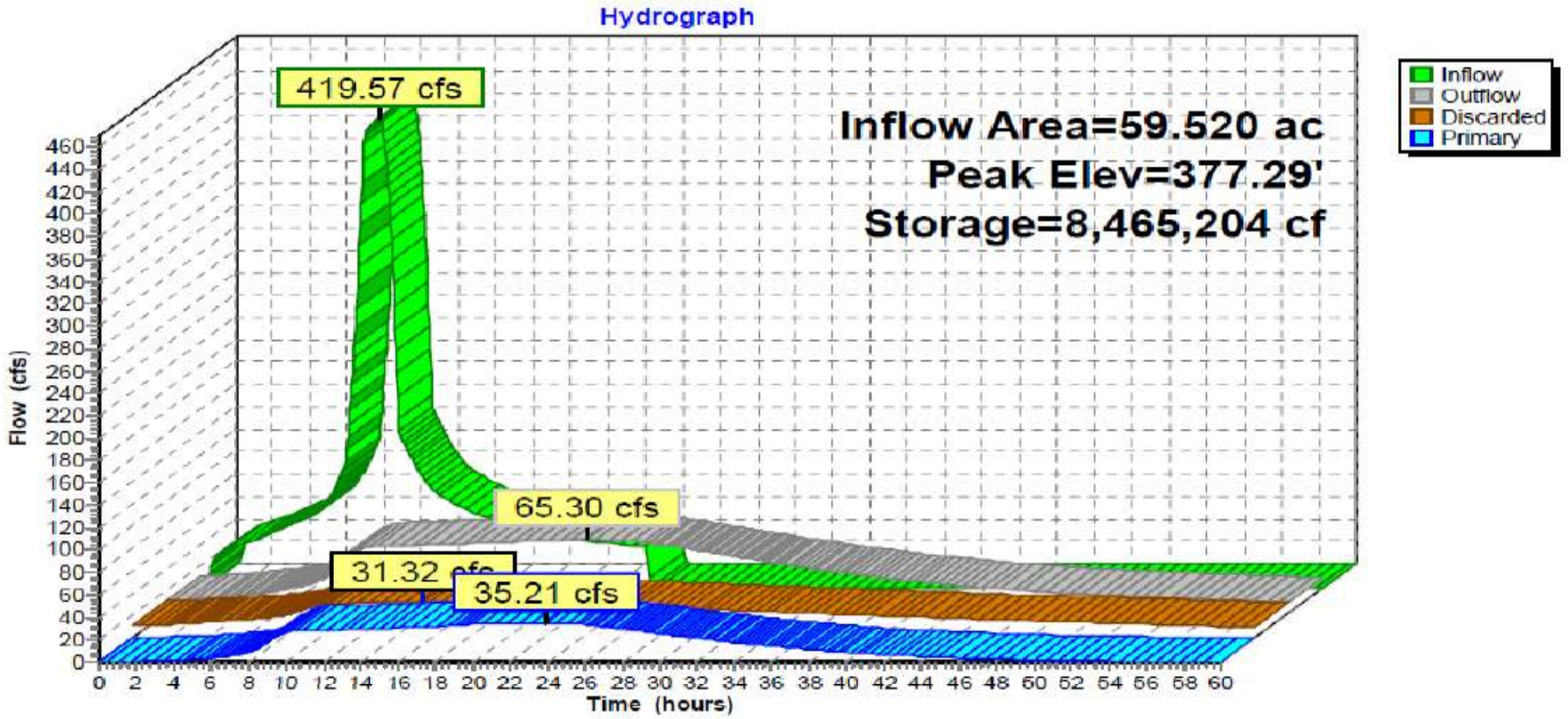
SOUTH SUBBASIN - CUMULATIVE STORAGE PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS	
Geosyntec consultants	Figure E-2
GLP8027	8/24/2021

R001356



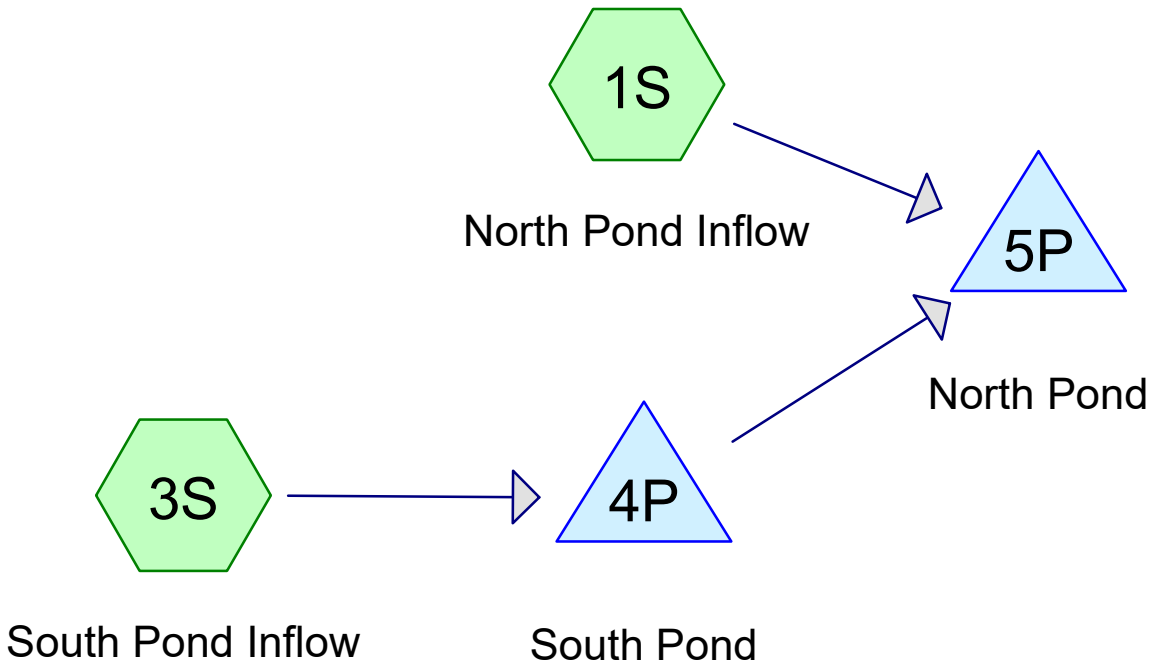
HYDROGRAPH PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS		
Geosyntec consultants		Figure E-3
GLP8027	8/24/2021	

R001357



HYDROGRAPH PERIODIC CERTIFICATION JOPPA POWER PLANT JOPPA, ILLINOIS		
Geosyntec consultants		Figure E-4
GLP8027	8/24/2021	

R001358



Subcat Reach Pond Link

Routing Diagram for 2021-08_Joppa_HH Model_Periodic Review
Prepared by SCCM, Printed 8/18/2021
HydroCAD® 10.00-26 s/n 00928 © 2020 HydroCAD Software Solutions LLC

Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
112.640	98	Unconnected pavement, HSG B (1S, 3S)
112.640	**98**	**TOTAL AREA**

Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
112.640	HSG B	1S, 3S
0.000	HSG C	
0.000	HSG D	
0.000	Other	
112.640		**TOTAL AREA**

Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	112.640	0.000	0.000	0.000	112.640	Unconnected pavement	1S, 3S
0.000	**112.640**	**0.000**	**0.000**	**0.000**	**112.640**	**TOTAL AREA**	

Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	4P	373.20	372.20	175.0	0.0057	0.020	36.0	0.0	0.0
2	4P	372.00	350.00	900.0	0.0244	0.013	24.0	0.0	0.0
3	5P	368.90	355.50	200.0	0.0670	0.013	48.0	0.0	12.0

Time span=0.00-60.00 hrs, dt=0.05 hrs, 1201 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Dyn-Stor-Ind method - Pond routing by Dyn-Stor-Ind method

Subcatchment 1S: North Pond Inflow Runoff Area=53.120 ac 100.00% Impervious Runoff Depth=35.76"
Tc=5.0 min CN=98 Runoff=374.46 cfs 158.281 af

Subcatchment 3S: South Pond Inflow Runoff Area=59.520 ac 100.00% Impervious Runoff Depth=35.76"
Tc=5.0 min CN=98 Runoff=419.57 cfs 177.351 af

Pond 4P: South Pond Peak Elev=377.29' Storage=8,465,204 cf Inflow=419.57 cfs 177.351 af
Discarded=31.32 cfs 104.811 af Primary=35.21 cfs 74.924 af Outflow=65.30 cfs 179.735 af

Pond 5P: North Pond Peak Elev=375.96' Storage=2,942,288 cf Inflow=399.65 cfs 233.205 af
48.0" Round Culvert w/ 12.0" inside fill n=0.013 L=200.0' S=0.0670 '/' Outflow=105.32 cfs 233.218 af

Total Runoff Area = 112.640 ac Runoff Volume = 335.632 af Average Runoff Depth = 35.76"
0.00% Pervious = 0.000 ac 100.00% Impervious = 112.640 ac

Summary for Subcatchment 1S: North Pond Inflow

[49] Hint: Tc<2dt may require smaller dt

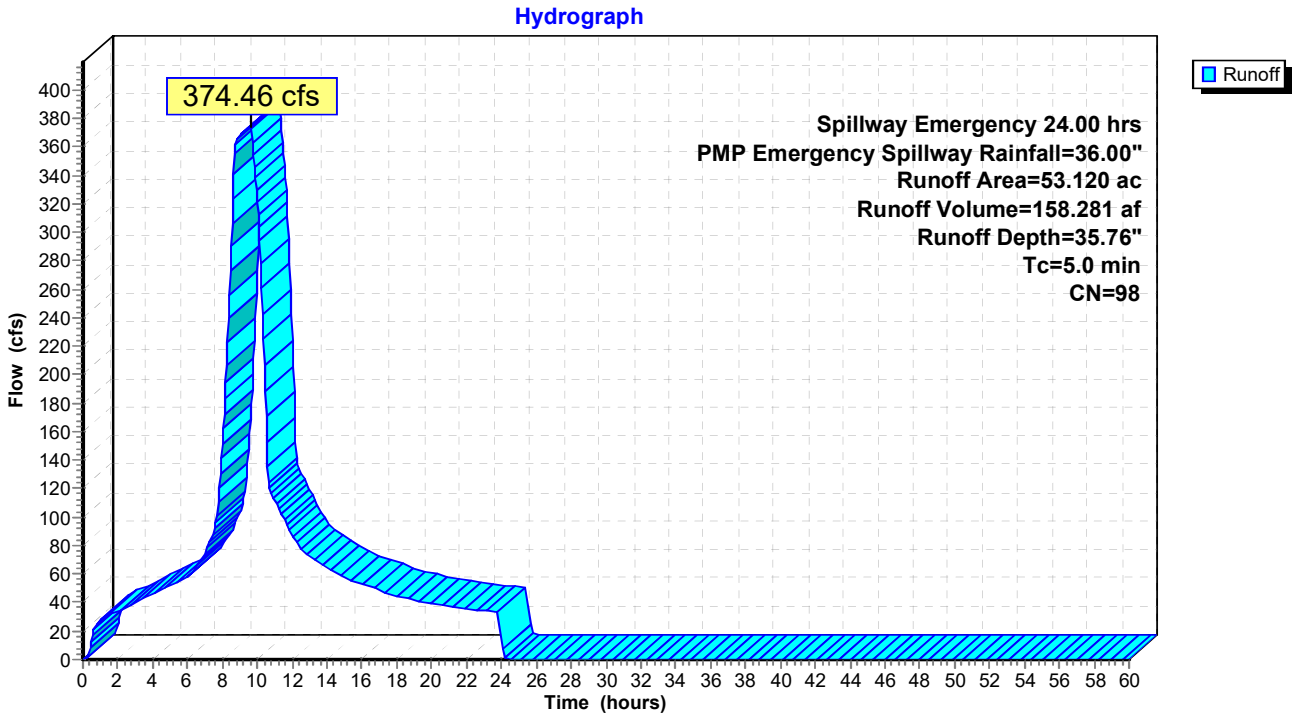
Runoff = 374.46 cfs @ 9.60 hrs, Volume= 158.281 af, Depth=35.76"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Spillway Emergency 24.00 hrs PMP Emergency Spillway Rainfall=36.00"

Area (ac)	CN	Description
53.120	98	Unconnected pavement, HSG B
53.120		100.00% Impervious Area
53.120		100.00% Unconnected

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry, Direct Inflow**

Subcatchment 1S: North Pond Inflow



Summary for Subcatchment 3S: South Pond Inflow

[49] Hint: Tc<2dt may require smaller dt

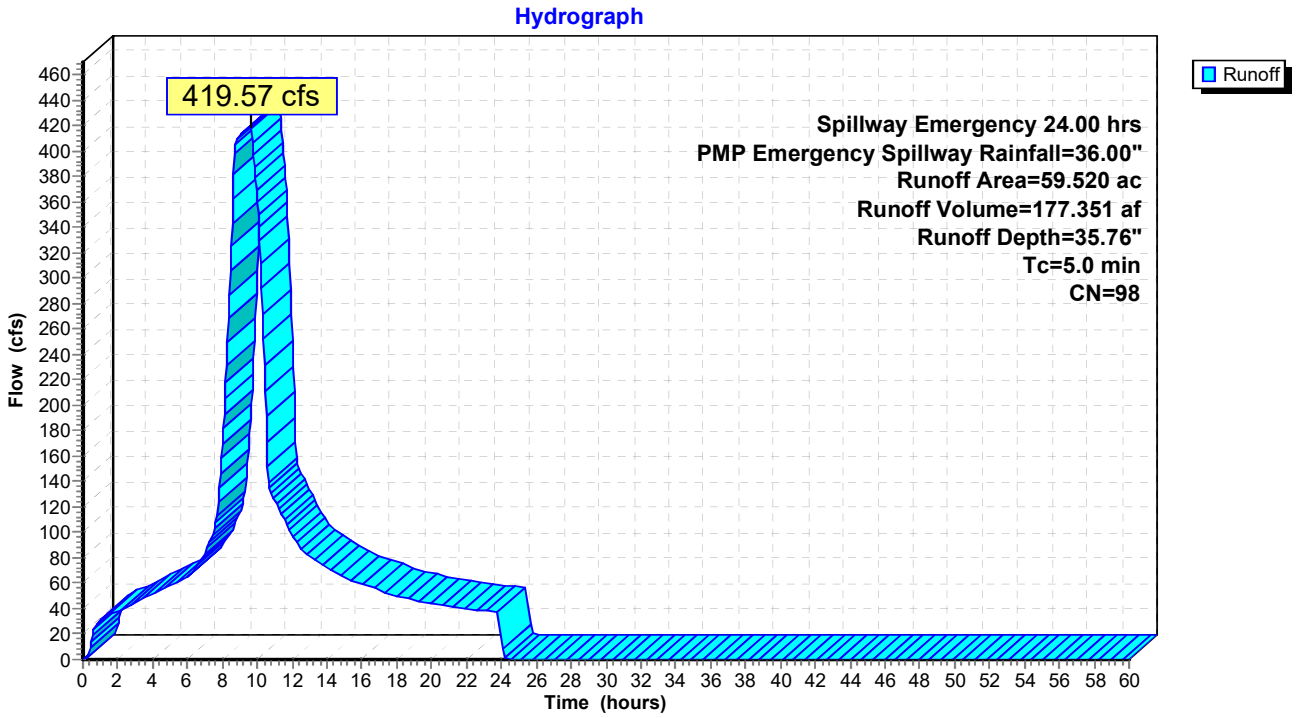
Runoff = 419.57 cfs @ 9.60 hrs, Volume= 177.351 af, Depth=35.76"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Spillway Emergency 24.00 hrs PMP Emergency Spillway Rainfall=36.00"

Area (ac)	CN	Description
59.520	98	Unconnected pavement, HSG B
59.520		100.00% Impervious Area
59.520		100.00% Unconnected

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
5.0					**Direct Entry, Direct Inflow**

Subcatchment 3S: South Pond Inflow



Summary for Pond 4P: South Pond

Inflow Area = 59.520 ac,100.00% Impervious, Inflow Depth = 35.76" for PMP Emergency Spillway event
Inflow = 419.57 cfs @ 9.60 hrs, Volume= 177.351 af
Outflow = 65.30 cfs @ 22.53 hrs, Volume= 179.735 af, Atten= 84%, Lag= 775.6 min
Discarded = 31.32 cfs @ 15.46 hrs, Volume= 104.811 af
Primary = 35.21 cfs @ 23.99 hrs, Volume= 74.924 af

Routing by Dyn-Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Starting Elev= 373.50' Surf.Area= 954,920 sf Storage= 4,136,553 cf
Peak Elev= 377.29' @ 15.46 hrs Surf.Area= 1,464,313 sf Storage= 8,465,204 cf (4,328,651 cf above start)

Plug-Flow detention time= 1,778.7 min calculated for 84.703 af (48% of inflow)
Center-of-Mass det. time= 876.5 min (1,536.1 - 659.7)

Volume	Invert	Avail.Storage	Storage Description
#1	369.00'	9,563,776 cf	**Custom Stage Data (Conic)** Listed below (Recalc)

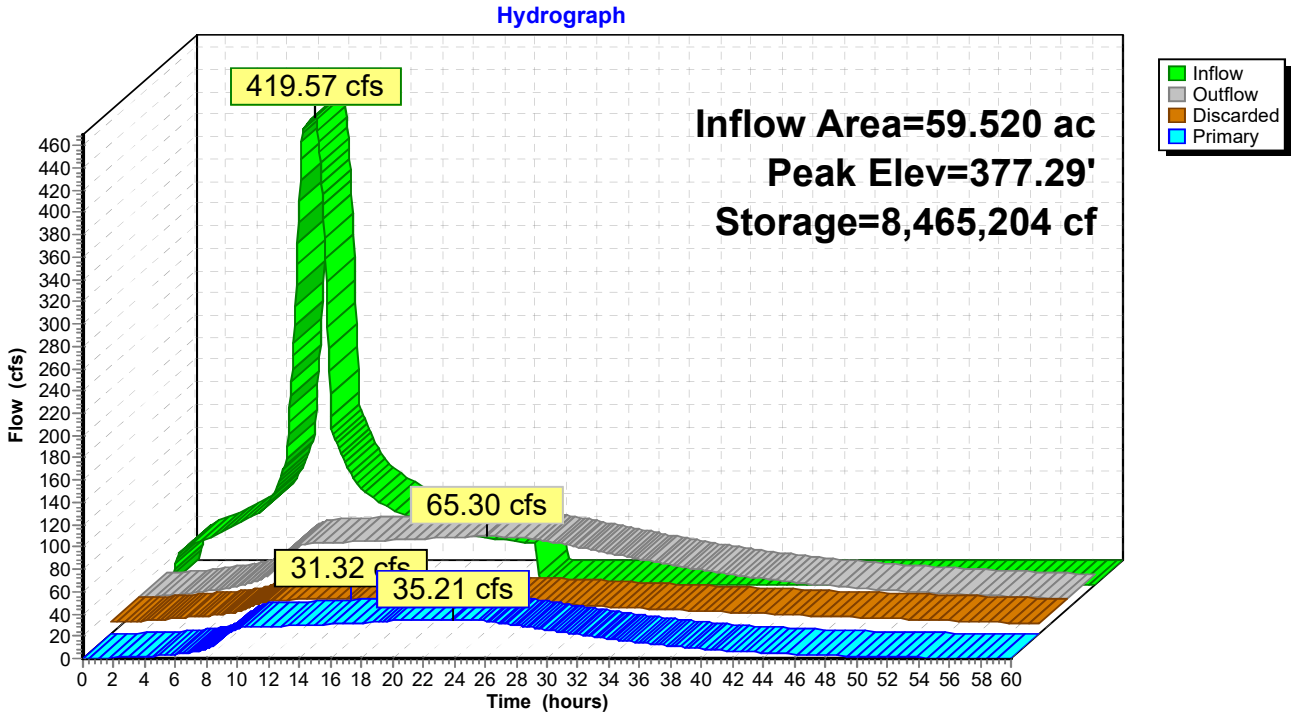
Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)	Wet.Area (sq-ft)
369.00	883,378	0	0	883,378
373.00	947,474	3,660,956	3,660,956	948,894
374.00	962,395	954,925	4,615,881	964,211
375.00	1,039,863	1,000,879	5,616,760	1,041,761
376.00	1,216,987	1,127,265	6,744,024	1,218,925
377.00	1,404,766	1,309,754	8,053,779	1,406,747
378.00	1,617,733	1,509,997	9,563,776	1,619,759

Device	Routing	Invert	Outlet Devices
#1	Primary	373.20'	**36.0" Round Culvert** L= 175.0' CPP, projecting, no headwall, Ke= 0.900 Inlet / Outlet Invert= 373.20' / 372.20' S= 0.0057 '/' Cc= 0.900 n= 0.020 Corrugated PE, corrugated interior, Flow Area= 7.07 sf
#2	Discarded	372.00'	**24.0" Round Culvert** L= 900.0' CPP, square edge headwall, Ke= 0.500 Inlet / Outlet Invert= 372.00' / 350.00' S= 0.0244 '/' Cc= 0.900 n= 0.013 Corrugated PE, smooth interior, Flow Area= 3.14 sf
#3	Device 2	372.70'	**24.0" Horiz. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Discarded OutFlow Max=31.32 cfs @ 15.46 hrs HW=377.29' (Free Discharge)
↑—**2=Culvert** (Inlet Controls 31.32 cfs @ 9.97 fps)
↑—**3=Orifice/Grate** (Passes 31.32 cfs of 32.40 cfs potential flow)

Primary OutFlow Max=35.26 cfs @ 23.99 hrs HW=376.91' TW=375.12' (Dynamic Tailwater)
↑—**1=Culvert** (Outlet Controls 35.26 cfs @ 5.16 fps)

Pond 4P: South Pond



Summary for Pond 5P: North Pond

Inflow Area = 112.640 ac,100.00% Impervious, Inflow Depth > 24.84" for PMP Emergency Spillway event
Inflow = 399.65 cfs @ 9.63 hrs, Volume= 233.205 af
Outflow = 105.32 cfs @ 12.56 hrs, Volume= 233.218 af, Atten= 74%, Lag= 176.2 min
Primary = 105.32 cfs @ 12.56 hrs, Volume= 233.218 af

Routing by Dyn-Stor-Ind method, Time Span= 0.00-60.00 hrs, dt= 0.05 hrs
Starting Elev= 370.00' Surf.Area= 27,734 sf Storage= 9,245 cf
Peak Elev= 375.96' @ 12.56 hrs Surf.Area= 1,165,823 sf Storage= 2,942,288 cf (2,933,043 cf above start)

Plug-Flow detention time= 317.4 min calculated for 233.005 af (100% of inflow)
Center-of-Mass det. time= 314.1 min (1,213.6 - 899.4)

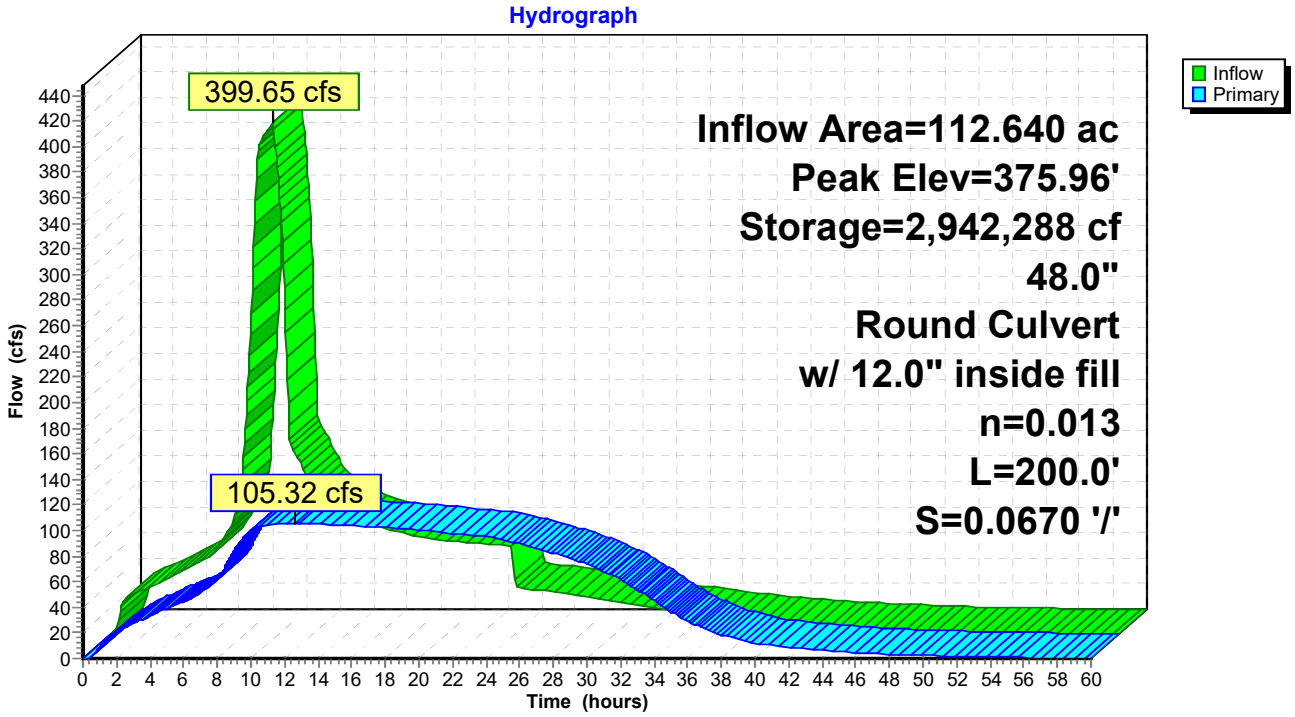
Volume	Invert	Avail.Storage	Storage Description
#1	369.00'	5,719,616 cf	**Custom Stage Data (Conic)**Listed below (Recalc)

Elevation (feet)	Surf.Area (sq-ft)	Inc.Store (cubic-feet)	Cum.Store (cubic-feet)	Wet.Area (sq-ft)
369.00	0	0	0	0
373.00	443,746	591,661	591,661	443,771
374.00	667,599	551,876	1,143,537	667,640
375.00	931,347	795,823	1,939,360	931,406
376.00	1,176,580	1,051,578	2,990,938	1,176,666
377.00	1,383,194	1,278,495	4,269,433	1,383,319
378.00	1,518,220	1,450,183	5,719,616	1,518,413

Device	Routing	Invert	Outlet Devices
#1	Primary	369.90'	**48.0" Round Culvert w/ 12.0" inside fill** L= 200.0' RCP, sq.cut end projecting, Ke= 0.500 Inlet / Outlet Invert= 368.90' / 355.50' S= 0.0670 '/' Cc= 0.900 n= 0.013, Flow Area= 10.11 sf

Primary OutFlow Max=105.32 cfs @ 12.56 hrs HW=375.96' (Free Discharge)
↑—**1=Culvert** (Inlet Controls 105.32 cfs @ 10.42 fps)

Pond 5P: North Pond



Luminant

Office Memorandum

Date: November 14, 2020

To: Cynthia Vodopivec

Matt Ballance
Jason Campbell
cc: Charles Koudelka

From: Vic Modeer

East Ash Pond Structural Stability Assessment
Electric Energy, Inc.
Subject: Joppa Power Station

The October 2016 certified "CCR Rule Report: Initial Structural Stability Assessment for the East Ash Pond at the Joppa Power Station" prepared by AECOM describes the outlets for the northern portion and southern portion of the East Ash Pond. The AECOM report states that the 26" (24" inside diameter) HDPE pipe cannot be structurally certified due to inability to complete a closed-circuit television inspection of the pipe. However, the outfall structure and the pipe section from the structure to the bottom of the embankment have been inspected numerous times by me and found to be structurally sufficient.

The 24" pipe was placed at an elevation 1' below the 36" pipe connecting the northern and southern portions of the East Ash Pond. The 24" HDPE outfall has an inlet invert elevation of approximately 372.0' and penetrates the embankment at a 1.0% slope until it reaches the downstream face, at which point the pipe follows the exterior contour of the slope until past the toe. The conduit was laid at grade just off the toe of the embankment back to the north where it outfalls into the acid basin. The interconnecting 36" diameter corrugated metal pipe (CMP) (Water Detention Facilities Inspection, March 17, 2009) was not included in the initial structural stability assessment as it was an internal pipe not affecting the structural stability. However, the 36" CMP pipe is significant because it originally carried the discharge from the southern portion of the East Ash Pond and it will carry any extreme rainfall events and any flow that is greater than 1' above the 24" outlet, and can be used as the main outlet for closure or maintenance of the 24" outlet.

AECOM's 2016 report could not certify that the pipe met the requirements of § 257.73(d)(1)(vi) because of the inability to access the pipe beyond a 90° bend beyond the toe of the dike in order to complete the inspection and was not because of any issues related to structural integrity. It is important to note that the HDPE pipe is not subject to a corrosion related failure based on the material of the pipe. Also, the pipe does not carry abrasive ash at a high enough velocity to cause erosive depletion in the wall thickness. This 24" outlet pipe has a location, configuration and surrounding dike soil conditions that do not lend themselves to a seepage type of failure. As background, in 1992, the 24" outlet, which connects to a 24" HDPE pipe that discharges in the acid basin located in the northeast tip of the north section of the impoundment, was added to allow drying and grading of the northern portion of the pond to reduce pond maintenance.

The embankment soil throughout the dike is a well compacted, very stiff, medium plasticity clay. The stability of the East Ash Pond embankment section at the south main outlet (Cross Section C-C, "CCR Rule Report: Initial Structural Stability Assessment for the East Ash Pond at the Joppa Power Station") had calculated factors of safety of 1.77, (§ 257.73(e)(1)(i) Minimum FS = 1.50), 1.71 (§ 257.73(e)(1)(ii) Minimum = 1.40) and 1.26 (§ 257.73(e)(1)(iii) Minimum = 1.00). The inspection history does not reveal any seepage throughout the entire embankment, including at the south section outlet. The soil type does not meet the criteria to be susceptible to concentrated leak erosion, backward erosion piping, or any other internal erosion process that would result from the low water head and velocity that exists around the south outlet discharge through the embankment (USBR-USACE (US Bureau of Reclamation–US Army Corps of Engineers), 2015. "Best Practices in Dam and Levee Safety Risk Analysis."; USACE, 2014. ER 1110-2-1156, "Safety of dams–Policy and procedures. Engineering and Design"; Briaud, Jean-Louis. "Case histories in soil and rock erosion: Woodrow Wilson bridge, Brazos River Meander, Normandy Cliffs, and New Orleans Levees." Journal of Geotechnical and Geoenvironmental Engineering 134, no. 10 (2008): 1425-1447.).

Please let me know if you have any questions.

Sincerely,

Vic Modeer, PE, D.GE
(IL, MO, IN, KY, OH, LA)
Consulting Engineer

October 2021

DOCUMENT 10

Region 4 U.S. Environmental Protection Agency Laboratory Services & Applied Science Division Athens, Georgia	
Operating Procedure	
Title: Pore Water Sampling	ID: LSASDPROC-513-R5
Issuing Authority: Field Services Branch Supervisor	
Effective Date: April 22, 2023	Review Due Date: May 12, 2024
Method Reference: N/A	SOP Author: Mel Parsons

Purpose

The purpose of this operating procedure is to describe the methods and considerations to be used when obtaining a pore water sample from soil or sediment.

Scope/Application

This document describes procedures generic to all pore water sampling methods to be used by field personnel when collecting and handling samples in the field. On the occasion that Laboratory Services and Applied Science Division (LSASD) personnel determine that any of the procedures described in this section are inappropriate, inadequate or impractical and that another procedure must be used to obtain a pore water sample, the variant procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

TABLE OF CONTENTS

Purpose 1
Scope/Application 1
1 General Information 3
1.1 Documentation/Verification 3
1.2 General Precautions 3
1.2.1 Safety 3
1.2.2 Procedural Precautions 3
1.2.3 Records 4
2 Sampling Methodology 4
2.1 General 4
2.2 Collection Considerations 4
2.3 Summary of Procedure 4
2.4 Sampling Equipment 4
2.5 Pore Water Sampler Deployment Considerations 5
2.6 Pore Water Collection 6
2.6.2 Syringe 7
2.7 Quality Control 7
2.8 Specific Sampling Equipment Quality Assurance Techniques 8
3 Special Sampling Considerations 8
3.1 Volatile Organic Compounds (VOC) 8
3.2 Dissolved Metals Sample Collection 8
3.3 Special Precautions for Pore Water Sampling 9
3.4 Sample Handling and Preservation Requirements 9
References 14
Revision History 15

1 General Information

1.1 Documentation/Verification

This procedure was prepared by persons deemed technically competent by LSASD management, based on their knowledge, skills and abilities and has been tested in practice and reviewed in print by a subject matter expert. The official copy of this procedure resides on the LSASD local area network (LAN). The Document Control Coordinator is responsible for ensuring the most recent version of the procedure is placed on the LAN and for maintaining records of review conducted prior to its issuance.

1.2 General Precautions

1.2.1 Safety

Proper safety precautions must be observed when collecting pore water samples. Refer to the LSASD Safety, Health and Environmental Management Program Procedures and Policy Manual (most recent version) and any pertinent site-specific Health and Safety Plans (HASP) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. When using this procedure, minimize exposure to potential health hazards through the use of protective clothing, eye wear and gloves. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.2.2 Procedural Precautions

The following precautions should be considered when collecting pore water samples:

- Special care must be taken not to contaminate samples. This includes storing samples in a secure location to preclude conditions which could alter the properties of the sample. Samples shall be custody sealed during long-term storage or shipment.

- Collected samples are in the custody of the sampler or sample custodian until the samples are relinquished to another party.

- If samples are transported by the sampler, they will remain under his/her custody or be secured until they are relinquished.

- Shipped samples shall conform to all U.S. Department of Transportation (DOT) rules of shipment found in Title 49 of the Code of Federal Regulations (49 CFR parts 171 to 179), and/or International Air Transportation Association (IATA) hazardous materials shipping requirements found in the current edition of IATA's Dangerous Goods Regulations.

- Documentation of field sampling is done in a bound logbook. Chain-of-custody documents shall be filled out and remain with the samples until custody is relinquished.

- All shipping documents, such as bills of lading, will be retained by the project leader and stored in a secure place.

1.2.3 Records

Information generated or obtained by LSASD personnel will be organized and accounted for in accordance with LSASD records management procedures found in LSASD Operating Procedure for Control of Records, LSASDPROC-002 (most recent version). Field notes, recorded in a bound field logbook, will be generated, as well as chain-of-custody documentation, in accordance with LSASD Operating Procedure for Logbooks, LSASDPROC-010 (most recent version), and LSASD Operating Procedure for Sample and Evidence Management, LSASDPROC-005 (most recent version).

2 Sampling Methodology

2.1 General

The pore water sampling techniques and equipment described in this procedure are designed to minimize effects on the chemical and physical integrity of the sample. If the procedures in this section are followed, a representative sample of the pore water should be obtained.

2.2 Collection Considerations

The physical location of the investigator when collecting a sample may dictate the equipment to be used. Wading is the preferred method for reaching the sampling location, particularly if the stream has a noticeable current (i.e., is not impounded). However, wading may disrupt bottom sediments causing biased results; therefore, the sampler should enter the area downstream of the sampling location and collect the sample facing upstream. If the stream is too deep to wade, the pore water sample may be collected from a platform such as a boat or by SCUBA diving. If sampling from a boat or in water deeper than the length of the sampler, extensions may be utilized. If SCUBA diving, all diving activity must be conducted in accordance with EPA's Diving Safety Manual, current version.

2.3 Summary of Procedure

Pore water is collected using a pore water extracting device (Figure 1). The most common type used by LSASD is the PushPoint™ sampler (M.H.E. Products 2003), made out of stainless-steel tubing. The sampling end of the pore water device is inserted into the sediment to the desired depth, and pore water is extracted using a syringe or peristaltic pump. The device is suitable for use only in fine-grained material (no gravel or cobble). Other similar devices may be used providing that the integrity of the sample is maintained, and no ambient surface water is allowed in contact with the sample.

2.4 Sampling Equipment

A PushPoint™ or similar sampler typically consists of a pointed tubular stainless-steel tube with a screened zone at one end and a sampling port at the other. The pointed end with the screened zone consists of a series of very fine interlaced machined slots to allow pore water to enter the sampler.

A removable guard rod adds rigidity to the sampler during sediment insertion. The length of the screened zone will depend on the site-specific study design. Depending on the data quality objectives (DQO) of the study, filters may be placed over the screened zone if additional screening is needed. Pore water is collected through the opposite end of the device by connecting flexible tubing and using a syringe or peristaltic pump to extract the sample. Teflon® tubing is the preferred tubing to be used for collecting pore water samples. However, other tubing may be used, depending upon the DQOs for the specific application.

There are many modifications that can be incorporated into the procedure to satisfy data quality objectives for a specific application. The procedures discussed in the following sections provide guidance on the basic operation of pore water sampling devices and issues to consider when collecting pore water.

An alternative system is available in LSASD inventory for use in soft sediments in water deeper than wading depth. A well screen and short riser approximately ¾" in diameter are threaded to fasten to the bottom of a custom flange. Internal threads on the screen accept a tubing adapter. The accompanying rimmed flange has a coupling with both top and bottom threads. The well screen is screwed into the bottom of the flange and Teflon® tubing is attached to the tubing adapter threaded into the well screen. For deployment, the tubing is then inserted through a PVC pipe or well casing which is then screwed into the upper threads of the flange. The entire assembly can be deployed in water up to ten feet of depth from a well anchored boat.

2.5 Pore Water Sampler Deployment Considerations

It is critical in the collection of pore water to avoid surface water intrusion. Water will flow in a path of least resistance. If space is created around the sides of the sampling end of the pore water device during deployment, surface water may flow down the outside of the device to the screened area and into the intended sample. Therefore, the pore water device should be used with a sampling flange (Figure 2), especially when collecting pore water near the sediment-surface water interface. If pore water is collected from deep in sediments, a flange may not be necessary. When inserted though the flange, the body of the pore water device should form a watertight seal to eliminate surface water intrusion during sample collection. Flanges should include an outer vertical cutting ring to enhance sealing. Flange systems can be augmented by flexible plastic sheeting of appropriate material. The sheeting can be weighted to conform to a stream bottom by objects obtained from other areas of the stream away from the sampling location. Several of the flanges in LSASD inventory have a threaded nut and washer to facilitate sealing the flange to a polyethylene sheet.

The flange can be made of any material that will not cross contaminate the intended sample. If both inorganic and organic analyses are required, the flange should be made of inert material such as stainless steel or Teflon®. The size of the flange depends on the volume of pore water to be collected. If large volumes of pore water are to be collected, use a large flange size. A useful estimate can be made for planning by taking the required water volume, tripling it to assume 33% porosity, and then calculating the dimensions of a cylinder of this volume, based upon the penetration depth of the sampler. The flange should cover at least this estimated volume. If it is not practical to use a large flange, then multiple devices may be deployed, and smaller volumes can be collected from several devices for a composite sample. If multiple devices are deployed, they should be spaced an appropriate distance apart so they will not interfere with one another.

In general, the volume of pore water that can be collected at a given location is limited. Collecting large volumes of pore water will ultimately result in the collection of water from the overlying water body. Often, minimum required volumes must be negotiated with the laboratory to limit the volumes withdrawn.

Where significant differences in parameters such as pH or conductivity exist between the surface water and pore water, a check can be made at the end of sampling to assess whether surface water intrusion has occurred by measuring the pore water parameters at the beginning and conclusion of sampling. Fluorescent dye tracing can also be used for this purpose.

2.6 Pore Water Collection

The flange is first placed at the desired sampling point with the push-point removed to allow any water to escape from under the flange. The flange rim should be carefully worked into the soil or sediment until the flange is flush with the surface. The pore water device should then be inserted through the compression adapter on the flange and into the soil or sediment as carefully as possible (Figure 2). When the sampler is inserted to the desired depth, the compression adapter should be tightened. The push-point's guard rod can then be withdrawn. Do not reinsert the guard rod into the sampler for any reason until the sampler has been cleaned (particles rolled between the two metal surfaces will lock the parts together and permanently damage the sampler.)

When deploying the pore water device, care must be taken not to disturb the sampling area. If the sampler is wading, the sampler should lean out and insert the pore water device as far as possible away from where the sampler is standing to reduce potential effects of the sampler on the integrity of the pore water sample. Depth of penetration of the pore water device depends on the objectives of the specific investigation.

After the pore water device has been successfully deployed, attach the sample tubing to the sampling port of the pore water device. Short pieces of Silastic® tubing can be used to splice Teflon® sample tubing to a push-point sampler, taking care to butt the tubing to the sampler at the center of the splice. Then attach the other end of the tubing to a sample withdrawing device, such as a syringe or a peristaltic pump (according to LSASD Operating Procedure for Pump Operation, LSASDPROC-203). Before collecting a pore water sample, be sure to purge out all air and surface water from the pore water sampler and sample tubing with the appropriate amount of pore water. This step can be accomplished by calculating the volume of the sampler and attached tubing and pumping this volume plus an additional 10 percent of pore water through the sampler and tubing prior to collecting the sample. If utilizing a syringe for collection, a three-way valve with a side syringe must be utilized for the surface water purge in order not to cross contaminate the sampling syringe.

2.6.1 Peristaltic Pump/Vacuum Jar Collection

The peristaltic pump/vacuum jug can be used for sample collection of organic or inorganic samples because it allows for the sample to be collected without coming in contact with the pump head tubing, maintaining the integrity of the sample. This is accomplished by placing a Teflon® transfer cap assembly onto the neck of a pre-cleaned standard 1-liter amber glass container (Figure 3). Teflon® tubing (¼-inch O.D.) connects the container to both the pump and the sample source. The

pump creates a vacuum in the container, thereby drawing the sample into the container without it coming into contact with the pump head tubing.

Because the sample is exposed to a vacuum and is agitated as it enters the vacuum jug, this method cannot be used for collection of samples for volatile organic compounds. An alternative method for collecting volatile organics involves filling the Teflon® tubing with sample by running the pump for a short period of time. Once the tubing is full of water, the tubing is removed from the pore water sampler and, then pinched off at the pump in order to maintain the vacuum while it is being disconnected from the pump head tubing. The water is then allowed to carefully drain, by gravity, into the sample vials. Alternatively, without disconnecting the tubing from the pump head, the contained sample can be pushed out of the tubing, into the sample vials, by reversing the peristaltic pump at very low speed. Great care must still be taken with this method in order not to agitate the sample during the transfer process or to transfer water that has been in contact with the Silastic® tubing into the vials.

Because pore water is typically collected from an anaerobic environment, it is preferable, especially when collecting samples for nutrient analysis, to maintain the integrity of the sample by minimizing exposure to air. This can be accomplished by purging the sample container with an inert gas such as nitrogen or argon prior to sampling. In addition, if analyzing for nutrients or metals, the container can be pre-preserved in order to minimize exposure of the sample to ambient conditions.

An alternative, when collecting samples for metals, nutrients, or other sample analyses not affected by Silastic® tubing and when exposure to air is not a concern, is to collect the sample directly from the discharge of the pump head tubing after an adequate purge has been demonstrated. When collecting samples in this manner, there are several considerations of which to be aware. The pump head tubing (Silastic®, etc.) must be changed after each sample and a rinsate blank must be collected from a representative piece of the pump head tubing (only one blank per investigation). Also, precautions must be taken to ensure that the end of the discharge tubing is not allowed to touch the ground or other surface to ensure the integrity of samples collected in this manner.

2.6.2 Syringe

An alternative to using the pump and vacuum container is to use a syringe as the mechanism to draw the pore water through the sampling device. The tubing from the sampling port of the pore water device can be directly attached to a syringe with a three-way valve and a side syringe and the pore water sample can be manually withdrawn. The valve is first switched to the side syringe, which is used for purging air and any ambient surface water in the system prior to sampling. The volume to be purged is determined by the length and diameter of the sampling device and attached tubing. Once the sampler has been purged, the valve is switched to the sampling syringe and the sample is drawn into the syringe. The syringe can be used as the final sample container or the pore water can be transferred to another container, depending on project objectives and analytical requirements. This is the best method to use if the sample is to be collected underwater by SCUBA diving.

2.7 Quality Control

If possible, a control or background sample should be collected from a location not affected by the possible contaminants of concern and submitted with the other samples. In streams or other bodies of moving water, the control sample should be collected upstream of the sampled area. For impounded bodies of water, particularly small lakes or ponds, it may be difficult or inappropriate to obtain an unbiased control from the same body of water from which the samples are collected. In these cases, it may be appropriate to collect a background sample from a similar impoundment located near the sampled body of water if there is a reasonable certainty that the background location has not been impacted. Equipment blanks should be collected if equipment is field cleaned and reused on-site or, if necessary, to document that low- level contaminants were not introduced by pumps, bailers or other sampling equipment.

2.8 Specific Sampling Equipment Quality Assurance Techniques

All equipment used to collect pore water samples shall be cleaned as outlined in the LSASD Operating Procedure for Field Equipment Cleaning and Decontamination, LSASDPROC-205 (most recent version) or LSASD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC, LSASDPROC-206 (most recent version) and repaired, if necessary, before being stored at the conclusion of field studies. Cleaning procedures utilized in the field or field repairs shall be thoroughly documented in field records.

3 Special Sampling Considerations

3.1 Volatile Organic Compounds (VOC)

Pore water samples for VOC analysis must be collected in 40 ml glass vials with Teflon® septa. The vial may be either preserved with concentrated hydrochloric acid or they may be unpreserved. Preserved samples have a two-week holding time, whereas, unpreserved samples have only a seven day holding time. During most sampling events, preserved vials are used due to their extended holding time. In some situations, however, it may be necessary to use unpreserved vials. For example, if the surface water sample contains a high concentration of dissolved calcium carbonate, there may be an effervescent reaction between the hydrochloric acid and the water, producing large numbers of fine bubbles. This will render the sample unacceptable. In this case, unpreserved vials should be used, and arrangements must be confirmed with the laboratory to ensure that they can accept the unpreserved vials and meet the shorter sample holding times.

Samples for VOC analysis must be collected using either stainless steel or Teflon® equipment. Samples should be collected with as little agitation or disturbance as possible. The vial should be filled so that there is a meniscus at the top of the vial and absolutely no bubbles or headspace should be present in the vial after it is capped. After the cap is securely tightened, the vial should be inverted and tapped on the palm of one hand to see if any undetected bubbles are dislodged. If a bubble or bubbles are present, the vial should be refilled. Care should be taken not to flush any preservative out of the vial during topping off. If, after attempting to refill and cap the vial, bubbles are still present, a new vial should be obtained, and the sample should be re-collected.

3.2 Dissolved Metals Sample Collection

If a dissolved metals pore water sample is to be collected, an in-line filtration should be used. The use of disposable, high-capacity filter cartridges (barrel-type) or membrane filters in an in-line filter

apparatus is preferred. The high-capacity, barrel-type filter is preferred due to the higher surface area associated with this configuration.

Potential differences could result from variations in filtration procedures used to process water samples for the determination of trace element concentrations. A number of factors associated with filtration can substantially alter "dissolved" trace element concentrations; these include filter pore size, filter type, filter diameter, filtration method, volume of sample processed, suspended sediment concentration, suspended sediment grain-size distribution, concentration of colloids and colloidally-associated trace elements, and concentration of organic matter. Therefore, consistency is critical in the comparison of short-term and long-term results. Further guidance on filtration may be obtained from Section 4.7.3 of the LSASD Groundwater Sampling Procedure (LSASDPROC-301).

3.3 Special Precautions for Pore Water Sampling

- A clean pair of new, non-powdered, disposable latex gloves will be worn each time a different location is sampled, and the gloves should be donned prior to handling sampling equipment. The gloves should not come in contact with the media being sampled and should be changed any time during sample collection when their cleanliness is compromised.
- All background or control samples shall be collected and placed in separate ice chests or shipping containers. Sample collection activities shall proceed progressively from the least suspected contaminated area to the most suspected contaminated area. Samples of waste or highly contaminated media must not be placed in the same ice chest as environmental (i.e., containing low contaminant levels) or background samples.
- If possible, one member of the field sampling team should take all the notes and photographs, fill out tags, etc., while the other members collect the samples.
- Samplers must use new, verified, certified clean disposable equipment, or pre-cleaned non-disposable equipment. Non-disposable equipment should be pre-cleaned according to procedures contained in LSASD Operating Procedure for Field Equipment Cleaning and Decontamination (LSASDPROC-205), for collection of samples for trace metals or organic compound analyses.

3.4 Sample Handling and Preservation Requirements

- Pore water will typically be collected using a peristaltic pump and placed directly into sampling containers. In some cases, a syringe may be used to collect the pore water and then either left in the syringe as the sample container or transferred into an appropriate container.
- During sample collection, if transferring the sample from a collection device, make sure that the device does not come in contact with the sample containers.
- Place the sample into appropriate, labeled containers. Samples collected for VOC analysis must not have any headspace (see Section 3.1).
- All samples requiring preservation must be preserved as soon as practically possible, soon after sample collection. If pre-preserved VOA vials are used, these will be preserved with concentrated hydrochloric acid prior to departure for the field investigation. For all other chemical preservatives, LSASD will use the appropriate chemical preservative generally stored in an individual single-use vial as described in the LSASD Operating Procedure for Field Sampling Quality Control (LSASDPROC-011). The adequacy of sample preservation will be checked after the addition of the preservative for all samples, except for the samples collected for VOC analysis. If it is determined that a sample is not acceptably preserved, additional preservative should be added to achieve adequate preservation. Preservation requirements for surface water samples are found in

the USEPA Laboratory Services Branch *Laboratory Operations and Quality Assurance Manual* (LOQAM).

Figure 1. Pore Water Sampling Device

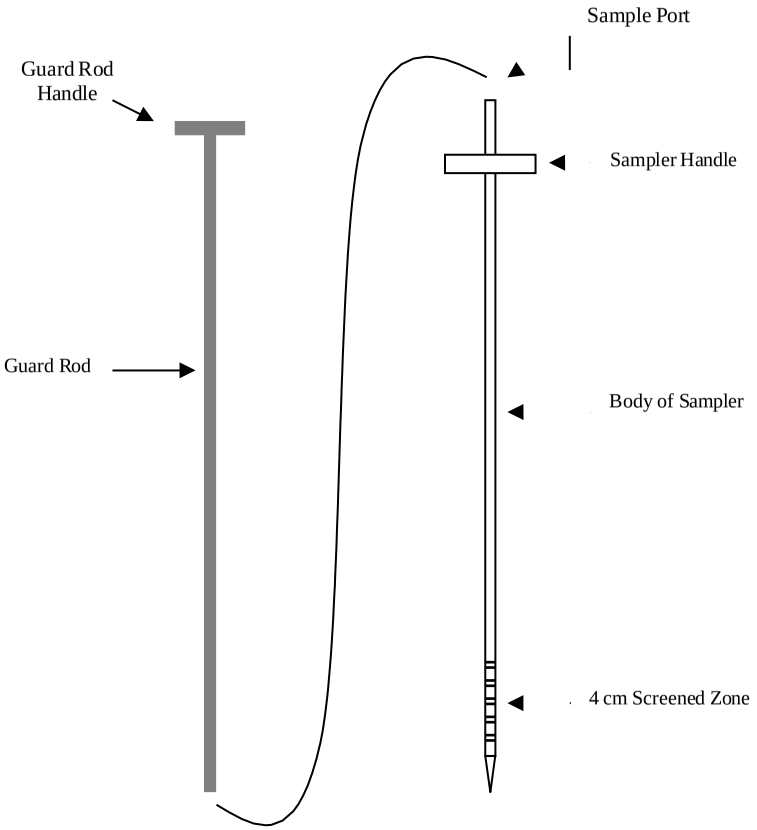


Figure 1A. Disassembled Device

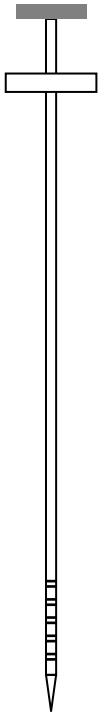
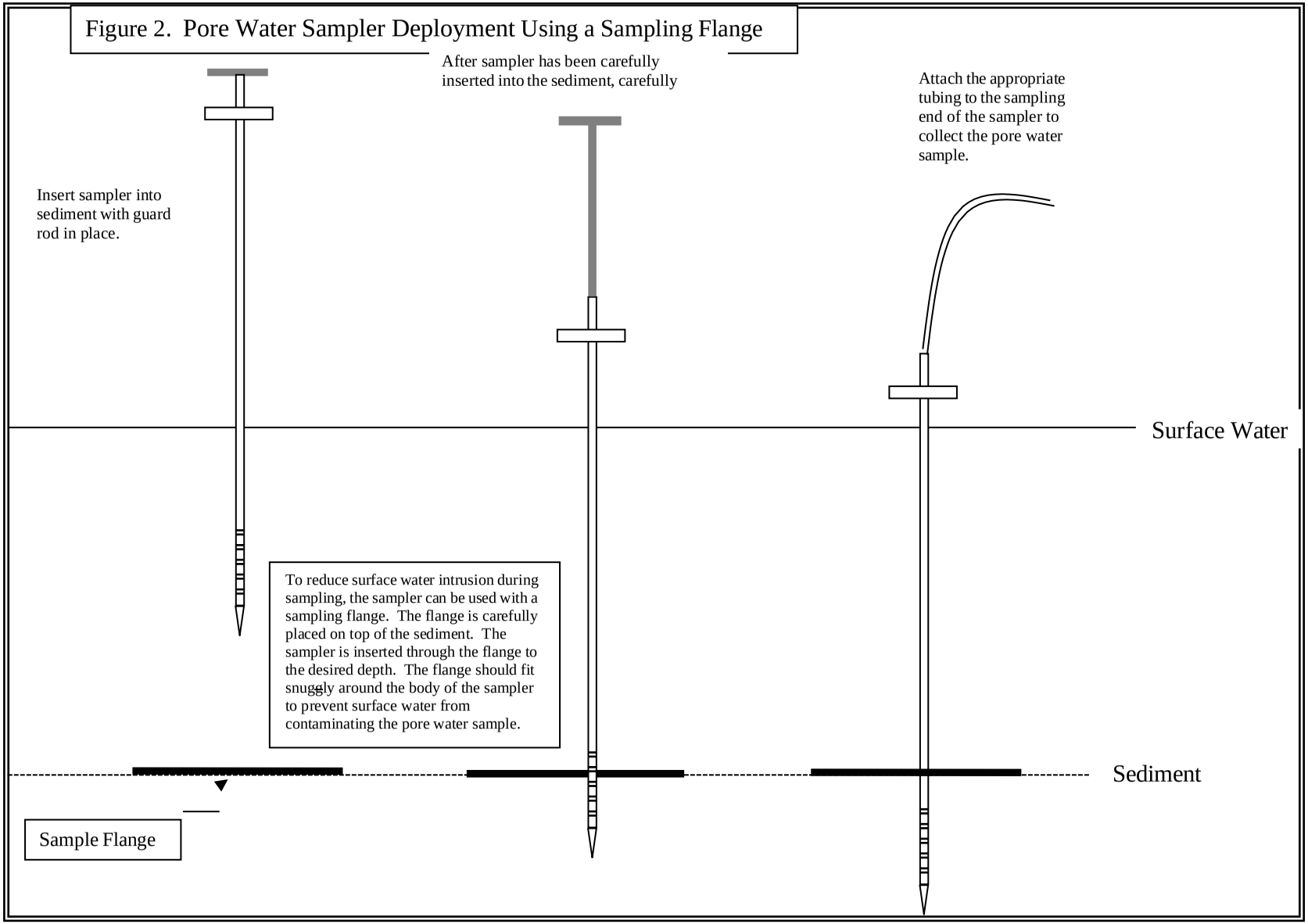


Figure 1B. Assembled Device

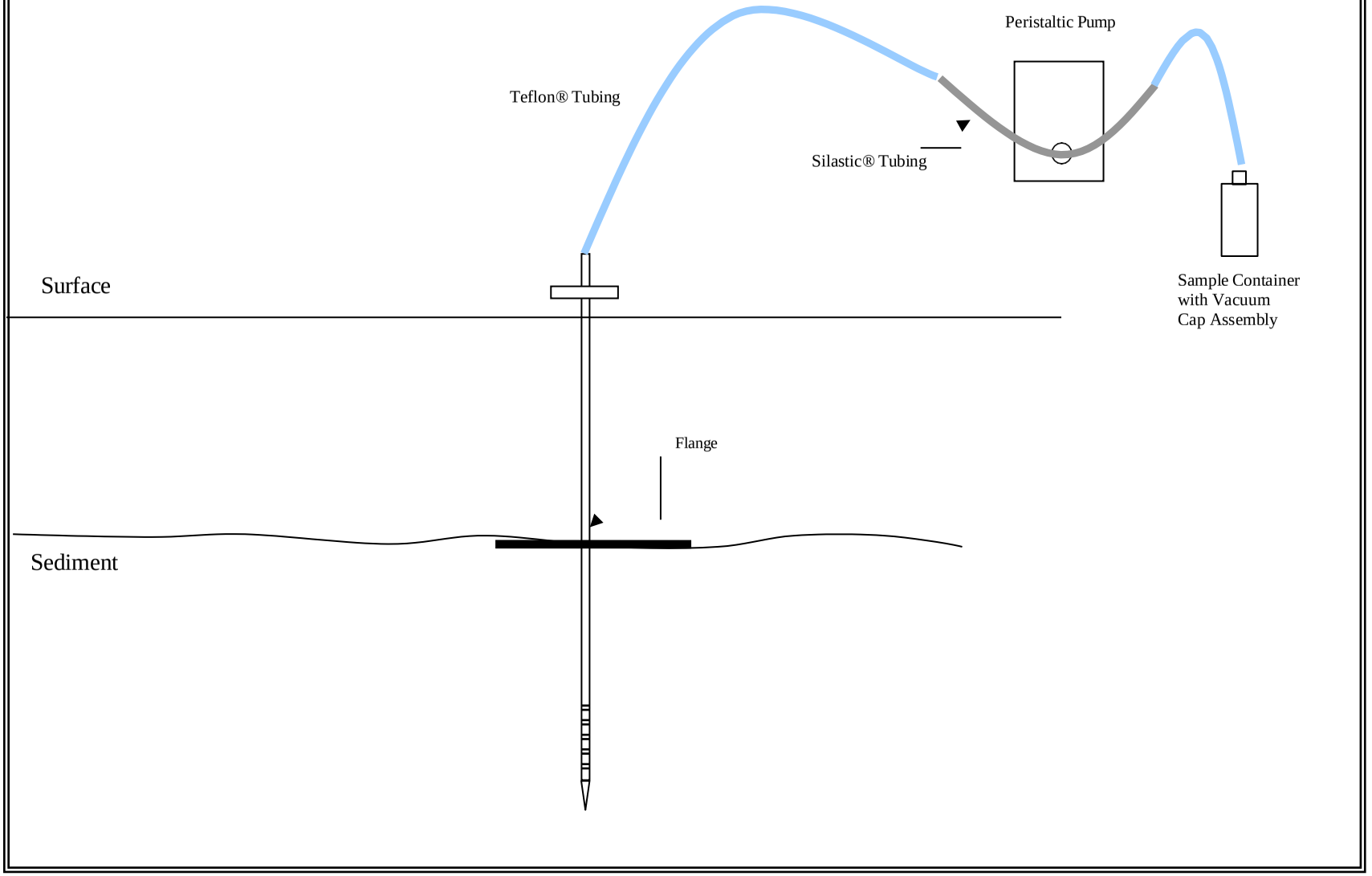
Actual length and width of device will vary, depending on sampling needs and site conditions.
Note: cm = centimeter

Figure 2. Pore Water Sampler Deployment Using a Sampling Flange



R001386

Figure 3. Pore Water Sampler Deployment Using a Peristaltic Pump to Sample



R001387

References

International Air Transport Authority (IATA). Dangerous Goods Regulations, Most Recent Version.

M.H.E. Products. 2003. PushPoint Sampler (US Pat. # 6,470,967) Operators Manual and Applications Guide, Version 2.01. East Tawas, MI. http://www.mheproducts.com

LSASD Operating Procedure for Control of Records, LSASDPROC-002, Most Recent Version.

LSASD Operating Procedure for Sample and Evidence Management, LSASDPROC-005, Most Recent Version.

LSASD Operating Procedure for Logbooks, LSASDPROC-010, Most Recent Version.

LSASD Operating Procedure for Surface Water Sampling, LSASDPROC-201, Most Recent Version.

LSASD Operating Procedure for Pump Operation, LSASDPROC-203, Most Recent Version.

LSASD Operating Procedure for Field Equipment Cleaning and Decontamination, LSASDPROC-205, Most Recent Version.

LSASD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC, LSASDPROC-206, Most Recent Version.

LSASD Operating Procedure for Groundwater Sampling, LSASDPROC-301, Most Recent Version.

LSASD Operating Procedure for Potable Water Supply Sampling, LSASDPROC-305, Most Recent Version.

Title 49 Code of Federal Regulations, Pts. 171 to 179, Most Recent Version.

USEPA LSBLOQAM. Laboratory Services Branch Laboratory Operations and Quality Assurance Manual Region 4, Laboratory Services and Applied Science Division, Athens, GA. Most Recent Version.

USEPA SHEMP Safety, Health and Environmental Management Program Procedures and Policy Manual. Laboratory Services and Applied Science Division, Region 4, Athens, GA. Most Recent Version.

LSASD Operating Procedure for Field Sampling Quality Control, LSASDPROC-011, Most Recent Version.

USEPA. 2016. Diving Safety Manual, current version. US Environmental Protection Agency, Washington, DC.

Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the LSASD Document Control Coordinator on the LSASD local area network (LAN).

History	Effective Date
Replaced Chief with Supervisor; General formatting revisions.	April 22, 2023
LSASDPROC-513-R4, Pore Water Sampling, *replaces SESDPROC-513-R3.* Laboratory Services and Applied Science Division replaces Science and Ecosystem Support Division **Title Page:** Changed the Field Quality Manager from Hunter Johnson to Stacie Masters. **General:** Corrected typographical, grammatical, and/or editorial errors. Added language to clarify some procedures.	May 13, 2020
SESDPROC-513-R3, Pore Water Sampling, replaces SESDPROC-513-R2. **General:** Corrected any typographical, grammatical, and/or editorial errors. **Title Page:** Changed the Field Quality Manager from Bobby Lewis to Hunter Johnson. Updated cover page to represent SESD reorganization. John Deatrick was not listed as the Supervisor of the Field Services Branch	December 16, 2016
SESDPROC-513-R2, Pore Water Sampling, *replaces SESDPROC-513-R1.*	February 28, 2013
SESDPROC-513-R1, Pore Water Sampling, *replaces SESDPROC-513-R0.*	January 29, 2013
SESDPROC-513-R0, Pore Water Sampling, *Original Issue*	February 05, 2007

DOCUMENT 11

10/19/23

Dyregg Meeting CCR

* Duck Creek, Newton, Vermillion
- Technical
- Joppa VN - CCA to ~~pass~~ preserve
  + Working w/ City of Joppa to help Community Wells
- Treating each impoundment like a CCA - CAP, construct, etc
- Annual - May miss some elevation due to technical issues

* Check for ASD!!
  - → Agency for 30 days
  - → 14 day Public Notice

* Newton *
+ About 8 more too
+ Verbal discuss w/ Vistra

DOCUMENT 12

Check for ASD

- Low Permeability
- ★ Hydraulic Conductivity of glacial till ($\times 10^{-8}$? or else)
- ★ APW 15 - Check

- UCU - range 6.3×10^{-9} to 2.1×10^{-8}
  mean = 1.1×10^{-8} ↑!
- Present - all of GW (Lynn, me, Lauren, Justin, + Matt)
- Visira - Rhys Fuller, Phil Morris, Vic Modeer, + Stuart Cravens
- ★ Court Order of CWLP - 845 vs 620 ★

- ★ Looking into geochemical Concept Model + submitting it
- Responses do not have time limit?
- Dynegy Stance - big sites could start next year (ex. Newton) for Closure
- By 2025, all sites in 2025

DOCUMENT 13

Luminant

Electric Energy, Inc.
1500 Eastport Plaza Drive
Collinsville, IL 62234

October 21, 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

RECEIVED
OCT 20 2023
IEPA
BOW/WPC/PERMIT SECTION

Re: Joppa Power Plant East Ash Pond; IEPA ID # W1270100004-02

Dear Mr. LeCrone:

In accordance with Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.650(e), Electric Energy, Inc. (EEI) is submitting this Alternative Source Demonstration (ASD) for exceedances observed from the Quarter 2 2023 sampling event at the Joppa Power Plant East Ash Pond, identified by Illinois Environmental Protection Agency (IEPA) ID No. W1270100004-02.

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, East Ash Pond Joppa Power Plant, Joppa Illinois

Intended for
Electric Energy, Inc.

Date
October 21, 2023

Project No.
1940103649-011

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION

EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS
IEPA ID: W1270100004-02

RAMBOLL Bright ideas. Sustainable change.

CERTIFICATIONS

I, Anne Frances Ackerman, a qualified professional engineer in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Anne Frances Ackerman
Qualified Professional Engineer
062-060586
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 21, 2023

I, Brian G. Hennings, a professional geologist in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Brian G. Hennings
Professional Geologist
196-001482
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 21, 2023

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA
T 414-837-3607
F 414-837-3608
https://ramboll.com

CONTENTS

1.	**Introduction**	**3**
2.	**Background**	**4**
2.1	Site Location and Description	4
2.2	Description of East Ash Pond CCR Unit	4
2.3	Geology and Hydrogeology	4
2.4	Groundwater and EAP Monitoring	6
3.	**Alternative Source Demonstration: Lines of Evidence for Cobalt**	**7**
3.1	LOE #1: Cobalt Concentrations at G05 are Consistent with Cobalt Mobilization from Native Soils Due to Reductive Dissolution of Manganese Oxides	7
3.2	LOE #2: Cobalt Concentrations at G05 are Greater Than Source Concentrations	9
3.3	LOE #3: Cobalt Concentrations at G05 Are Not Correlated with Concentrations of CCR Indicator Parameters	10
4.	**Alternative Source Demonstration: Lines of Evidence for pH**	**12**
4.1	LOE #1: G11 and G51D are Upgradient of the EAP	12
4.2	LOE #2: Groundwater Chemistry at G11 and G51D is Aligned with the Groundwater Signature Observed West of the Monitoring Wells	12
4.3	LOE #3: pH Exceedances at G11 and G51D are Consistent with Iron Oxidation	12
5.	**Conclusions**	**14**
6.	**References**	**15**

TABLES (IN TEXT)

Table A	Cobalt Concentration Ranges in G05 and EAP Porewater (March 2021 to May 2023)

FIGURES (IN TEXT)

Figure A	Scatter Plot and Linear Regression Results of Cobalt and Manganese in UA Solids
Figure B	Scatter Plot and Linear Regression Results of Total Cobalt and Total Manganese in Groundwater
Figure C	Scatter Plot of Cobalt Versus Boron and Sulfate Concentrations at Monitoring Well G05

FIGURES (ATTACHED)

Figure 1	Top of Uppermost Aquifer
Figure 2	Sampling Locations and Potentiometric Surface Map – May 1, 2023

APPENDICES (ATTACHED)

Appendix A	Supporting Solid Phase Analytical Data
Appendix B	Supporting Analysis for Reductive Dissolution of Manganese Oxides as a Likely Source of Cobalt Concentrations at G05
Appendix C	Supporting Groundwater and Porewater Analytical Data
Appendix D	Geochemical Analysis of Joppa East Ash Pond Groundwater in Support of An Alternative Source Demonstration (Life Cycle Geo, LLC, 2023)

ACRONYMS AND ABBREVIATIONS

35 I.A.C.	Title 35 of the Illinois Administrative Code
ASD	Alternative Source Demonstration
CCR	coal combustion residuals
E001	Event 1
EAP	East Ash Pond
Geosyntec	Geosyntec Consultants
GWPS	groundwater protection standard
JPP	Joppa Power Plant
LAU	Lower aquifer unit
LCU	lower confining unit
LOE(s)	Line(s) of evidence
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
NAVD88	North American Vertical Datum of 1988
NRT/OBG	Natural Resource Technology, an OBG Company
NTU	nephelometric turbidity units
OBG	O'Brien and Gere Engineers, Inc.
ORP	oxidation reduction potential
PCA	principal component analysis
PMP	potential migration pathway
Ramboll	Ramboll Americas Engineering Solutions, Inc.
SI	surface impoundment
UA	uppermost aquifer
UCU	upper confining unit
WAP	West Ash Pond

1. INTRODUCTION

Under Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e), 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, an owner or operator of a coal combustion residuals (CCR) surface impoundment (SI) may complete a written demonstration that a source other than the CCR SI caused the contamination and the CCR SI 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 (Alternative Source Demonstration [ASD]).

This ASD has been prepared on behalf of Electric Energy Inc. by Ramboll Americas Engineering Solutions, Inc (Ramboll), to provide pertinent information pursuant to 35 I.A.C. § 845.650(e) for the Joppa Power Plant (JPP) East Ash Pond (EAP) (*i.e.,* Site) located near Joppa, Illinois.

The most recent quarterly sampling event (Event 1 [E001]) was completed on May 3, 2023, and analytical data were received on June 23, 2023. In accordance with 35 I.A.C. § 845.610(b)(3)(C), comparison of statistically derived values with the GWPSs described in 35 I.A.C. § 845.600 to determine exceedances of the GWPS was completed by August 22, 2023, within 60 days of receipt of the analytical data (Ramboll, 2023). The statistical comparison identified the following GWPS exceedances at compliance groundwater monitoring wells:

- Boron at wells G06, G07, G08, G09, G10
- Cobalt at well G05
- pH at wells G11 and G51D

Pursuant to 35 I.A.C. § 845.650(e), the lines of evidence (LOE) presented in **Section 3** and **Section 4** demonstrate that sources other than the EAP are the cause of the cobalt and pH GWPS exceedances (respectively) listed above. Cobalt is believed to be naturally occurring and pH is associated with iron oxidation. This ASD was completed by October 21, 2023, within 60 days of determination of the exceedances (August 22, 2023), as required by 35 I.A.C. § 845.650(e).

Boron GWPS exceedances at the EAP will be addressed in accordance with 35 I.A.C. § 845.660.

2. BACKGROUND

2.1 Site Location and Description

The JPP is west of the Village of Joppa in Massac County, Illinois, northeast of the Ohio River in Section 14, Township 15 South, Range 3 East. The JPP property is bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north and west, the Village of Joppa to the east, and the Ohio River to the south. The EAP is located in the west half of Section 14 directly north of the JPP and is bounded immediately to the east by the railway right-of-way, which is adjacent to forested portions of residential property in the Village of Joppa.

2.2 Description of East Ash Pond CCR Unit

The JPP operated the EAP for management of CCR waste streams between 1973 and 2022. Another inactive SI, referred to as the West Ash Pond (WAP), is present in the western portion of the JPP property, and a permit exempt landfill is present in the northwestern portion of the JPP property. The landfill and the WAP are not the subject of this ASD but are relevant to the discussion of the LOEs presented below.

The EAP is an unlined CCR SI which was used to manage both fly ash and bottom ash. The EAP perimeter embankment height varies from approximately 15 to 45 feet above the outboard toe of slope and the crest is at an approximate elevation of 380 feet North American Vertical Datum of 1988 (NAVD88) (O'Brien and Gere Engineers, Inc. [OBG], 2010).

2.3 Geology and Hydrogeology

The information used to describe the hydrogeology is based on the local geology obtained from published sources, hydrogeologic investigation data, and boring data collected during site investigations conducted from 1997 to 2022 (Natural Resource Technology, an OBG Company [NRT/OBG], 2017; Ramboll, 2021a; Geosyntec, 2023).

Quaternary deposits in the Joppa area consist mainly of diamictons and lacustrine/alluvial deposits that were deposited during Illinoian and Pre-Illinoian glaciations (Lineback, 1979; Willman et al., 1975). The unconsolidated deposits include the following units (beginning at the ground surface):

- **Upper Confining Unit (UCU):** The uppermost hydrostratigraphic unit is comprised of the Equality Formation, the Silt Unit, and Metropolis Formation deposits. The average thickness of this unit is approximately 40 feet with a range of 8 to 58 feet. The UCU underlies the CCR fill in all locations and is thinnest in the southeast portion of the unit. These deposits are predominantly fine-grained, comprised of clay, silt, and silty clay with limited intervals of sandy material. This hydrostratigraphic unit was encountered at all locations and extends down to the McNairy Formation.
- **Uppermost Aquifer (UA):** The UA consists of the McNairy Formation and Mounds Gravel which are composed of highly permeable sands and gravels with isolated lenses of finer grained material. The Mounds Gravel has been interpreted as a braided river deposit, located within eroded portions of the McNairy Formation (Nelson and Masters, 2008). The McNairy formation, underlying the Mounds Gravel, at the site is mostly composed of medium to fine grained sand with mica and lenses of silt and clay. At the EAP, this unit has been further divided into the Upper McNairy Formation consisting of relatively thick fine to medium grained

sand with some gravel while the Lower McNairy exhibits more variability including lenses and zones with higher silt and clay content.

A northwest to southeast trending stratigraphic high in the UA is present through the center of the EAP and bifurcates near the eastern extent of the unit. This stratigraphic high (elevations higher than 305 ft) is illustrated on **Figure 1** where the UA is bounded by the UCU which is shaded purple where elevations extend below 305 feet. Wells screened within the UA along the southern fork of the stratigraphic high (G07, G08, G12S/D, G13S/D) generally encountered thicker gravel layers at higher elevations and reported higher hydraulic conductivities (Ramboll, 2021a; Geosyntec, 2023). The thicker gravels at higher elevations also extend east and southeast of the EAP (G12S/D, G13S/D, G16S/D) and connect to the Ohio River as illustrated in **Figure 1**. The UA was encountered at a thickness of up to 58 feet thick, with elevations ranging from 215 to 316.6 feet, and is underlain by the lower confining unit (LCU).

- **Lower Confining Unit (LCU):** Clay, silt, or chert gravel residuum in on-Site wells (Nelson, 1997) has been interpreted and characterized as part of the Lower McNairy Formation, Post Creek (Tuscaloosa) Formation, or weathered limestone residuum. This material has been encountered in all borings advanced to bedrock. Based on material descriptions (high clay and/or silt content, and partial cementation), continuous lateral extent, and vertical gradients observed between the UA and the lower aquifer unit (LAU), this unit is identified as the LCU.
- **Lower Aquifer Unit (LAU):** The LAU, composed of the Salem Limestone bedrock, is the lowermost hydrostratigraphic unit identified and is considered a potential migration pathway (PMP). The limestone bedrock is encountered at an elevation of approximately 200 feet NAVD88 below the EAP, slopes towards a syncline to the east (Nelson and Masters, 2008), and has a reported thickness of 200 to 500 feet. The Salem Limestone is used to supply water for various uses in the region and provides non-potable water for the JPP and potable water for the Village of Joppa.

Groundwater elevations in the UA (referenced to NAVD88) across the EAP ranged from approximately 312 to 322 feet during E001 (**Figure 2**). Historically they have ranged from approximately 305 feet near the Ohio River to 330 feet near the northern property boundary. Depth to groundwater measurements used to generate the groundwater elevation contours shown on **Figure 2** were collected on May 1, 2023. Groundwater elevations vary seasonally and may fluctuate by about 10 feet within a well.

Groundwater flow directions are largely a result of the aquifer geology described above. The shallow highly permeable gravels present a path of least resistance (preferential flow pathway) for groundwater migrating toward the Ohio River which is the receiving body of water in the region (**Figure 1**). Wells located to the north of the UA stratigraphic high, such as G05, were terminated shortly after penetrating the UA and did not encounter significant gravel layers indicating gravel may be at a lower elevation or not present, and flow through this area may not be as significant. Interpreted groundwater flow directions are illustrated on **Figure 1** with flow to the southeast, generally parallel to the UA stratigraphic high across the EAP, and then south toward the Ohio River.

2.4 Groundwater and EAP Monitoring

The monitoring system for the EAP is shown on **Figure 2** and consists of two background monitoring wells (G01D and G02D) and 12 compliance monitoring wells (G03, G05, G06, G07, G08, G09, G10 G11, G51D, G52D, G53D, and G54D) screened within the UA. The monitoring system also includes two temporary water level only surface water staff gage (XSG01 and SG02) to monitor potential impacts from the EAP (Ramboll, 2021b). Porewater samples are collected from locations XPW01 and XPW02 on the northern side of the EAP, and from XPW03 on the southern side of the EAP (**Figure 2**). To further delineate potential boron exceedances, 10 monitoring wells were installed in September 2021 (nests G12 through G16) and 21 wells (10 off-Site) were installed between May 2022 and September 2023 (nests G17 through G24, and G13; Geosyntec Consultants [Geosyntec], 2023).

3. ALTERNATIVE SOURCE DEMONSTRATION: LINES OF EVIDENCE FOR COBALT

As allowed by 35 I.A.C. § 845.650(e), this ASD demonstrates that sources other than the EAP (the CCR unit) caused the cobalt exceedance at G05. LOEs supporting the ASD for the pH exceedances at G11 and G51D are presented in **Section 4**. This section presents the LOEs supporting the ASD for cobalt at G05, which include the following:

1. Cobalt concentrations at G05 are consistent with cobalt mobilization from native soils due to reductive dissolution of manganese oxides.
2. Cobalt concentrations at G05 are greater than source concentrations.
3. Cobalt concentrations at G05 are not correlated with concentrations of CCR indicator parameters.

3.1 LOE #1: Cobalt Concentrations at G05 are Consistent with Cobalt Mobilization from Native Soils Due to Reductive Dissolution of Manganese Oxides

Cobalt and manganese are often closely associated with each other in soils due to their similar chemical properties (Uren, 2013). Under oxidizing conditions, manganese is present in the solid phase as manganese oxides. Cobalt sorbs strongly to manganese oxides and is thus often associated with manganese in the solid phase. When solid-phase manganese oxides in soils are dissolved by reduction of manganese to a more soluble species (a process called reductive dissolution), the cobalt previously sorbed to the manganese oxide surface is also released. If cobalt concentrations in groundwater are primarily controlled by the reductive dissolution of manganese oxides, cobalt and manganese concentrations in both soils and groundwater will be correlated with one another. This LOE demonstrates that cobalt concentrations at G05 are consistent with reductive dissolution of manganese, and the cobalt exceedance at G05 is therefore likely due to natural variation in groundwater quality. Solid phase data were used to determine if cobalt and manganese are associated in the solid phase. Groundwater redox potential and pH were assessed to determine if reductive dissolution of manganese oxides is thermodynamically favorable under observed groundwater conditions. To inform further analysis of groundwater data, wells with a geochemical signature similar to G05 were identified using principal component analysis (PCA). The relationship between cobalt and manganese in similar groundwater was then evaluated using regression analysis.

Figure A on the following page shows the relationship between total cobalt and total manganese in soil samples from the UA at five soil boring locations (data tabulated in **Appendix A**). The strong correlation between cobalt and manganese in these data (R^2 of 0.99) indicates that they are likely physically associated in soils, consistent with literature data (Uren, 2013). It is possible that cobalt released from CCR porewater could become associated with naturally occurring manganese oxides in the downgradient environment and accumulate in the soils; however, this is not likely at the site based on the following observations: 1) Cobalt is not present in CCR porewater (described further in **Section 3.2**), indicating that the EAP could not be a source of cobalt to the downgradient solid phase; 2) The ratio of cobalt to manganese is consistent across five different samples, some of which are from areas of the site with no known influence from

CCR porewater (*i.e.*, have had no reported exceedances). Therefore, the cobalt present in the UA soil is likely naturally occurring.

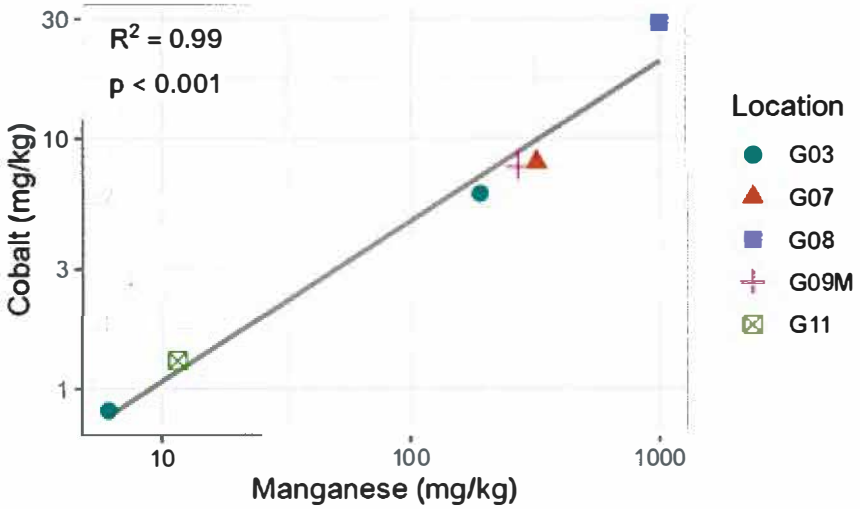


Figure A. Scatter Plot and Linear Regression Results of Cobalt and Manganese in UA Solids
mg/kg = milligrams per kilogram

The thermodynamic favorability of manganese oxide reductive dissolution depends on the oxidation reduction potential (ORP) and pH of the groundwater. The pH and ORP of the groundwater samples collected from the EAP monitoring network all indicate that manganese is expected to exist in the reduced Mn^{2+} form in groundwater (**see Appendix B**), supporting the conclusion that reductive dissolution of manganese oxides can occur in the groundwater.

To determine if cobalt and manganese are correlated in groundwater, locations with a similar groundwater signature to G05 were identified for appropriate inclusion in the correlation analysis. PCA, a multivariate statistical approach, was used to evaluate how the groundwater composition at G05 related to the groundwater composition of EAP porewater, background groundwater, and downgradient groundwater north versus south of the UA stratigraphic high (**Section 2.3**). Details about the PCA analysis are included in **Appendix B**. The PCA results indicate that the geochemical signatures of the UA wells located on either side of the northwest to southeast trending stratigraphic high in the UA that extends through the EAP are largely distinct from one another, with wells to the north of the stratigraphic high being more similar to background. This difference may be related to the differences in stratigraphic conditions, with wells to the north of the stratigraphic high having less gravel beds, while the wells to the south of the stratigraphic high have shallow highly permeable gravels which create a preferential flow pathway to the south. Groundwater from well G05 is most like other northeast wells, suggesting similar geochemical influences.

Figure B on the following page shows the relationship between total cobalt and total manganese in wells to the north of the stratigraphic high (data tabulated in **Appendix C**). To avoid potential confounding effects due to the presence of suspended solids in the groundwater sample, only samples with a turbidity less than 50 nephelometric turbidity units (NTU) were used in the

correlation analysis. The strong (R^2 of 0.77) statistically significant ($p < 0.001$) correlation between total cobalt and total manganese in the groundwater suggests similar controls on concentrations.

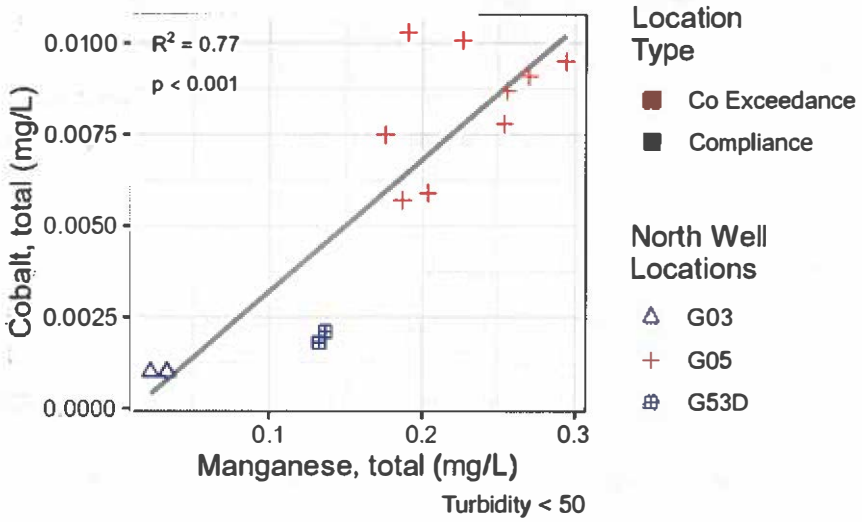


Figure B. Scatter Plot and Linear Regression Results of Total Cobalt and Total Manganese in Groundwater

The strong association between cobalt and manganese in both the soil and groundwater, in addition to groundwater conditions in the area of G05 favoring manganese reduction, supports the conclusion that reductive dissolution of manganese oxides in native soil is occurring and is strongly influencing the cobalt concentrations in the groundwater rather than the EAP.

3.2 LOE #2: Cobalt Concentrations at G05 are Greater Than Source Concentrations

Table A on the following page provides the range of cobalt concentrations detection in G05 between March 2021 and May 2023. Porewater samples collected from XPW01, XPW02 and XPW03 between March 2021 and May 2023 did not have cobalt concentrations above the reporting limit. A summary of the laboratory data is included in **Appendix C**.

Table A. Cobalt Concentration Ranges in G0S and EAP Porewater (March 2021 to May 2023).

Sample Location	Cobalt (mg/L)			
	Samples	Non-Detects	Minimum	Maximum
Composite Porewater[1]	24	24	<0.0001	<0.001
G05	11	0	0.0057	0.0103

[1] Composite Porewater includes summary statistics of data collected at EAP porewater locations XPW01, XPW02, and XPW03

mg/L = milligrams per liter

The following observations can be made from **Table A**:

- The concentration of cobalt in compliance monitoring well G05 ranged from 0.0057 mg/L to 0.0103 mg/L.
- Cobalt was not detected in EAP porewater, with reporting limits ranging from 0.0001 mg/L to 0.001 mg/L.
- The minimum cobalt concentration observed at G05 is five times the highest reporting limit for cobalt in porewater.

If the EAP were the source of cobalt in downgradient groundwater, EAP porewater concentrations of cobalt would be expected to be higher than the groundwater concentrations. Cobalt was not detected above the reporting limit in any porewater samples, indicating that cobalt concentrations are not related to the EAP.

3.3 LOE #3: Cobalt Concentrations at G05 Are Not Correlated with Concentrations of CCR Indicator Parameters

Boron is commonly used as an indicator parameter for contaminant transport of CCR because: (i) it is commonly present at elevated concentrations in coal ash leachate; (ii) it is mobile and typically not very reactive but conservative (*i.e.*, low rates of sorption or degradation) in groundwater; and (iii) it is less likely than other constituents to be present at elevated concentrations in background groundwater from natural or other anthropogenic sources. Porewater in the EAP is elevated in both boron and sulfate (**Appendix C**), indicating that these parameters are Site-specific key indicators for CCR. If an exceedance is identified for a monitored CCR parameter but concentrations of boron and sulfate are not correlated with that parameter, it is unlikely that the CCR unit is the source of the GWPS exceedance.

A scatter plot of cobalt versus boron and sulfate concentrations for G05 between March 2021 and May 2023 is presented in **Figure C** on the following page and laboratory data is included in **Appendix C.** The p-value of a Kendall correlation test for non-parametric data are also included on **Figure C**. Typically, a p-value greater than 0.05 is considered to be a statistically insignificant relationship.

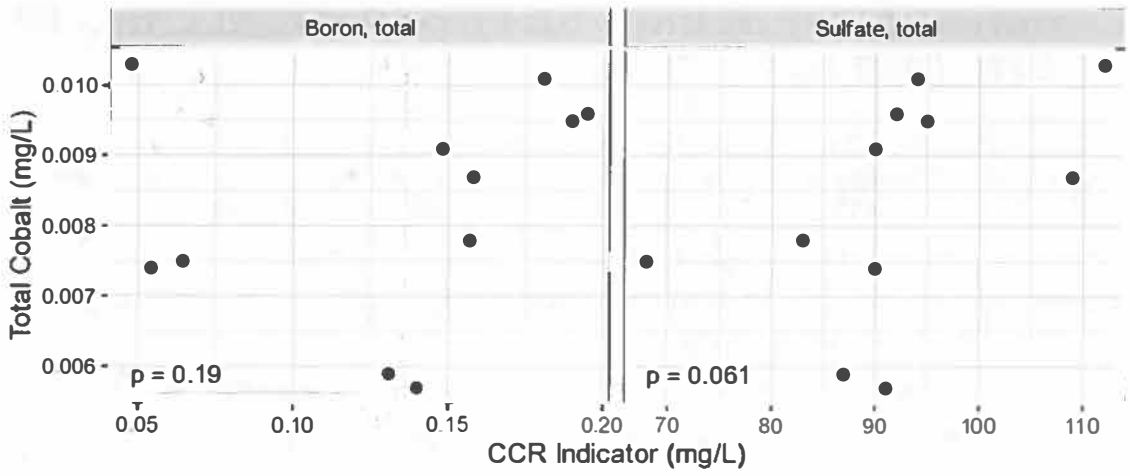


Figure C. Scatter Plot of Cobalt Versus Boron and Sulfate Concentrations at Monitoring Well G0S

Calculated p-values greater than 0.05 indicate that cobalt is not correlated with boron and sulfate at monitoring well G05. A lack of correlation between cobalt and CCR indicators in the compliance monitoring well indicates the EAP is not the source of the cobalt exceedance.

4. ALTERNATIVE SOURCE DEMONSTRATION: LINES OF EVIDENCE FOR pH

As allowed by 35 I.A.C. § 845.650(e), this ASD demonstrates that sources other than the EAP (the CCR unit) caused the pH exceedances at G11 and G51D. This section presents the LOEs supporting the ASD for pH at G11 and G51D, which include the following:

1. G11 and G51D are upgradient of the EAP.
2. Groundwater chemistry at G11 and G51D is aligned with the groundwater signature observed west of the monitoring wells.
3. pH exceedances at G11 and G51D are consistent with iron oxidation.

These LOEs are summarized below and described in greater detail in **Appendix D**.

4.1 LOE #1: G11 and G51D are Upgradient of the EAP

As described in **Section 2.3** dominant UA groundwater flow direction at the EAP is to the southeast, generally parallel to the UA stratigraphic high across the EAP, and then south toward the Ohio River (**Figure 1**). Wells G11 and G51D are located on the western edge of the EAP and are upgradient of the EAP. Therefore, it is unlikely that porewater from the EAP would flow in the direction of G11 and G51D. Because the wells with pH exceedances are upgradient of the unit, it is unlikely that the EAP is the source of the exceedances.

4.2 LOE #2: Groundwater Chemistry at G11 and G51D is Aligned with the Groundwater Signature Observed West of the Monitoring Wells

Groundwater from exceedance wells G11 and G51D exhibit a high degree of similarity with groundwater from upgradient UA wells west of G11 and G51D (western groundwater) as opposed to eastern groundwater or CCR porewaters from other compliance wells in the EAP monitoring network (eastern groundwater). PCA (**Appendix D**) was used to compare the geochemical compositions of the western groundwater, CCR porewaters, and pH exceedance wells G11 and G51D. The PCA found that:

- Exceedance wells G51D and G11 exhibit a high degree of similarity with the western (*i.e.*, upgradient) wells screened in the UA.
- The CCR porewaters are distinctly separate from the groundwater samples.

The similarity of the groundwater composition at G11 and G51D to upgradient western groundwater, as opposed to eastern groundwater or CCR porewater, suggests that the EAP does not influence the groundwater at G11 and G51D and therefore is not the source of the pH exceedances.

4.3 LOE #3: pH Exceedances at G11 and G51D are Consistent with Iron Oxidation

The PCA analysis (**Appendix D**) suggests chemical evolution and/or communication within the western groundwater. The western UCU groundwater composition is dominated by the redox-sensitive parameters manganese, iron, and sulfate. The UA groundwater composition is spread between a composition similar to the UCU and a composition similar to background. Groundwater

composition at wells G11 and G51D is very similar to (*i.e.*, plots close to on the PCA diagram) the background wells, all of which are dominated by alkalinity, chloride, fluoride and sodium.

Redox conditions were evaluated along the flow path from upgradient (further northwest) to downgradient (further southeast) groundwater wells. A distinct redox transition was identified, shifting from more reducing conditions in upgradient waters to more oxidizing conditions in downgradient wells, including the exceedance wells. The reducing upgradient waters are characterized by lower ORP and higher iron concentrations, while downgradient waters are largely the opposite with higher ORP and lower iron concentrations.

This change in redox condition is the likely source of acidity in G11 and G51D. It is likely that dissolved iron present in reducing environments moves downgradient with groundwater and subsequently oxidizes. The oxidation of dissolved iron to iron oxides is known to produce acidity. In this way, reduced upgradient waters from the northwest provides the constituent (*i.e.*, reduced iron) necessary to cause a drop in pH (*i.e.*, through iron oxidation) in G11 and G51D, once transported into an area with sufficient dissolved oxygen to drive the precipitation reaction. The oxidized environment in wells G11 and G51D likely results from mixing with the upgradient oxidized background groundwater. Therefore, mixing of groundwater resulting in natural variability in the groundwater conditions is the likely driver of the pH exceedances at G11 and G51D.

5. CONCLUSIONS

Based on the LOEs presented below and described in **Section 3**, it has been demonstrated that sources other than the EAP (the CCR unit) caused the cobalt exceedance at G05.

1. Cobalt concentrations at G05 are consistent with cobalt mobilization from native soils due to reductive dissolution of manganese oxides.
2. Cobalt concentrations at G05 are greater than source concentrations.
3. Cobalt concentrations at G05 are not correlated with concentrations of CCR indicator parameters.

Furthermore, based on the LOEs presented below and described in **Section 4**, it has been demonstrated that sources other than the EAP caused the pH exceedances at G11 and G51D.

1. G11 and G51D are upgradient of the EAP.
2. Groundwater chemistry at G11 and G51D is aligned with the groundwater signature observed west of the monitoring wells.
3. pH exceedances at G11 and G51D are consistent with iron oxidation.

Pursuant to 35 I.A.C. § 845.650(e), the LOEs presented in **Section 3** and **Section 4** demonstrate that sources other than the EAP were the cause of the cobalt and pH GWPS exceedances (respectively) listed above. Boron GWPS exceedances at the EAP will be addressed in accordance with 35 I.A.C. § 845.660.

6. REFERENCES

Geosyntec Consultants, Inc. (Geosyntec), 2023. *Supplemental Site Investigation Report. Joppa Power Station, East Ash Pond (CCR Unit #401), Electric Energy, Inc.*

Life Cycle Geo, LLC., 2023, *Geochemical Analysis of Joppa East Ash Pond Groundwater in Support of an Alternative Source Demonstration.*

Lineback, J., 1979, *Quaternary Deposits of Illinois: Illinois State Geological Survey map, scale 1:500,000.*

Natural Resource Technology, an OBG Company (NRT/OBG), 2017. *Hydrogeologic Monitoring Plan, Joppa East Ash Pond – CCR Unit ID 401, Joppa Power Station, Joppa, Illinois, Electric Energy, Inc.* October 17, 2017.

Nelson, W.J. and Masters, J.M., 2008. Geology of Joppa Quadrangle, Massac County, Illinois. Illinois Department of Natural Resources. Illinois State Geological Survey. Champaign, Illinois.

O'Brien & Gere Engineers, Inc. (OBG), 2010. *Dam Safety Assessment of CCW Impoundments. Joppa Plant, Prepared for: US Environmental Protection Agency, Washington, DC.* September 24, 2010.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021a. *Hydrogeologic Site Characterization Report. Joppa Power Plant, East Ash Pond, Joppa, Illinois. Electric Energy, Inc.* October 25, 2021.

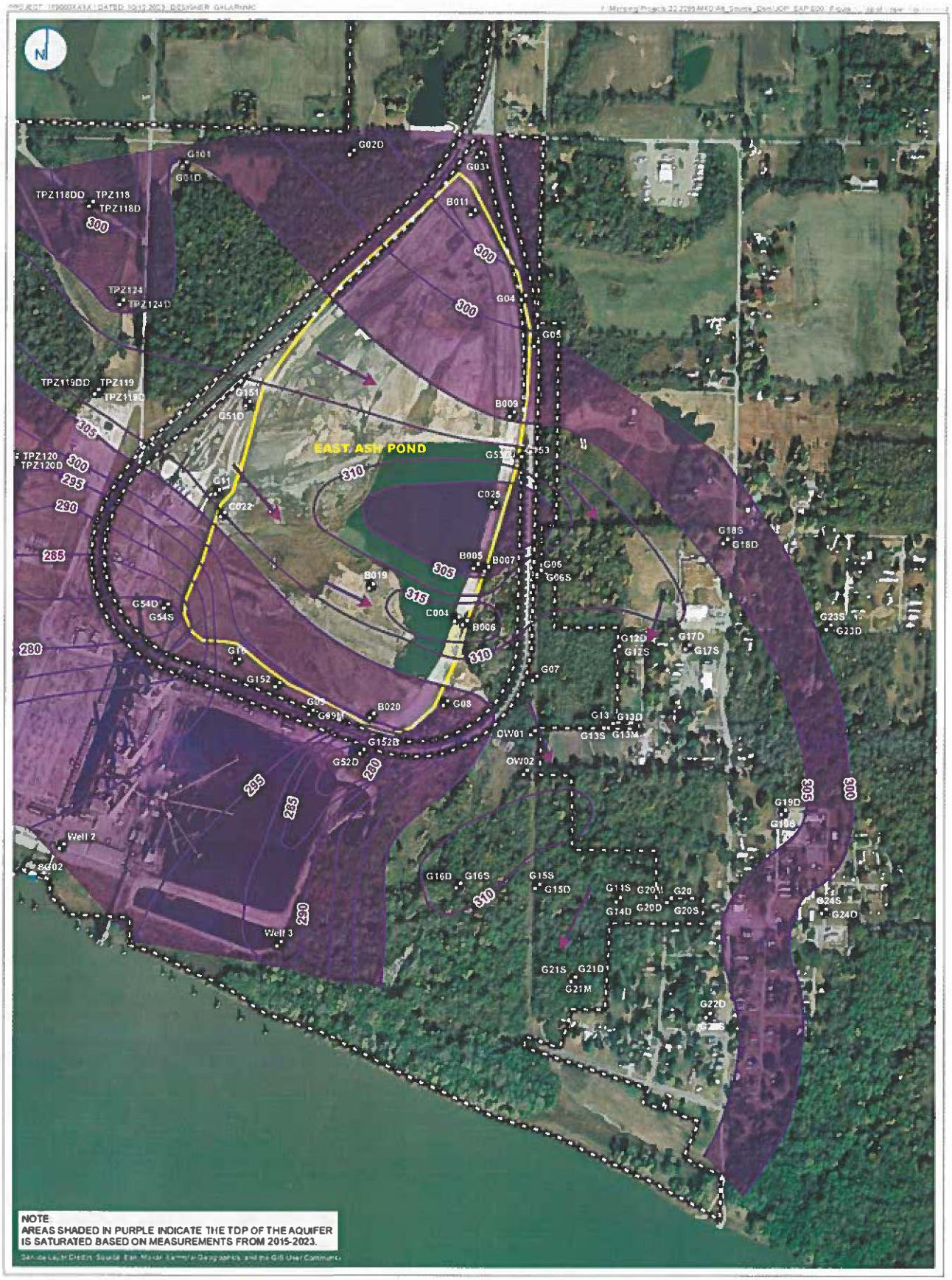
Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021b. *Groundwater Monitoring Plan, Joppa Power Plant, East Ash Pond, Joppa, Illinois, Electric Energy, Inc.* October 25, 2021.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2023. *35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances, 2023 Quarter 2, East Ash Pond, Joppa Power Plant, Joppa, Illinois*. August 22, 2023.

Uren, N.C. 2013. *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Ed. B.J. Alloway. Springer Science+Business Media. Chapter 12: Cobalt and Manganese. p 335-366.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975. *Handbook of Illinois Stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.*

FIGURES



MONITORING WELL
STAFF GAGE, RIVER
TOP OF MCNAIRY FORMATION ELEVATION (5-FT CONTOUR INTERVAL)
FLOW DIRECTION
AREA WHERE TOP OF AQUIFER IS SATURATED BASED ON MEASUREMENTS FROM 2015-2023
REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

0 300 600 Feet

TOP OF UPPERMOST AQUIFER

FIGURE 1

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION
EAST ASH POND
JOPPA POWER PLANT JOPPA, ILLINOIS

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

- COMPLIANCE MONITORING WELL
- BACKGROUND MONITORING WELL
- PORE WATER WELL
- STAFF GAGE, RIVER
- MONITORING WELL
- STAFF GAGE, CCR UNIT
- GROUNDWATER ELEVATION CONTOUR (2-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- REGULATED UNIT (SUBJECT UNIT)
- PROPERTY BOUNDARY

0 300 600 Feet

SAMPLING LOCATIONS AND POTENTIOMETRIC SURFACE MAP - MAY 1, 2023

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

FIGURE 2

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC

RAMBOLL

APPENDICES

APPENDIX A
SUPPORTING SOLID PHASE ANALYTICAL DATA

APPENDIX A.
SUPPORTING SOLIDS PHASE ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Boring ID	Sample Elevation (feet NAVD88)	Cobalt (mg/kg)	Manganese (mg/kg)
G03	284.84 - 297.34	6.0	190
G03	294.84 - 296.84	0.82	6.1
G07	294.34 - 300.34	8.0	320
G08	261.72 - 266.72	29	1000
G09M	264.60 - 266.60	7.7	270
G11	303.38 - 305.38	1.3	11.6

Notes:
NAVD88 = North American Vertical Datum of 1988
mg/kg = milligrams per kilogram

APPENDIX B
SUPPORTING ANALYSIS OF REDUCTIVE DISSOLUTION OF MANGANESE OXIDES AS A LIKELY SOURCE OF COBALT CONCENTRATIONS AT G05

RAMBOLL

ENVIRONMENT
& HEALTH

TECHNICAL MEMORANDUM

Project no. 1940103649-011
Client Electric Energy, Inc.
Prepared by Alison O'Connor, Ph.D.

Supporting Analysis for Reductive Dissolution of Manganese Oxides as a Likely Source of Cobalt Concentrations at G0S

Joppa Power Plant, East Ash Pond

October 12, 2023

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608

1 INTRODUCTION

This document serves as an appendix for the October 21, 2023, Alternative Source Demonstration (ASD) for Joppa Power Plant (JPP) East Ash Pond (EAP) for monitoring Event 1 (E001), completed to fulfil the requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e).

Cobalt and manganese are often closely associated in soils due to their similar chemical properties (Uren, 2013). In igneous rocks, cobalt and manganese occur together in minerals due to carrying +2 charge and having similar atomic radii (Uren, 2013). Cobalt and manganese are released together during weathering processes and are often transported together through the environment. In highly oxidizing environments, manganese 2+ can be oxidized to manganese 4+ which exists as solid phase manganese oxide minerals. Cobalt sorbs strongly to manganese oxides compared to other divalent cations (McKenzie, 1967; Backes et al., 1995). Therefore, manganese-associated cobalt is released when solid-phase manganese oxides in soils are dissolved by reduction to a more soluble species.

This line of evidence (LOE) demonstrates that cobalt concentrations at G05 are consistent with reductive dissolution of manganese, and the cobalt exceedance at G05 is therefore likely due to natural variation in groundwater quality. Solid phase data were used to determine if cobalt and manganese are associated in the solid phase. To inform further analysis of groundwater data, wells with a geochemical signature like G05 were identified using principal component analysis (PCA). The relationship between cobalt and manganese in similar groundwater was then evaluated using regression analysis.

2 METHODS

2.1 Solid Phase Measurements

Total cobalt and total manganese data were available for samples collected from the uppermost aquifer (UA) at five boring locations. Six total samples were available (two samples were collected from G03). These soil data represent the acid-digestible portion of the solids phase, which may be mobilized under environmental relevant geochemical conditions. Any metals entrained within the highly refractory aluminosilicate matrix are not extracted.

2.2 Regression Analysis

Least squares linear regression (abbreviated here as regression analysis) was used in this work to understand correlations between data. Regression analysis determines the equation for the line that minimizes the sum of the squared differences between the data and the regression estimate. Regression analysis assumes that the errors in the regression (called residuals) have a mean of zero and are randomly distributed around the mean following a normal distribution. The distribution of regression residuals can be visualized by plotting the residuals against the fitted values.

The relationship between the variables is assessed using the p value and the R^2 of the regression. The p value represents the chance the relationship between the data is due to random variability. A cut off p value of 0.05 often is used to determine if a regression is statistically significant (*i.e.*, it has less than a 5 percent (%) chance of being due to random variability). The R^2 value represents the proportion of the variance in the dependent variable that is explained by the independent variable. A higher R^2 value indicates a close relationship between the two variables (with an R^2 of 1 representing a perfectly straight line).

2.3 Principal Component Analysis

Groundwater data is frequently defined by many chemical parameters and may therefore be described statistically as "multivariate". PCA is a common multivariate statistical approach that simplifies multivariate data by combining those variables into a smaller number of new variables called principal components. This is possible because in multivariate data sets, there is often some correlation between variables. These correlations represent "redundant" information that may be mathematically removed by PCA. The principal components represent linear combinations of the original data which maximize the variance between the samples, and which are uncorrelated with one another. PCA thereby allows patterns in the data to be more easily recognized and correlations between input variables to be assessed.

The goal of this PCA was to identify wells similar to G05 and which are therefore likely affected by similar geochemical processes. The groundwater potentiometric map (E001 ASD Figure 2) and stratigraphic conditions in the UA (E001 ASD Section 2.3) suggest that wells in different areas downgradient of the EAP may be influenced by different areas of upgradient water. Additionally, as discussed in Appendix D, compliance wells G11 and G51D are strongly influenced by groundwater west of the EAP. To focus this analysis on identifying distinct populations of downgradient groundwater, the dataset for this PCA included only background wells, EAP porewater, and compliance wells east and south of the EAP (*i.e.*, downgradient from the unit; see E001 ASD Figure 2) screened in the UA.

Samples with a turbidity greater than 50 nephelometric turbidity units (NTU) were excluded from the analysis to mitigate the confounding influence of suspended solids. Geochemical parameters excluded from the PCA were to have measurements in over half the samples or to have an overall proportion of detected measurements exceeding 50 %. Individual samples missing data for more than half of the parameters (7 of 14 included in the PCA) were excluded from the analysis. Any measurements that were below the reporting limit were assumed to be half the reporting limit. Results for pH were converted to milligrams per liter (mg/L) H^+ ion for consistency with other analytes. Any missing values were imputed (*i.e.*, interpolated based on the available data) using the nearest neighbor method. The final data set (**Attachment A**) contained 1,232 parameter measurements (67 of which were imputed) from 88 individual groundwater samples at 15 wells in the vicinity of the EAP (three porewater wells, two background wells, and 10 compliance wells). All data were log transformed, scaled, and centered so that parameters with larger concentrations did not have disproportionate influence on the results.

Results of the PCA analysis are presented in a biplot. In a PCA biplot, the axes represent the new "variables," or principal components (PCs). The length of the arrows represents how strongly each individual variable contributes to the PCs, and the direction of the arrow along the respective axis represents the direction of the contribution (positive or negative). Each data point represents a sample plotted according to the PCs.

2.4 Pourbaix Diagrams

Pourbaix diagrams, also called Eh-pH diagrams, are visual representations of redox speciation under equilibrium conditions at a given pH (x axis) an Eh (y axis). Eh is the measure of redox potential based on the standard hydrogen electrode and is calculated by converting an oxidation reduction potential (ORP) measurement using an equation appropriate to the type of electrode used in the ORP sensor (typically silver/silver chloride or calomel). An Aqua TROLL field meter was used to measure ORP in the field. The equation to convert ORP to Eh for this meter is[1]:

Eh = ORP (mV) + 221.4 – 0.9*Temperature (°C)

3 RESULTS AND DISCUSSION

3.1 Regression quality

The results of the regressions of aquifer solids and groundwater data are presented in the main text of the ASD. This section discusses how the regressions meet the standard assumptions.

For the regression of aquifer solids data, the residuals are most extreme in the negative direction, but the mean of the residuals is zero and there is considerable scatter (**Figure B-1**). Therefore, the regression meets the assumptions relatively well.

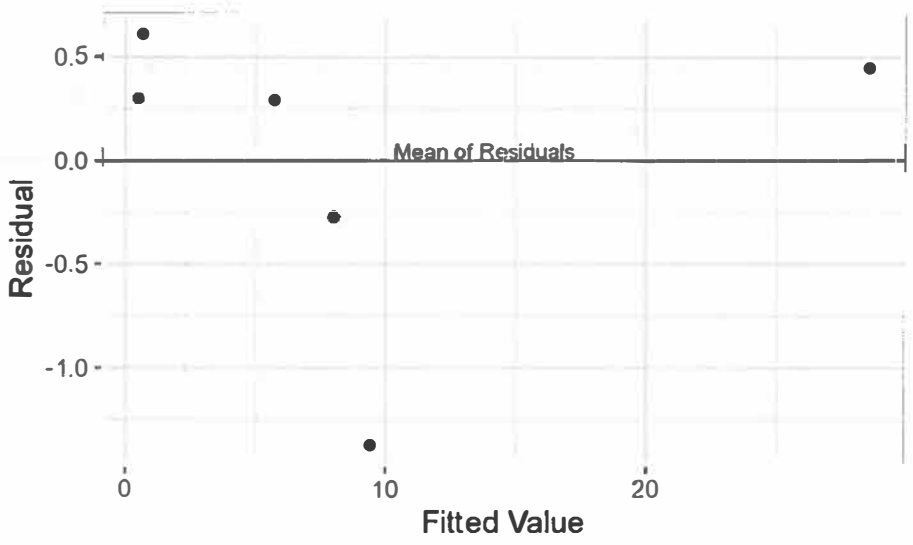


Figure B-1. Plot of residuals against fitted values for the UA solids cobalt versus manganese regression model.

[1] As reported at https://in-situ.com/us/news/orp-field-measurements-reporting-redox-potential-eh-correctly

For the regression of groundwater data, the residuals are most extreme toward the middle of the fitted values, but the mean of the residuals is zero and there is considerable scatter (**Figure B-2**). Therefore, the regression meets the assumptions relatively well.

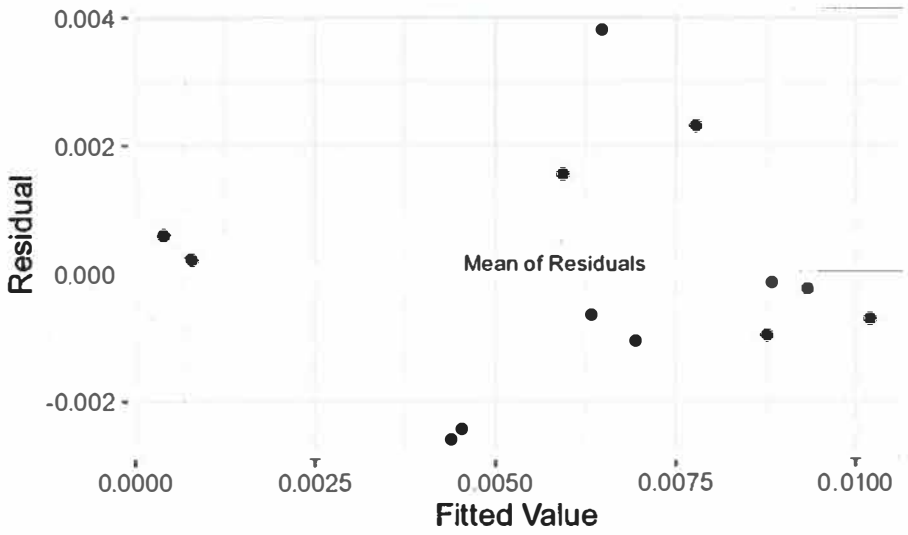


Figure B-2. Plot of residuals against fitted values for the groundwater cobalt versus manganese regression model.

3.2 Pourbaix Diagram

Figure B-3 shows the Pourbaix diagram for manganese with 2023 groundwater data plotted. Manganese is expected to exist in the reduced Mn^{2+} form at all groundwater locations (including G05), as opposed to insoluble manganese oxide mineral forms (*i.e.*, birnessite and todorokite). This indicates that reductive dissolution of manganese oxide minerals is thermodynamically favorable at G05, which supports this mechanism as a source of cobalt in the groundwater.

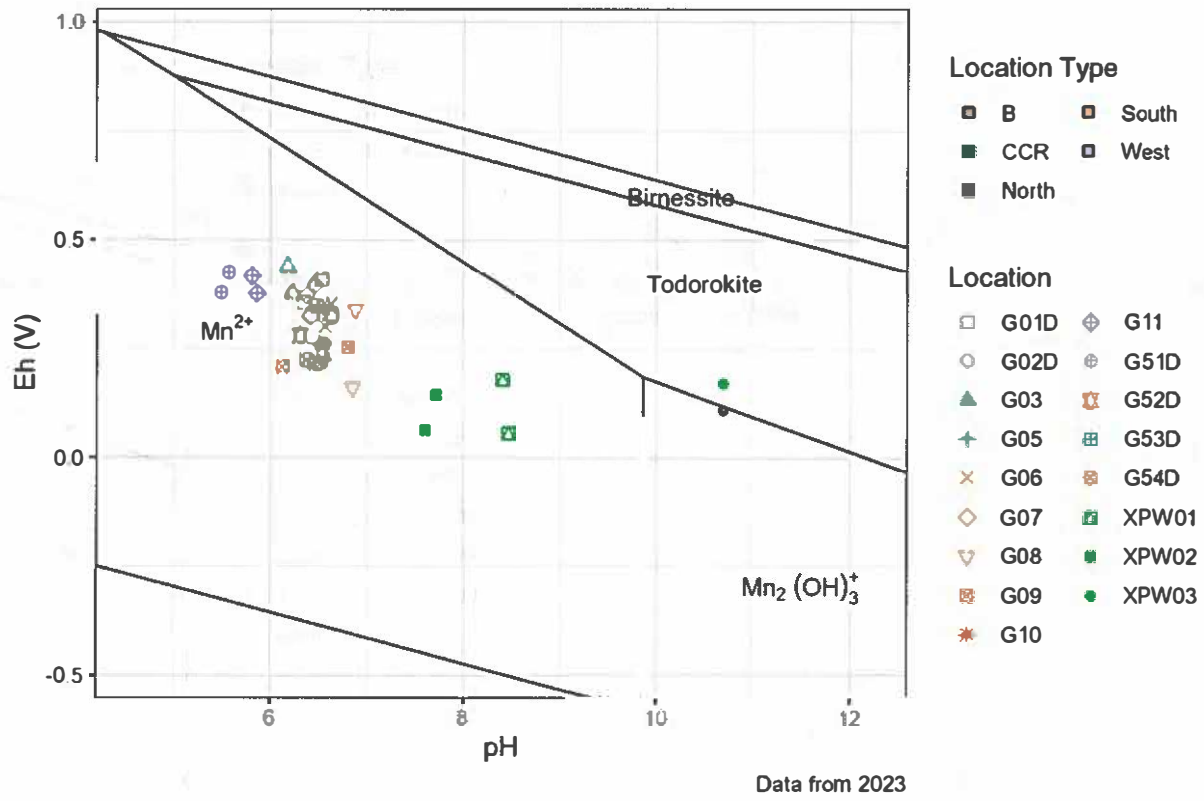


Figure B-3. Manganese Pourbaix diagram with 2023 Eh and pH data from groundwater and porewater.

3.3 PCA

The PCA biplot (**Figure B-4**) shows the results of the PCA analysis with wells colored by location type: background, CCR porewater, north of the UA stratigraphic high ("north"), south of the UA stratigraphic high ("south"), and G05 as the cobalt exceedance location. Approximately 58% of the variability in the data is encompassed in the first two principal component (PC1 explains approximately 40% of the variability in the data, and PC2 explains approximately 18%). Ninety-five % confidence ellipses for the north wells and south wells are shown in their respective location type colors. The minimal overlap of the 95% confidence ellipses shows that the groundwater compositions from the north wells and the south wells are largely distinct from one another. Well G05 plots within the 95% confidence ellipse for the north wells, indicating similarity of groundwater composition. The similarity between the north wells and dissimilarity from the south wells indicates that groundwater from these two groups of wells should be considered as distinct populations of data.

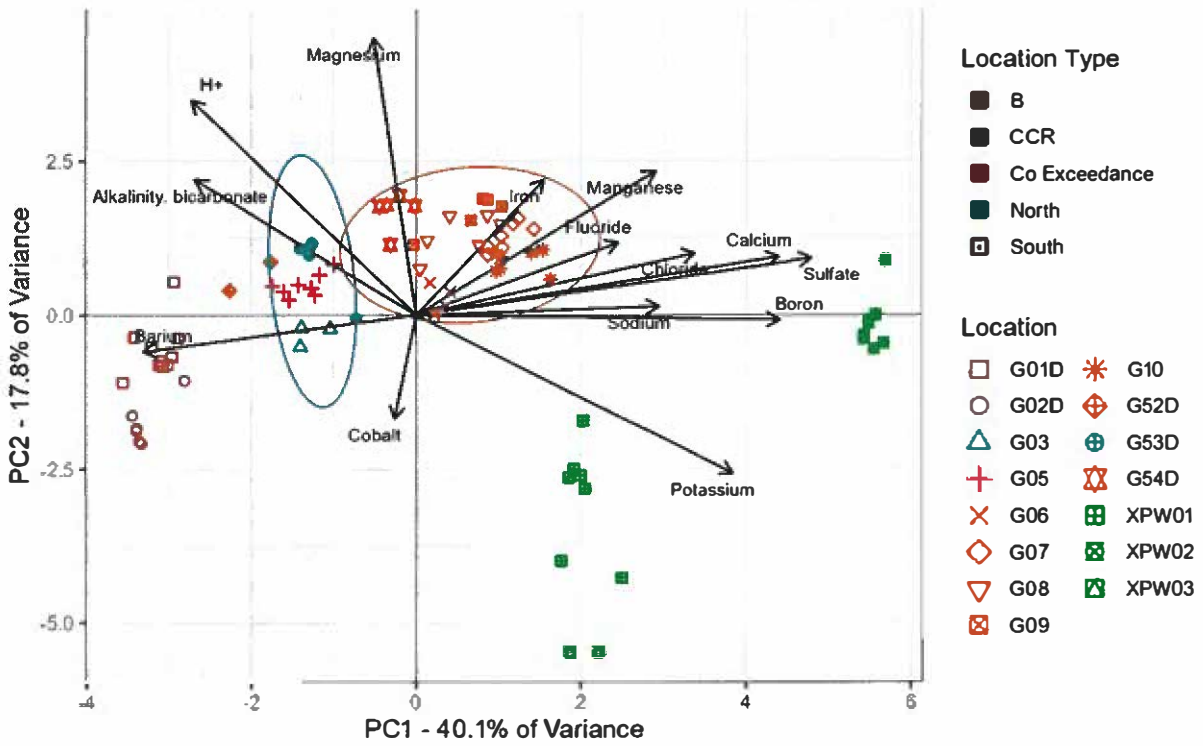


Figure B-4. Biplot of PCA results.

3.4 Redox Environment at JPP EAP

Appendix D of the associated E001 ASD, which addresses pH exceedances on the west side of the EAP, identifies a redox front west of the pond as driving iron oxidation and an associated drop in pH. The redox potential at which iron reduction/oxidation occurs is more reducing than the manganese reduction/oxidation potential. The redox potential and pH at wells G51D and G11 are consistent with an iron redox transition (Appendix D, Attachment 6-B) but all recent EAP groundwater samples fall within manganese-reducing conditions (Figure B-3). G05 is not substantially more reducing than other nearby wells without elevated cobalt. Appendix A of the E001 ASD shows that cobalt and manganese concentrations in the soil encompass 1.5 and 2.5 orders of magnitude difference, respectively, across the UA. In contrast to a redox front driving an iron speciation transition west of the EAP, local variations in solid phase cobalt and manganese concentrations appear to drive the differences in cobalt concentrations in groundwater.

4 CONCLUSIONS

The methods and results reported in this appendix support the conclusion that cobalt concentrations at G05 are consistent with mobilization due to reductive dissolution of manganese oxides. The regression analyses for cobalt and manganese correlation in solid phase material and groundwater are validated by illustrating the quality of the regressions. The Pourbaix diagram shows the manganese speciation in greater detail and concludes that reductive dissolution of manganese is thermodynamically favorable. The detailed PCA results show that the wells north and south of the UA stratigraphic high have distinct groundwater quality signatures and should be analyzed as distinct populations. Along with the strong association between cobalt and manganese in both the soil and groundwater, these results support the

conclusion that the reductive dissolution of manganese oxides is a primary control on cobalt concentrations in the groundwater.

5 REFERENCES

Backes, C.A., McLaren, R.G., Rate, A.W. and Swift, R.S., 1995. Kinetics of Cadmium and Cobalt Desorption from Iron and Manganese Oxides. *Soil Sci. Soc. Am. J.*, **59**: 778-785.

McKenzie, R.M., 1967. The sorption of cobalt by manganese minerals in soils. *Aust. J. Soil Res.* **5**: 235-246.

Uren, N.C., 2013. *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Ed. B.J. Alloway. Springer Science+Business Media. Chapter 12: Cobalt and Manganese. p 335-366.

ATTACHMENTS

Attachment A Electronic PCA Data

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	3/3/2021	Alkalinity, bicarbonate	209	FALSE	FALSE
G01D	3/3/2021	Calcium	25.8	FALSE	FALSE
G01D	3/3/2021	Magnesium	7.79	FALSE	FALSE
G01D	3/3/2021	Sodium	79	FALSE	FALSE
G01D	3/3/2021	Potassium	1.24	FALSE	FALSE
G01D	3/3/2021	Chloride	10	FALSE	FALSE
G01D	3/3/2021	Sulfate	18	FALSE	FALSE
G01D	3/3/2021	Fluoride	0.2	FALSE	FALSE
G01D	3/3/2021	Barium	0.137	FALSE	FALSE
G01D	3/3/2021	Boron	0.158	FALSE	TRUE
G01D	3/3/2021	Cobalt	0.0015	FALSE	FALSE
G01D	3/3/2021	Iron	1.09	FALSE	FALSE
G01D	3/3/2021	Manganese	0.0232	FALSE	FALSE
G01D	3/3/2021	H+	0.000000251	FALSE	FALSE
G01D	3/24/2021	Alkalinity, bicarbonate	219	FALSE	FALSE
G01D	3/24/2021	Calcium	24.8	FALSE	FALSE
G01D	3/24/2021	Magnesium	7.06	FALSE	FALSE
G01D	3/24/2021	Sodium	73.9	FALSE	FALSE
G01D	3/24/2021	Potassium	1.05	FALSE	FALSE
G01D	3/24/2021	Chloride	9	FALSE	FALSE
G01D	3/24/2021	Sulfate	21	FALSE	FALSE
G01D	3/24/2021	Fluoride	0.21	FALSE	FALSE
G01D	3/24/2021	Barium	0.136	FALSE	FALSE
G01D	3/24/2021	Boron	0.158	FALSE	TRUE
G01D	3/24/2021	Cobalt	0.0316	FALSE	TRUE
G01D	3/24/2021	Iron	1.15	FALSE	FALSE
G01D	3/24/2021	Manganese	0.0181	FALSE	FALSE
G01D	3/24/2021	H+	0.000000324	FALSE	FALSE
G01D	4/14/2021	Alkalinity, bicarbonate	240	FALSE	FALSE
G01D	4/14/2021	Calcium	23.3	FALSE	FALSE
G01D	4/14/2021	Magnesium	7.56	FALSE	FALSE
G01D	4/14/2021	Sodium	94.5	FALSE	FALSE
G01D	4/14/2021	Potassium	0.979	FALSE	FALSE
G01D	4/14/2021	Chloride	6	FALSE	FALSE
G01D	4/14/2021	Sulfate	39	FALSE	FALSE
G01D	4/14/2021	Fluoride	0.23	FALSE	FALSE
G01D	4/14/2021	Barium	0.112	FALSE	FALSE
G01D	4/14/2021	Boron	0.158	FALSE	TRUE
G01D	4/14/2021	Cobalt	0.0316	FALSE	TRUE
G01D	4/14/2021	Iron	0.698	FALSE	FALSE
G01D	4/14/2021	Manganese	0.0117	FALSE	FALSE
G01D	4/14/2021	H+	0.0000002	FALSE	FALSE
G01D	5/12/2021	Alkalinity, bicarbonate	200	FALSE	FALSE
G01D	5/12/2021	Calcium	24.9	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	5/12/2021	Magnesium	7.55	FALSE	FALSE
G01D	5/12/2021	Sodium	82.5	FALSE	FALSE
G01D	5/12/2021	Potassium	1.13	FALSE	FALSE
G01D	5/12/2021	Chloride	7	FALSE	FALSE
G01D	5/12/2021	Sulfate	20	FALSE	FALSE
G01D	5/12/2021	Fluoride	0.21	FALSE	FALSE
G01D	5/12/2021	Barium	0.133	FALSE	FALSE
G01D	5/12/2021	Boron	0.0167	FALSE	FALSE
G01D	5/12/2021	Cobalt	0.0316	FALSE	TRUE
G01D	5/12/2021	Iron	0.65	FALSE	FALSE
G01D	5/12/2021	Manganese	0.012	FALSE	FALSE
G01D	5/12/2021	H+	0.000000324	FALSE	FALSE
G01D	6/1/2021	Alkalinity, bicarbonate	198	FALSE	FALSE
G01D	6/1/2021	Calcium	24.4	FALSE	FALSE
G01D	6/1/2021	Magnesium	7.36	FALSE	FALSE
G01D	6/1/2021	Sodium	75.3	FALSE	FALSE
G01D	6/1/2021	Potassium	1.26	FALSE	FALSE
G01D	6/1/2021	Chloride	7	FALSE	FALSE
G01D	6/1/2021	Sulfate	18	FALSE	FALSE
G01D	6/1/2021	Fluoride	0.23	FALSE	FALSE
G01D	6/1/2021	Barium	0.134	FALSE	FALSE
G01D	6/1/2021	Boron	0.158	FALSE	TRUE
G01D	6/1/2021	Cobalt	0.0316	FALSE	TRUE
G01D	6/1/2021	Iron	1.92	FALSE	FALSE
G01D	6/1/2021	Manganese	0.0249	FALSE	FALSE
G01D	6/1/2021	H+	0.000000457	FALSE	FALSE
G01D	6/14/2021	Alkalinity, bicarbonate	219	FALSE	FALSE
G01D	6/14/2021	Calcium	24.4	FALSE	FALSE
G01D	6/14/2021	Magnesium	7.41	FALSE	FALSE
G01D	6/14/2021	Sodium	78.8	FALSE	FALSE
G01D	6/14/2021	Potassium	1.26	FALSE	FALSE
G01D	6/14/2021	Chloride	9	FALSE	FALSE
G01D	6/14/2021	Sulfate	20	FALSE	FALSE
G01D	6/14/2021	Fluoride	0.23	FALSE	FALSE
G01D	6/14/2021	Barium	0.136	FALSE	FALSE
G01D	6/14/2021	Boron	0.158	FALSE	TRUE
G01D	6/14/2021	Cobalt	0.0316	FALSE	TRUE
G01D	6/14/2021	Iron	0.831	FALSE	FALSE
G01D	6/14/2021	Manganese	0.0147	FALSE	FALSE
G01D	6/14/2021	H+	0.000000347	FALSE	FALSE
G01D	7/21/2021	Alkalinity, bicarbonate	204	FALSE	FALSE
G01D	7/21/2021	Calcium	26	FALSE	FALSE
G01D	7/21/2021	Magnesium	7.54	FALSE	FALSE
G01D	7/21/2021	Sodium	75.1	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	7/21/2021	Potassium	1.24	FALSE	FALSE
G01D	7/21/2021	Chloride	9	FALSE	FALSE
G01D	7/21/2021	Sulfate	18	FALSE	FALSE
G01D	7/21/2021	Fluoride	0.21	FALSE	FALSE
G01D	7/21/2021	Barium	0.125	FALSE	FALSE
G01D	7/21/2021	Boron	0.158	FALSE	TRUE
G01D	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G01D	7/21/2021	Iron	1.35	FALSE	FALSE
G01D	7/21/2021	Manganese	0.0121	FALSE	FALSE
G01D	7/21/2021	H+	0.000000427	FALSE	FALSE
G01D	9/20/2021	Alkalinity, bicarbonate	215	FALSE	FALSE
G01D	9/20/2021	Calcium	26	FALSE	FALSE
G01D	9/20/2021	Magnesium	7.54	TRUE	NA
G01D	9/20/2021	Sodium	75.1	TRUE	NA
G01D	9/20/2021	Potassium	1.12	TRUE	NA
G01D	9/20/2021	Chloride	9	FALSE	FALSE
G01D	9/20/2021	Sulfate	18	FALSE	FALSE
G01D	9/20/2021	Fluoride	0.21	FALSE	FALSE
G01D	9/20/2021	Barium	0.145	FALSE	FALSE
G01D	9/20/2021	Boron	0.158	FALSE	TRUE
G01D	9/20/2021	Cobalt	0.0316	FALSE	TRUE
G01D	9/20/2021	Iron	1.15	TRUE	NA
G01D	9/20/2021	Manganese	0.0147	TRUE	NA
G01D	9/20/2021	H+	0.000000309	FALSE	FALSE
G01D	9/20/2022	Alkalinity, bicarbonate	171	TRUE	NA
G01D	9/20/2022	Calcium	25.5	FALSE	FALSE
G01D	9/20/2022	Magnesium	7.79	TRUE	NA
G01D	9/20/2022	Sodium	82.5	TRUE	NA
G01D	9/20/2022	Potassium	1.13	TRUE	NA
G01D	9/20/2022	Chloride	8	FALSE	FALSE
G01D	9/20/2022	Sulfate	23	FALSE	FALSE
G01D	9/20/2022	Fluoride	0.19	FALSE	FALSE
G01D	9/20/2022	Barium	0.142	FALSE	FALSE
G01D	9/20/2022	Boron	0.014	FALSE	FALSE
G01D	9/20/2022	Cobalt	0.0007	FALSE	FALSE
G01D	9/20/2022	Iron	1.15	TRUE	NA
G01D	9/20/2022	Manganese	0.0181	TRUE	NA
G01D	9/20/2022	H+	0.000000316	FALSE	FALSE
G01D	3/7/2023	Alkalinity, bicarbonate	223	FALSE	FALSE
G01D	3/7/2023	Calcium	23	FALSE	FALSE
G01D	3/7/2023	Magnesium	7.66	FALSE	FALSE
G01D	3/7/2023	Sodium	85.8	FALSE	FALSE
G01D	3/7/2023	Potassium	1.06	FALSE	FALSE
G01D	3/7/2023	Chloride	5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	3/7/2023	Sulfate	36	FALSE	FALSE
G01D	3/7/2023	Fluoride	0.21	FALSE	FALSE
G01D	3/7/2023	Barium	0.134	FALSE	FALSE
G01D	3/7/2023	Boron	0.029	FALSE	FALSE
G01D	3/7/2023	Cobalt	0.0022	FALSE	FALSE
G01D	3/7/2023	Iron	1.09	TRUE	NA
G01D	3/7/2023	Manganese	0.0181	TRUE	NA
G01D	3/7/2023	H+	0.000000295	FALSE	FALSE
G01D	5/2/2023	Alkalinity, bicarbonate	240	FALSE	FALSE
G01D	5/2/2023	Calcium	28.8	FALSE	FALSE
G01D	5/2/2023	Magnesium	8.43	FALSE	FALSE
G01D	5/2/2023	Sodium	90.3	FALSE	FALSE
G01D	5/2/2023	Potassium	1.28	FALSE	FALSE
G01D	5/2/2023	Chloride	10	FALSE	FALSE
G01D	5/2/2023	Sulfate	26	FALSE	FALSE
G01D	5/2/2023	Fluoride	0.22	FALSE	FALSE
G01D	5/2/2023	Barium	0.213	FALSE	FALSE
G01D	5/2/2023	Boron	0.021	FALSE	FALSE
G01D	5/2/2023	Cobalt	0.0058	FALSE	FALSE
G01D	5/2/2023	Iron	4.09	FALSE	FALSE
G01D	5/2/2023	Manganese	0.345	FALSE	FALSE
G01D	5/2/2023	H+	0.000000457	FALSE	FALSE
G02D	5/12/2021	Alkalinity, bicarbonate	153	FALSE	FALSE
G02D	5/12/2021	Calcium	34.6	FALSE	FALSE
G02D	5/12/2021	Magnesium	10.4	FALSE	FALSE
G02D	5/12/2021	Sodium	53.6	FALSE	FALSE
G02D	5/12/2021	Potassium	1.17	FALSE	FALSE
G02D	5/12/2021	Chloride	18	FALSE	FALSE
G02D	5/12/2021	Sulfate	27	FALSE	FALSE
G02D	5/12/2021	Fluoride	0.18	FALSE	FALSE
G02D	5/12/2021	Barium	0.208	FALSE	FALSE
G02D	5/12/2021	Boron	0.0356	FALSE	FALSE
G02D	5/12/2021	Cobalt	0.0316	FALSE	TRUE
G02D	5/12/2021	Iron	0.316	FALSE	TRUE
G02D	5/12/2021	Manganese	0.0707	FALSE	TRUE
G02D	5/12/2021	H+	0.000000447	FALSE	FALSE
G02D	7/21/2021	Alkalinity, bicarbonate	148	FALSE	FALSE
G02D	7/21/2021	Calcium	36.6	FALSE	FALSE
G02D	7/21/2021	Magnesium	10.1	FALSE	FALSE
G02D	7/21/2021	Sodium	38.7	FALSE	FALSE
G02D	7/21/2021	Potassium	1.14	FALSE	FALSE
G02D	7/21/2021	Chloride	22	FALSE	FALSE
G02D	7/21/2021	Sulfate	20	FALSE	FALSE
G02D	7/21/2021	Fluoride	0.2	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G02D	7/21/2021	Barium	0.181	FALSE	FALSE
G02D	7/21/2021	Boron	0.0329	FALSE	FALSE
G02D	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G02D	7/21/2021	Iron	0.0594	FALSE	FALSE
G02D	7/21/2021	Manganese	0.0026	FALSE	FALSE
G02D	7/21/2021	H+	0.000000661	FALSE	FALSE
G02D	9/20/2021	Alkalinity, bicarbonate	156	FALSE	FALSE
G02D	9/20/2021	Calcium	34.3	FALSE	FALSE
G02D	9/20/2021	Magnesium	10.2	TRUE	NA
G02D	9/20/2021	Sodium	38.7	TRUE	NA
G02D	9/20/2021	Potassium	1.12	TRUE	NA
G02D	9/20/2021	Chloride	20	FALSE	FALSE
G02D	9/20/2021	Sulfate	19	FALSE	FALSE
G02D	9/20/2021	Fluoride	0.18	FALSE	FALSE
G02D	9/20/2021	Barium	0.189	FALSE	FALSE
G02D	9/20/2021	Boron	0.0313	FALSE	FALSE
G02D	9/20/2021	Cobalt	0.0316	FALSE	TRUE
G02D	9/20/2021	Iron	0.158	TRUE	NA
G02D	9/20/2021	Manganese	0.0032	TRUE	NA
G02D	9/20/2021	H+	0.000000479	FALSE	FALSE
G02D	1/24/2023	Alkalinity, bicarbonate	136	FALSE	FALSE
G02D	1/24/2023	Calcium	35.9	FALSE	FALSE
G02D	1/24/2023	Magnesium	10.2	FALSE	FALSE
G02D	1/24/2023	Sodium	29	FALSE	FALSE
G02D	1/24/2023	Potassium	1.11	FALSE	FALSE
G02D	1/24/2023	Chloride	23	FALSE	FALSE
G02D	1/24/2023	Sulfate	12	FALSE	FALSE
G02D	1/24/2023	Fluoride	0.21	FALSE	FALSE
G02D	1/24/2023	Barium	0.19	FALSE	FALSE
G02D	1/24/2023	Boron	0.0311	FALSE	FALSE
G02D	1/24/2023	Cobalt	0.0316	FALSE	TRUE
G02D	1/24/2023	Iron	0.158	FALSE	TRUE
G02D	1/24/2023	Manganese	0.0014	FALSE	FALSE
G02D	1/24/2023	H+	0.000000229	FALSE	FALSE
G02D	3/8/2023	Alkalinity, bicarbonate	141	FALSE	FALSE
G02D	3/8/2023	Calcium	37.3	FALSE	FALSE
G02D	3/8/2023	Magnesium	10.3	FALSE	FALSE
G02D	3/8/2023	Sodium	28.3	FALSE	FALSE
G02D	3/8/2023	Potassium	1.12	FALSE	FALSE
G02D	3/8/2023	Chloride	21	FALSE	FALSE
G02D	3/8/2023	Sulfate	11	FALSE	FALSE
G02D	3/8/2023	Fluoride	0.2	FALSE	FALSE
G02D	3/8/2023	Barium	0.171	FALSE	FALSE
G02D	3/8/2023	Boron	0.027	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G02D	3/8/2023	Cobalt	0.0316	FALSE	TRUE
G02D	3/8/2023	Iron	0.158	TRUE	NA
G02D	3/8/2023	Manganese	0.0032	TRUE	NA
G02D	3/8/2023	H+	0.000000275	FALSE	FALSE
G02D	5/3/2023	Alkalinity, bicarbonate	140	FALSE	FALSE
G02D	5/3/2023	Calcium	38.7	FALSE	FALSE
G02D	5/3/2023	Magnesium	10.4	FALSE	FALSE
G02D	5/3/2023	Sodium	39.1	FALSE	FALSE
G02D	5/3/2023	Potassium	1.14	FALSE	FALSE
G02D	5/3/2023	Chloride	21	FALSE	FALSE
G02D	5/3/2023	Sulfate	13	FALSE	FALSE
G02D	5/3/2023	Fluoride	0.22	FALSE	FALSE
G02D	5/3/2023	Barium	0.21	FALSE	FALSE
G02D	5/3/2023	Boron	0.0412	FALSE	FALSE
G02D	5/3/2023	Cobalt	0.0316	FALSE	TRUE
G02D	5/3/2023	Iron	0.049	FALSE	FALSE
G02D	5/3/2023	Manganese	0.0032	FALSE	FALSE
G02D	5/3/2023	H+	0.000000347	FALSE	FALSE
G03	6/15/2021	Alkalinity, bicarbonate	148	FALSE	FALSE
G03	6/15/2021	Calcium	46.7	FALSE	FALSE
G03	6/15/2021	Magnesium	15.1	FALSE	FALSE
G03	6/15/2021	Sodium	40.4	FALSE	FALSE
G03	6/15/2021	Potassium	1.26	FALSE	FALSE
G03	6/15/2021	Chloride	22	FALSE	FALSE
G03	6/15/2021	Sulfate	79	FALSE	FALSE
G03	6/15/2021	Fluoride	0.22	FALSE	FALSE
G03	6/15/2021	Barium	0.0705	FALSE	FALSE
G03	6/15/2021	Boron	0.225	FALSE	FALSE
G03	6/15/2021	Cobalt	0.0316	FALSE	TRUE
G03	6/15/2021	Iron	1.69	FALSE	FALSE
G03	6/15/2021	Manganese	0.033	FALSE	FALSE
G03	6/15/2021	H+	0.000000575	FALSE	FALSE
G03	7/6/2021	Alkalinity, bicarbonate	140	FALSE	FALSE
G03	7/6/2021	Calcium	42.1	FALSE	FALSE
G03	7/6/2021	Magnesium	14	FALSE	FALSE
G03	7/6/2021	Sodium	38	FALSE	FALSE
G03	7/6/2021	Potassium	1.13	FALSE	FALSE
G03	7/6/2021	Chloride	22	FALSE	FALSE
G03	7/6/2021	Sulfate	77	FALSE	FALSE
G03	7/6/2021	Fluoride	0.22	FALSE	FALSE
G03	7/6/2021	Barium	0.0564	FALSE	FALSE
G03	7/6/2021	Boron	0.235	FALSE	FALSE
G03	7/6/2021	Cobalt	0.0316	FALSE	TRUE
G03	7/6/2021	Iron	1.06	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G03	7/6/2021	Manganese	0.0226	FALSE	FALSE
G03	7/6/2021	H+	0.000000457	FALSE	FALSE
G03	7/21/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
G03	7/21/2021	Calcium	50	FALSE	FALSE
G03	7/21/2021	Magnesium	15.7	FALSE	FALSE
G03	7/21/2021	Sodium	40.2	FALSE	FALSE
G03	7/21/2021	Potassium	1.39	FALSE	FALSE
G03	7/21/2021	Chloride	24	FALSE	FALSE
G03	7/21/2021	Sulfate	92	FALSE	FALSE
G03	7/21/2021	Fluoride	0.2	FALSE	FALSE
G03	7/21/2021	Barium	0.0555	FALSE	FALSE
G03	7/21/2021	Boron	0.294	FALSE	FALSE
G03	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G03	7/21/2021	Iron	2.42	FALSE	FALSE
G03	7/21/2021	Manganese	0.0334	FALSE	FALSE
G03	7/21/2021	H+	0.000000437	FALSE	FALSE
G05	3/4/2021	Alkalinity, bicarbonate	180	FALSE	FALSE
G05	3/4/2021	Calcium	55.3	FALSE	FALSE
G05	3/4/2021	Magnesium	17.2	FALSE	FALSE
G05	3/4/2021	Sodium	44.1	FALSE	FALSE
G05	3/4/2021	Potassium	1.37	FALSE	FALSE
G05	3/4/2021	Chloride	13	FALSE	FALSE
G05	3/4/2021	Sulfate	94	FALSE	FALSE
G05	3/4/2021	Fluoride	0.28	FALSE	FALSE
G05	3/4/2021	Barium	0.13	FALSE	FALSE
G05	3/4/2021	Boron	0.181	FALSE	FALSE
G05	3/4/2021	Cobalt	0.0101	FALSE	FALSE
G05	3/4/2021	Iron	0.905	FALSE	FALSE
G05	3/4/2021	Manganese	0.227	FALSE	FALSE
G05	3/4/2021	H+	0.000000316	FALSE	FALSE
G05	4/13/2021	Alkalinity, bicarbonate	206	FALSE	FALSE
G05	4/13/2021	Calcium	68.5	FALSE	FALSE
G05	4/13/2021	Magnesium	19.5	FALSE	FALSE
G05	4/13/2021	Sodium	53.7	FALSE	FALSE
G05	4/13/2021	Potassium	2.14	FALSE	FALSE
G05	4/13/2021	Chloride	21	FALSE	FALSE
G05	4/13/2021	Sulfate	95	FALSE	FALSE
G05	4/13/2021	Fluoride	0.33	FALSE	FALSE
G05	4/13/2021	Barium	0.126	FALSE	FALSE
G05	4/13/2021	Boron	0.19	FALSE	FALSE
G05	4/13/2021	Cobalt	0.0095	FALSE	FALSE
G05	4/13/2021	Iron	2	FALSE	FALSE
G05	4/13/2021	Manganese	0.294	FALSE	FALSE
G05	4/13/2021	H+	0.000000316	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	5/11/2021	Alkalinity, bicarbonate	193	FALSE	FALSE
G05	5/11/2021	Calcium	60.3	FALSE	FALSE
G05	5/11/2021	Magnesium	19.4	FALSE	FALSE
G05	5/11/2021	Sodium	49.6	FALSE	FALSE
G05	5/11/2021	Potassium	1.97	FALSE	FALSE
G05	5/11/2021	Chloride	19	FALSE	FALSE
G05	5/11/2021	Sulfate	109	FALSE	FALSE
G05	5/11/2021	Fluoride	0.34	FALSE	FALSE
G05	5/11/2021	Barium	0.132	FALSE	FALSE
G05	5/11/2021	Boron	0.158	FALSE	FALSE
G05	5/11/2021	Cobalt	0.0087	FALSE	FALSE
G05	5/11/2021	Iron	1.14	FALSE	FALSE
G05	5/11/2021	Manganese	0.256	FALSE	FALSE
G05	5/11/2021	H+	0.000000417	FALSE	FALSE
G05	6/1/2021	Alkalinity, bicarbonate	190	FALSE	FALSE
G05	6/1/2021	Calcium	57.1	FALSE	FALSE
G05	6/1/2021	Magnesium	18.6	FALSE	FALSE
G05	6/1/2021	Sodium	45.5	FALSE	FALSE
G05	6/1/2021	Potassium	2.18	FALSE	FALSE
G05	6/1/2021	Chloride	21	FALSE	FALSE
G05	6/1/2021	Sulfate	83	FALSE	FALSE
G05	6/1/2021	Fluoride	0.34	FALSE	FALSE
G05	6/1/2021	Barium	0.144	FALSE	FALSE
G05	6/1/2021	Boron	0.157	FALSE	FALSE
G05	6/1/2021	Cobalt	0.0078	FALSE	FALSE
G05	6/1/2021	Iron	0.81	FALSE	FALSE
G05	6/1/2021	Manganese	0.254	FALSE	FALSE
G05	6/1/2021	H+	0.000000331	FALSE	FALSE
G05	7/6/2021	Alkalinity, bicarbonate	178	FALSE	FALSE
G05	7/6/2021	Calcium	51.8	FALSE	FALSE
G05	7/6/2021	Magnesium	17.6	FALSE	FALSE
G05	7/6/2021	Sodium	45.9	FALSE	FALSE
G05	7/6/2021	Potassium	2.04	FALSE	FALSE
G05	7/6/2021	Chloride	22	FALSE	FALSE
G05	7/6/2021	Sulfate	90	FALSE	FALSE
G05	7/6/2021	Fluoride	0.34	FALSE	FALSE
G05	7/6/2021	Barium	0.139	FALSE	FALSE
G05	7/6/2021	Boron	0.148	FALSE	FALSE
G05	7/6/2021	Cobalt	0.0091	FALSE	FALSE
G05	7/6/2021	Iron	0.729	FALSE	FALSE
G05	7/6/2021	Manganese	0.27	FALSE	FALSE
G05	7/6/2021	H+	0.00000038	FALSE	FALSE
G05	7/20/2021	Alkalinity, bicarbonate	186	FALSE	FALSE
G05	7/20/2021	Calcium	55.9	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	7/20/2021	Magnesium	18.5	FALSE	FALSE
G05	7/20/2021	Sodium	43.4	FALSE	FALSE
G05	7/20/2021	Potassium	1.75	FALSE	FALSE
G05	7/20/2021	Chloride	20	FALSE	FALSE
G05	7/20/2021	Sulfate	87	FALSE	FALSE
G05	7/20/2021	Fluoride	0.32	FALSE	FALSE
G05	7/20/2021	Barium	0.133	FALSE	FALSE
G05	7/20/2021	Boron	0.131	FALSE	FALSE
G05	7/20/2021	Cobalt	0.0059	FALSE	FALSE
G05	7/20/2021	Iron	0.747	FALSE	FALSE
G05	7/20/2021	Manganese	0.204	FALSE	FALSE
G05	7/20/2021	H+	0.000000447	FALSE	FALSE
G05	7/26/2022	Alkalinity, bicarbonate	181	FALSE	FALSE
G05	7/26/2022	Calcium	50.6	FALSE	FALSE
G05	7/26/2022	Magnesium	17.6	FALSE	FALSE
G05	7/26/2022	Sodium	35.4	FALSE	FALSE
G05	7/26/2022	Potassium	1.07	FALSE	FALSE
G05	7/26/2022	Chloride	15	FALSE	FALSE
G05	7/26/2022	Sulfate	68	FALSE	FALSE
G05	7/26/2022	Fluoride	0.37	FALSE	FALSE
G05	7/26/2022	Barium	0.141	FALSE	FALSE
G05	7/26/2022	Boron	0.0645	FALSE	FALSE
G05	7/26/2022	Cobalt	0.0075	FALSE	FALSE
G05	7/26/2022	Iron	1.38	FALSE	FALSE
G05	7/26/2022	Manganese	0.176	FALSE	FALSE
G05	7/26/2022	H+	0.000000234	FALSE	FALSE
G05	3/9/2023	Alkalinity, bicarbonate	179	FALSE	FALSE
G05	3/9/2023	Calcium	52.6	FALSE	FALSE
G05	3/9/2023	Magnesium	19.4	FALSE	FALSE
G05	3/9/2023	Sodium	41.8	FALSE	FALSE
G05	3/9/2023	Potassium	1.59	FALSE	FALSE
G05	3/9/2023	Chloride	22	FALSE	FALSE
G05	3/9/2023	Sulfate	90	FALSE	FALSE
G05	3/9/2023	Fluoride	0.32	FALSE	FALSE
G05	3/9/2023	Barium	0.175	FALSE	FALSE
G05	3/9/2023	Boron	0.0541	FALSE	FALSE
G05	3/9/2023	Cobalt	0.0074	FALSE	FALSE
G05	3/9/2023	Iron	0.81	TRUE	NA
G05	3/9/2023	Manganese	0.204	TRUE	NA
G05	3/9/2023	H+	0.000000316	FALSE	FALSE
G05	5/3/2023	Alkalinity, bicarbonate	163	FALSE	FALSE
G05	5/3/2023	Calcium	54.4	FALSE	FALSE
G05	5/3/2023	Magnesium	19.3	FALSE	FALSE
G05	5/3/2023	Sodium	46.7	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	5/3/2023	Potassium	1.68	FALSE	FALSE
G05	5/3/2023	Chloride	24	FALSE	FALSE
G05	5/3/2023	Sulfate	112	FALSE	FALSE
G05	5/3/2023	Fluoride	0.38	FALSE	FALSE
G05	5/3/2023	Barium	0.212	FALSE	FALSE
G05	5/3/2023	Boron	0.0478	FALSE	FALSE
G05	5/3/2023	Cobalt	0.0103	FALSE	FALSE
G05	5/3/2023	Iron	1.5	FALSE	FALSE
G05	5/3/2023	Manganese	0.191	FALSE	FALSE
G05	5/3/2023	H+	0.000000324	FALSE	FALSE
G06	5/11/2021	Alkalinity, bicarbonate	156	FALSE	FALSE
G06	5/11/2021	Calcium	93.4	FALSE	FALSE
G06	5/11/2021	Magnesium	26.8	FALSE	FALSE
G06	5/11/2021	Sodium	52.8	FALSE	FALSE
G06	5/11/2021	Potassium	2.5	FALSE	FALSE
G06	5/11/2021	Chloride	22	FALSE	FALSE
G06	5/11/2021	Sulfate	219	FALSE	FALSE
G06	5/11/2021	Fluoride	0.26	FALSE	FALSE
G06	5/11/2021	Barium	0.0311	FALSE	FALSE
G06	5/11/2021	Boron	3.37	FALSE	FALSE
G06	5/11/2021	Cobalt	0.0316	FALSE	TRUE
G06	5/11/2021	Iron	0.702	FALSE	FALSE
G06	5/11/2021	Manganese	0.0957	FALSE	FALSE
G06	5/11/2021	H+	0.000000372	FALSE	FALSE
G06	6/1/2021	Alkalinity, bicarbonate	167	FALSE	FALSE
G06	6/1/2021	Calcium	92.6	FALSE	FALSE
G06	6/1/2021	Magnesium	25.3	FALSE	FALSE
G06	6/1/2021	Sodium	46.4	FALSE	FALSE
G06	6/1/2021	Potassium	2.5	FALSE	FALSE
G06	6/1/2021	Chloride	22	FALSE	FALSE
G06	6/1/2021	Sulfate	216	FALSE	FALSE
G06	6/1/2021	Fluoride	0.28	FALSE	FALSE
G06	6/1/2021	Barium	0.0323	FALSE	FALSE
G06	6/1/2021	Boron	3.56	FALSE	FALSE
G06	6/1/2021	Cobalt	0.0316	FALSE	TRUE
G06	6/1/2021	Iron	1.69	FALSE	FALSE
G06	6/1/2021	Manganese	0.0892	FALSE	FALSE
G06	6/1/2021	H+	0.000000275	FALSE	FALSE
G06	6/15/2021	Alkalinity, bicarbonate	170	FALSE	FALSE
G06	6/15/2021	Calcium	91.5	FALSE	FALSE
G06	6/15/2021	Magnesium	25.2	FALSE	FALSE
G06	6/15/2021	Sodium	50.7	FALSE	FALSE
G06	6/15/2021	Potassium	2.57	FALSE	FALSE
G06	6/15/2021	Chloride	21	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G06	6/15/2021	Sulfate	230	FALSE	FALSE
G06	6/15/2021	Fluoride	0.28	FALSE	FALSE
G06	6/15/2021	Barium	0.028	FALSE	FALSE
G06	6/15/2021	Boron	2.97	FALSE	FALSE
G06	6/15/2021	Cobalt	0.0316	FALSE	TRUE
G06	6/15/2021	Iron	0.379	FALSE	FALSE
G06	6/15/2021	Manganese	0.0682	FALSE	FALSE
G06	6/15/2021	H+	0.000000309	FALSE	FALSE
G06	7/6/2021	Alkalinity, bicarbonate	163	FALSE	FALSE
G06	7/6/2021	Calcium	86.7	FALSE	FALSE
G06	7/6/2021	Magnesium	23.7	FALSE	FALSE
G06	7/6/2021	Sodium	50	FALSE	FALSE
G06	7/6/2021	Potassium	2.57	FALSE	FALSE
G06	7/6/2021	Chloride	22	FALSE	FALSE
G06	7/6/2021	Sulfate	223	FALSE	FALSE
G06	7/6/2021	Fluoride	0.27	FALSE	FALSE
G06	7/6/2021	Barium	0.0272	FALSE	FALSE
G06	7/6/2021	Boron	3.93	FALSE	FALSE
G06	7/6/2021	Cobalt	0.0316	FALSE	TRUE
G06	7/6/2021	Iron	0.495	FALSE	FALSE
G06	7/6/2021	Manganese	0.0631	FALSE	FALSE
G06	7/6/2021	H+	0.000000479	FALSE	FALSE
G06	7/20/2021	Alkalinity, bicarbonate	162	FALSE	FALSE
G06	7/20/2021	Calcium	90.6	FALSE	FALSE
G06	7/20/2021	Magnesium	24.4	FALSE	FALSE
G06	7/20/2021	Sodium	47	FALSE	FALSE
G06	7/20/2021	Potassium	2.37	FALSE	FALSE
G06	7/20/2021	Chloride	21	FALSE	FALSE
G06	7/20/2021	Sulfate	213	FALSE	FALSE
G06	7/20/2021	Fluoride	0.26	FALSE	FALSE
G06	7/20/2021	Barium	0.0244	FALSE	FALSE
G06	7/20/2021	Boron	3.41	FALSE	FALSE
G06	7/20/2021	Cobalt	0.0316	FALSE	TRUE
G06	7/20/2021	Iron	0.613	FALSE	FALSE
G06	7/20/2021	Manganese	0.0456	FALSE	FALSE
G06	7/20/2021	H+	0.000000389	FALSE	FALSE
G06	3/9/2023	Alkalinity, bicarbonate	161	FALSE	FALSE
G06	3/9/2023	Calcium	87.6	FALSE	FALSE
G06	3/9/2023	Magnesium	24.1	FALSE	FALSE
G06	3/9/2023	Sodium	42.1	FALSE	FALSE
G06	3/9/2023	Potassium	2.2	FALSE	FALSE
G06	3/9/2023	Chloride	21	FALSE	FALSE
G06	3/9/2023	Sulfate	221	FALSE	FALSE
G06	3/9/2023	Fluoride	0.22	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G06	3/9/2023	Barium	0.0257	FALSE	FALSE
G06	3/9/2023	Boron	2.95	FALSE	FALSE
G06	3/9/2023	Cobalt	0.0006	FALSE	FALSE
G06	3/9/2023	Iron	0.537	TRUE	NA
G06	3/9/2023	Manganese	0.0682	TRUE	NA
G06	3/9/2023	H+	0.000000269	FALSE	FALSE
G07	3/24/2021	Alkalinity, bicarbonate	171	FALSE	FALSE
G07	3/24/2021	Calcium	92.8	FALSE	FALSE
G07	3/24/2021	Magnesium	24.2	FALSE	FALSE
G07	3/24/2021	Sodium	71.4	FALSE	FALSE
G07	3/24/2021	Potassium	3.87	FALSE	FALSE
G07	3/24/2021	Chloride	21	FALSE	FALSE
G07	3/24/2021	Sulfate	258	FALSE	FALSE
G07	3/24/2021	Fluoride	0.42	FALSE	FALSE
G07	3/24/2021	Barium	0.0643	FALSE	FALSE
G07	3/24/2021	Boron	4.67	FALSE	FALSE
G07	3/24/2021	Cobalt	0.0035	FALSE	FALSE
G07	3/24/2021	Iron	2.71	FALSE	FALSE
G07	3/24/2021	Manganese	4.48	FALSE	FALSE
G07	3/24/2021	H+	0.000000398	FALSE	FALSE
G07	4/13/2021	Alkalinity, bicarbonate	164	FALSE	FALSE
G07	4/13/2021	Calcium	126	FALSE	FALSE
G07	4/13/2021	Magnesium	24.4	FALSE	FALSE
G07	4/13/2021	Sodium	90.4	FALSE	FALSE
G07	4/13/2021	Potassium	3.98	FALSE	FALSE
G07	4/13/2021	Chloride	20	FALSE	FALSE
G07	4/13/2021	Sulfate	274	FALSE	FALSE
G07	4/13/2021	Fluoride	0.42	FALSE	FALSE
G07	4/13/2021	Barium	0.0497	FALSE	FALSE
G07	4/13/2021	Boron	5.04	FALSE	FALSE
G07	4/13/2021	Cobalt	0.0024	FALSE	FALSE
G07	4/13/2021	Iron	1.2	FALSE	FALSE
G07	4/13/2021	Manganese	4.56	FALSE	FALSE
G07	4/13/2021	H+	0.000000501	FALSE	FALSE
G07	5/11/2021	Alkalinity, bicarbonate	162	FALSE	FALSE
G07	5/11/2021	Calcium	90.4	FALSE	FALSE
G07	5/11/2021	Magnesium	22.9	FALSE	FALSE
G07	5/11/2021	Sodium	68.6	FALSE	FALSE
G07	5/11/2021	Potassium	3.9	FALSE	FALSE
G07	5/11/2021	Chloride	19	FALSE	FALSE
G07	5/11/2021	Sulfate	248	FALSE	FALSE
G07	5/11/2021	Fluoride	0.41	FALSE	FALSE
G07	5/11/2021	Barium	0.0448	FALSE	FALSE
G07	5/11/2021	Boron	4.55	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G07	5/11/2021	Cobalt	0.00185	FALSE	FALSE
G07	5/11/2021	Iron	0.537	FALSE	FALSE
G07	5/11/2021	Manganese	3.71	FALSE	FALSE
G07	5/11/2021	H+	0.000000525	FALSE	FALSE
G07	6/1/2021	Alkalinity, bicarbonate	173	FALSE	FALSE
G07	6/1/2021	Calcium	96.6	FALSE	FALSE
G07	6/1/2021	Magnesium	22.9	FALSE	FALSE
G07	6/1/2021	Sodium	67.5	FALSE	FALSE
G07	6/1/2021	Potassium	4.32	FALSE	FALSE
G07	6/1/2021	Chloride	22	FALSE	FALSE
G07	6/1/2021	Sulfate	257	FALSE	FALSE
G07	6/1/2021	Fluoride	0.43	FALSE	FALSE
G07	6/1/2021	Barium	0.054	FALSE	FALSE
G07	6/1/2021	Boron	5.23	FALSE	FALSE
G07	6/1/2021	Cobalt	0.0023	FALSE	FALSE
G07	6/1/2021	Iron	2.49	FALSE	FALSE
G07	6/1/2021	Manganese	3.54	FALSE	FALSE
G07	6/1/2021	H+	0.000000562	FALSE	FALSE
G07	6/15/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G07	6/15/2021	Calcium	89.3	FALSE	FALSE
G07	6/15/2021	Magnesium	21.8	FALSE	FALSE
G07	6/15/2021	Sodium	66.7	FALSE	FALSE
G07	6/15/2021	Potassium	3.97	FALSE	FALSE
G07	6/15/2021	Chloride	20	FALSE	FALSE
G07	6/15/2021	Sulfate	246	FALSE	FALSE
G07	6/15/2021	Fluoride	0.41	FALSE	FALSE
G07	6/15/2021	Barium	0.0429	FALSE	FALSE
G07	6/15/2021	Boron	3.91	FALSE	FALSE
G07	6/15/2021	Cobalt	0.0013	FALSE	FALSE
G07	6/15/2021	Iron	0.294	FALSE	FALSE
G07	6/15/2021	Manganese	3.7	FALSE	FALSE
G07	6/15/2021	H+	0.000000562	FALSE	FALSE
G07	7/6/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G07	7/6/2021	Calcium	84.8	FALSE	FALSE
G07	7/6/2021	Magnesium	20.5	FALSE	FALSE
G07	7/6/2021	Sodium	66.5	FALSE	FALSE
G07	7/6/2021	Potassium	3.87	FALSE	FALSE
G07	7/6/2021	Chloride	21	FALSE	FALSE
G07	7/6/2021	Sulfate	258	FALSE	FALSE
G07	7/6/2021	Fluoride	0.4	FALSE	FALSE
G07	7/6/2021	Barium	0.0373	FALSE	FALSE
G07	7/6/2021	Boron	4.95	FALSE	FALSE
G07	7/6/2021	Cobalt	0.0012	FALSE	FALSE
G07	7/6/2021	Iron	0.134	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G07	7/6/2021	Manganese	4.1	FALSE	FALSE
G07	7/6/2021	H+	0.00000105	FALSE	FALSE
G07	7/20/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G07	7/20/2021	Calcium	96.5	FALSE	FALSE
G07	7/20/2021	Magnesium	23	FALSE	FALSE
G07	7/20/2021	Sodium	67.4	FALSE	FALSE
G07	7/20/2021	Potassium	4.03	FALSE	FALSE
G07	7/20/2021	Chloride	21	FALSE	FALSE
G07	7/20/2021	Sulfate	252	FALSE	FALSE
G07	7/20/2021	Fluoride	0.4	FALSE	FALSE
G07	7/20/2021	Barium	0.047	FALSE	FALSE
G07	7/20/2021	Boron	4.48	FALSE	FALSE
G07	7/20/2021	Cobalt	0.0014	FALSE	FALSE
G07	7/20/2021	Iron	0.639	FALSE	FALSE
G07	7/20/2021	Manganese	3.28	FALSE	FALSE
G07	7/20/2021	H+	0.000000724	FALSE	FALSE
G08	4/13/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G08	4/13/2021	Calcium	142	FALSE	FALSE
G08	4/13/2021	Magnesium	31.9	FALSE	FALSE
G08	4/13/2021	Sodium	33.6	FALSE	FALSE
G08	4/13/2021	Potassium	1.6	FALSE	FALSE
G08	4/13/2021	Chloride	15	FALSE	FALSE
G08	4/13/2021	Sulfate	286	FALSE	FALSE
G08	4/13/2021	Fluoride	0.34	FALSE	FALSE
G08	4/13/2021	Barium	0.0772	FALSE	FALSE
G08	4/13/2021	Boron	5.25	FALSE	FALSE
G08	4/13/2021	Cobalt	0.0041	FALSE	FALSE
G08	4/13/2021	Iron	4.82	FALSE	FALSE
G08	4/13/2021	Manganese	6.03	FALSE	FALSE
G08	4/13/2021	H+	0.0000001	FALSE	FALSE
G08	5/11/2021	Alkalinity, bicarbonate	185	FALSE	FALSE
G08	5/11/2021	Calcium	101	FALSE	FALSE
G08	5/11/2021	Magnesium	25.4	FALSE	FALSE
G08	5/11/2021	Sodium	24.3	FALSE	FALSE
G08	5/11/2021	Potassium	1.45	FALSE	FALSE
G08	5/11/2021	Chloride	12	FALSE	FALSE
G08	5/11/2021	Sulfate	203	FALSE	FALSE
G08	5/11/2021	Fluoride	0.36	FALSE	FALSE
G08	5/11/2021	Barium	0.0685	FALSE	FALSE
G08	5/11/2021	Boron	3.77	FALSE	FALSE
G08	5/11/2021	Cobalt	0.0022	FALSE	FALSE
G08	5/11/2021	Iron	1.33	FALSE	FALSE
G08	5/11/2021	Manganese	3.09	FALSE	FALSE
G08	5/11/2021	H+	0.000000115	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G08	6/1/2021	Alkalinity, bicarbonate	201	FALSE	FALSE
G08	6/1/2021	Calcium	114	FALSE	FALSE
G08	6/1/2021	Magnesium	27.2	FALSE	FALSE
G08	6/1/2021	Sodium	25.4	FALSE	FALSE
G08	6/1/2021	Potassium	1.48	FALSE	FALSE
G08	6/1/2021	Chloride	15	FALSE	FALSE
G08	6/1/2021	Sulfate	204	FALSE	FALSE
G08	6/1/2021	Fluoride	0.34	FALSE	FALSE
G08	6/1/2021	Barium	0.0588	FALSE	FALSE
G08	6/1/2021	Boron	4.63	FALSE	FALSE
G08	6/1/2021	Cobalt	0.0041	FALSE	FALSE
G08	6/1/2021	Iron	4.43	FALSE	FALSE
G08	6/1/2021	Manganese	3.15	FALSE	FALSE
G08	6/1/2021	H+	0.00000011	FALSE	FALSE
G08	7/23/2022	Alkalinity, bicarbonate	191	FALSE	FALSE
G08	7/23/2022	Calcium	118	FALSE	FALSE
G08	7/23/2022	Magnesium	29	FALSE	FALSE
G08	7/23/2022	Sodium	30.5	FALSE	FALSE
G08	7/23/2022	Potassium	1.46	FALSE	FALSE
G08	7/23/2022	Chloride	16	FALSE	FALSE
G08	7/23/2022	Sulfate	229	FALSE	FALSE
G08	7/23/2022	Fluoride	0.3	FALSE	FALSE
G08	7/23/2022	Barium	0.0387	FALSE	FALSE
G08	7/23/2022	Boron	4.74	FALSE	FALSE
G08	7/23/2022	Cobalt	0.0028	FALSE	FALSE
G08	7/23/2022	Iron	2.25	FALSE	FALSE
G08	7/23/2022	Manganese	2.89	FALSE	FALSE
G08	7/23/2022	H+	2.57E-08	FALSE	FALSE
G08	3/9/2023	Alkalinity, bicarbonate	174	FALSE	FALSE
G08	3/9/2023	Calcium	119	FALSE	FALSE
G08	3/9/2023	Magnesium	28.9	FALSE	FALSE
G08	3/9/2023	Sodium	28.5	FALSE	FALSE
G08	3/9/2023	Potassium	1.47	FALSE	FALSE
G08	3/9/2023	Chloride	15	FALSE	FALSE
G08	3/9/2023	Sulfate	297	FALSE	FALSE
G08	3/9/2023	Fluoride	0.23	FALSE	FALSE
G08	3/9/2023	Barium	0.0495	FALSE	FALSE
G08	3/9/2023	Boron	4.33	FALSE	FALSE
G08	3/9/2023	Cobalt	0.0036	FALSE	FALSE
G08	3/9/2023	Iron	2.25	TRUE	NA
G08	3/9/2023	Manganese	0.0892	TRUE	NA
G08	3/9/2023	H+	0.000000141	FALSE	FALSE
G08	5/3/2023	Alkalinity, bicarbonate	154	FALSE	FALSE
G08	5/3/2023	Calcium	140	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G08	5/3/2023	Magnesium	32.2	FALSE	FALSE
G08	5/3/2023	Sodium	41.7	FALSE	FALSE
G08	5/3/2023	Potassium	1.67	FALSE	FALSE
G08	5/3/2023	Chloride	16	FALSE	FALSE
G08	5/3/2023	Sulfate	363	FALSE	FALSE
G08	5/3/2023	Fluoride	0.29	FALSE	FALSE
G08	5/3/2023	Barium	0.0974	FALSE	FALSE
G08	5/3/2023	Boron	5.43	FALSE	FALSE
G08	5/3/2023	Cobalt	0.0113	FALSE	FALSE
G08	5/3/2023	Iron	16.8	FALSE	FALSE
G08	5/3/2023	Manganese	2.62	FALSE	FALSE
G08	5/3/2023	H+	0.000000132	FALSE	FALSE
G09	3/4/2021	Alkalinity, bicarbonate	188	FALSE	FALSE
G09	3/4/2021	Calcium	103	FALSE	FALSE
G09	3/4/2021	Magnesium	33.8	FALSE	FALSE
G09	3/4/2021	Sodium	72	FALSE	FALSE
G09	3/4/2021	Potassium	2.78	FALSE	FALSE
G09	3/4/2021	Chloride	24	FALSE	FALSE
G09	3/4/2021	Sulfate	351	FALSE	FALSE
G09	3/4/2021	Fluoride	0.25	FALSE	FALSE
G09	3/4/2021	Barium	0.0675	FALSE	FALSE
G09	3/4/2021	Boron	3.19	FALSE	FALSE
G09	3/4/2021	Cobalt	0.0108	FALSE	FALSE
G09	3/4/2021	Iron	1.93	FALSE	FALSE
G09	3/4/2021	Manganese	4.15	FALSE	FALSE
G09	3/4/2021	H+	0.000000631	FALSE	FALSE
G09	6/1/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G09	6/1/2021	Calcium	91.3	FALSE	FALSE
G09	6/1/2021	Magnesium	31.4	FALSE	FALSE
G09	6/1/2021	Sodium	65.3	FALSE	FALSE
G09	6/1/2021	Potassium	1.87	FALSE	FALSE
G09	6/1/2021	Chloride	23	FALSE	FALSE
G09	6/1/2021	Sulfate	284	FALSE	FALSE
G09	6/1/2021	Fluoride	0.33	FALSE	FALSE
G09	6/1/2021	Barium	0.0548	FALSE	FALSE
G09	6/1/2021	Boron	3.65	FALSE	FALSE
G09	6/1/2021	Cobalt	0.0096	FALSE	FALSE
G09	6/1/2021	Iron	5.65	FALSE	FALSE
G09	6/1/2021	Manganese	3.87	FALSE	FALSE
G09	6/1/2021	H+	0.000000575	FALSE	FALSE
G09	6/15/2021	Alkalinity, bicarbonate	179	FALSE	FALSE
G09	6/15/2021	Calcium	137	FALSE	FALSE
G09	6/15/2021	Magnesium	49.3	FALSE	FALSE
G09	6/15/2021	Sodium	58.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G09	6/15/2021	Potassium	1.56	FALSE	FALSE
G09	6/15/2021	Chloride	21	FALSE	FALSE
G09	6/15/2021	Sulfate	294	FALSE	FALSE
G09	6/15/2021	Fluoride	0.32	FALSE	FALSE
G09	6/15/2021	Barium	0.0136	FALSE	FALSE
G09	6/15/2021	Boron	0.282	FALSE	FALSE
G09	6/15/2021	Cobalt	0.0011	FALSE	FALSE
G09	6/15/2021	Iron	0.0556	FALSE	FALSE
G09	6/15/2021	Manganese	0.104	FALSE	FALSE
G09	6/15/2021	H+	0.00000107	FALSE	FALSE
G09	7/6/2021	Alkalinity, bicarbonate	163	FALSE	FALSE
G09	7/6/2021	Calcium	79	FALSE	FALSE
G09	7/6/2021	Magnesium	28.7	FALSE	FALSE
G09	7/6/2021	Sodium	68.3	FALSE	FALSE
G09	7/6/2021	Potassium	1.65	FALSE	FALSE
G09	7/6/2021	Chloride	22	FALSE	FALSE
G09	7/6/2021	Sulfate	289	FALSE	FALSE
G09	7/6/2021	Fluoride	0.36	FALSE	FALSE
G09	7/6/2021	Barium	0.0444	FALSE	FALSE
G09	7/6/2021	Boron	4.05	FALSE	FALSE
G09	7/6/2021	Cobalt	0.0089	FALSE	FALSE
G09	7/6/2021	Iron	5.69	FALSE	FALSE
G09	7/6/2021	Manganese	4.06	FALSE	FALSE
G09	7/6/2021	H+	0.000000513	FALSE	FALSE
G09	7/21/2021	Alkalinity, bicarbonate	164	FALSE	FALSE
G09	7/21/2021	Calcium	92.1	FALSE	FALSE
G09	7/21/2021	Magnesium	32	FALSE	FALSE
G09	7/21/2021	Sodium	64.3	FALSE	FALSE
G09	7/21/2021	Potassium	1.55	FALSE	FALSE
G09	7/21/2021	Chloride	21	FALSE	FALSE
G09	7/21/2021	Sulfate	286	FALSE	FALSE
G09	7/21/2021	Fluoride	0.31	FALSE	FALSE
G09	7/21/2021	Barium	0.0454	FALSE	FALSE
G09	7/21/2021	Boron	3.75	FALSE	FALSE
G09	7/21/2021	Cobalt	0.0085	FALSE	FALSE
G09	7/21/2021	Iron	5.11	FALSE	FALSE
G09	7/21/2021	Manganese	3.17	FALSE	FALSE
G09	7/21/2021	H+	0.00000102	FALSE	FALSE
G10	3/4/2021	Alkalinity, bicarbonate	108	FALSE	FALSE
G10	3/4/2021	Calcium	107	FALSE	FALSE
G10	3/4/2021	Magnesium	35.7	FALSE	FALSE
G10	3/4/2021	Sodium	60.3	FALSE	FALSE
G10	3/4/2021	Potassium	2.54	FALSE	FALSE
G10	3/4/2021	Chloride	35	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	3/4/2021	Sulfate	391	FALSE	FALSE
G10	3/4/2021	Fluoride	0.29	FALSE	FALSE
G10	3/4/2021	Barium	0.0608	FALSE	FALSE
G10	3/4/2021	Boron	4.98	FALSE	FALSE
G10	3/4/2021	Cobalt	0.0109	FALSE	FALSE
G10	3/4/2021	Iron	2.38	FALSE	FALSE
G10	3/4/2021	Manganese	1.14	FALSE	FALSE
G10	3/4/2021	H+	0.0000002	FALSE	FALSE
G10	3/24/2021	Alkalinity, bicarbonate	132	FALSE	FALSE
G10	3/24/2021	Calcium	115	FALSE	FALSE
G10	3/24/2021	Magnesium	39.3	FALSE	FALSE
G10	3/24/2021	Sodium	62.1	FALSE	FALSE
G10	3/24/2021	Potassium	2.91	FALSE	FALSE
G10	3/24/2021	Chloride	31	FALSE	FALSE
G10	3/24/2021	Sulfate	369	FALSE	FALSE
G10	3/24/2021	Fluoride	0.3	FALSE	FALSE
G10	3/24/2021	Barium	0.0553	FALSE	FALSE
G10	3/24/2021	Boron	4.31	FALSE	FALSE
G10	3/24/2021	Cobalt	0.0122	FALSE	FALSE
G10	3/24/2021	Iron	4.61	FALSE	FALSE
G10	3/24/2021	Manganese	1.38	FALSE	FALSE
G10	3/24/2021	H+	0.0000002	FALSE	FALSE
G10	5/11/2021	Alkalinity, bicarbonate	134	FALSE	FALSE
G10	5/11/2021	Calcium	120	FALSE	FALSE
G10	5/11/2021	Magnesium	41.1	FALSE	FALSE
G10	5/11/2021	Sodium	56.8	FALSE	FALSE
G10	5/11/2021	Potassium	2.13	FALSE	FALSE
G10	5/11/2021	Chloride	25	FALSE	FALSE
G10	5/11/2021	Sulfate	364	FALSE	FALSE
G10	5/11/2021	Fluoride	0.28	FALSE	FALSE
G10	5/11/2021	Barium	0.0453	FALSE	FALSE
G10	5/11/2021	Boron	3.95	FALSE	FALSE
G10	5/11/2021	Cobalt	0.00754	FALSE	FALSE
G10	5/11/2021	Iron	1.12	FALSE	FALSE
G10	5/11/2021	Manganese	0.702	FALSE	FALSE
G10	5/11/2021	H+	0.000000457	FALSE	FALSE
G10	6/1/2021	Alkalinity, bicarbonate	127	FALSE	FALSE
G10	6/1/2021	Calcium	124	FALSE	FALSE
G10	6/1/2021	Magnesium	38.5	FALSE	FALSE
G10	6/1/2021	Sodium	55	FALSE	FALSE
G10	6/1/2021	Potassium	2.27	FALSE	FALSE
G10	6/1/2021	Chloride	29	FALSE	FALSE
G10	6/1/2021	Sulfate	401	FALSE	FALSE
G10	6/1/2021	Fluoride	0.29	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	6/1/2021	Barium	0.0444	FALSE	FALSE
G10	6/1/2021	Boron	4.73	FALSE	FALSE
G10	6/1/2021	Cobalt	0.0071	FALSE	FALSE
G10	6/1/2021	Iron	2.82	FALSE	FALSE
G10	6/1/2021	Manganese	0.608	FALSE	FALSE
G10	6/1/2021	H+	0.000000316	FALSE	FALSE
G10	6/15/2021	Alkalinity, bicarbonate	149	FALSE	FALSE
G10	6/15/2021	Calcium	128	FALSE	FALSE
G10	6/15/2021	Magnesium	40.8	FALSE	FALSE
G10	6/15/2021	Sodium	59.3	FALSE	FALSE
G10	6/15/2021	Potassium	2.25	FALSE	FALSE
G10	6/15/2021	Chloride	26	FALSE	FALSE
G10	6/15/2021	Sulfate	407	FALSE	FALSE
G10	6/15/2021	Fluoride	0.28	FALSE	FALSE
G10	6/15/2021	Barium	0.0439	FALSE	FALSE
G10	6/15/2021	Boron	3.74	FALSE	FALSE
G10	6/15/2021	Cobalt	0.005	FALSE	FALSE
G10	6/15/2021	Iron	0.864	FALSE	FALSE
G10	6/15/2021	Manganese	0.47	FALSE	FALSE
G10	6/15/2021	H+	0.000000347	FALSE	FALSE
G10	7/6/2021	Alkalinity, bicarbonate	144	FALSE	FALSE
G10	7/6/2021	Calcium	119	FALSE	FALSE
G10	7/6/2021	Magnesium	37.3	FALSE	FALSE
G10	7/6/2021	Sodium	57.6	FALSE	FALSE
G10	7/6/2021	Potassium	2.09	FALSE	FALSE
G10	7/6/2021	Chloride	26	FALSE	FALSE
G10	7/6/2021	Sulfate	415	FALSE	FALSE
G10	7/6/2021	Fluoride	0.27	FALSE	FALSE
G10	7/6/2021	Barium	0.0356	FALSE	FALSE
G10	7/6/2021	Boron	4.81	FALSE	FALSE
G10	7/6/2021	Cobalt	0.0049	FALSE	FALSE
G10	7/6/2021	Iron	0.556	FALSE	FALSE
G10	7/6/2021	Manganese	0.416	FALSE	FALSE
G10	7/6/2021	H+	0.000000309	FALSE	FALSE
G10	7/20/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
G10	7/20/2021	Calcium	132	FALSE	FALSE
G10	7/20/2021	Magnesium	40	FALSE	FALSE
G10	7/20/2021	Sodium	56.5	FALSE	FALSE
G10	7/20/2021	Potassium	2.06	FALSE	FALSE
G10	7/20/2021	Chloride	26	FALSE	FALSE
G10	7/20/2021	Sulfate	410	FALSE	FALSE
G10	7/20/2021	Fluoride	0.26	FALSE	FALSE
G10	7/20/2021	Barium	0.0368	FALSE	FALSE
G10	7/20/2021	Boron	4.2	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	7/20/2021	Cobalt	0.0045	FALSE	FALSE
G10	7/20/2021	Iron	0.473	FALSE	FALSE
G10	7/20/2021	Manganese	0.348	FALSE	FALSE
G10	7/20/2021	H+	0.000000324	FALSE	FALSE
G52D	9/20/2021	Alkalinity, bicarbonate	147	FALSE	FALSE
G52D	9/20/2021	Calcium	47.8	FALSE	FALSE
G52D	9/20/2021	Magnesium	16.4	TRUE	NA
G52D	9/20/2021	Sodium	49.2	TRUE	NA
G52D	9/20/2021	Potassium	0.355	TRUE	NA
G52D	9/20/2021	Chloride	13	FALSE	FALSE
G52D	9/20/2021	Sulfate	83	FALSE	FALSE
G52D	9/20/2021	Fluoride	0.26	FALSE	FALSE
G52D	9/20/2021	Barium	0.232	FALSE	FALSE
G52D	9/20/2021	Boron	0.158	FALSE	TRUE
G52D	9/20/2021	Cobalt	0.0011	FALSE	FALSE
G52D	9/20/2021	Iron	0.537	TRUE	NA
G52D	9/20/2021	Manganese	3.71	TRUE	NA
G52D	9/20/2021	H+	0.000000513	FALSE	FALSE
G52D	3/10/2023	Alkalinity, bicarbonate	156	FALSE	FALSE
G52D	3/10/2023	Calcium	49.3	FALSE	FALSE
G52D	3/10/2023	Magnesium	15.3	FALSE	FALSE
G52D	3/10/2023	Sodium	27.7	FALSE	FALSE
G52D	3/10/2023	Potassium	0.768	FALSE	FALSE
G52D	3/10/2023	Chloride	12	FALSE	FALSE
G52D	3/10/2023	Sulfate	74	FALSE	FALSE
G52D	3/10/2023	Fluoride	0.22	FALSE	FALSE
G52D	3/10/2023	Barium	0.307	FALSE	FALSE
G52D	3/10/2023	Boron	0.0319	FALSE	FALSE
G52D	3/10/2023	Cobalt	0.0022	FALSE	FALSE
G52D	3/10/2023	Iron	0.639	TRUE	NA
G52D	3/10/2023	Manganese	3.71	TRUE	NA
G52D	3/10/2023	H+	0.000000288	FALSE	FALSE
G53D	3/25/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G53D	3/25/2021	Calcium	38.6	FALSE	FALSE
G53D	3/25/2021	Magnesium	15.7	FALSE	FALSE
G53D	3/25/2021	Sodium	50.8	FALSE	FALSE
G53D	3/25/2021	Potassium	0.278	FALSE	FALSE
G53D	3/25/2021	Chloride	19	FALSE	FALSE
G53D	3/25/2021	Sulfate	71	FALSE	FALSE
G53D	3/25/2021	Fluoride	0.71	FALSE	FALSE
G53D	3/25/2021	Barium	0.112	FALSE	FALSE
G53D	3/25/2021	Boron	0.355	FALSE	FALSE
G53D	3/25/2021	Cobalt	0.0026	FALSE	FALSE
G53D	3/25/2021	Iron	1.69	TRUE	NA

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G53D	3/25/2021	Manganese	0.0334	TRUE	NA
G53D	3/25/2021	H+	0.000000295	FALSE	FALSE
G53D	9/20/2021	Alkalinity, bicarbonate	171	FALSE	FALSE
G53D	9/20/2021	Calcium	38.5	FALSE	FALSE
G53D	9/20/2021	Magnesium	16.4	TRUE	NA
G53D	9/20/2021	Sodium	50.8	TRUE	NA
G53D	9/20/2021	Potassium	0.355	TRUE	NA
G53D	9/20/2021	Chloride	19	FALSE	FALSE
G53D	9/20/2021	Sulfate	78	FALSE	FALSE
G53D	9/20/2021	Fluoride	0.7	FALSE	FALSE
G53D	9/20/2021	Barium	0.103	FALSE	FALSE
G53D	9/20/2021	Boron	0.402	FALSE	FALSE
G53D	9/20/2021	Cobalt	0.0021	FALSE	FALSE
G53D	9/20/2021	Iron	1.69	TRUE	NA
G53D	9/20/2021	Manganese	0.0334	TRUE	NA
G53D	9/20/2021	H+	0.000000537	FALSE	FALSE
G53D	3/15/2022	Alkalinity, bicarbonate	176	FALSE	FALSE
G53D	3/15/2022	Calcium	38.1	FALSE	FALSE
G53D	3/15/2022	Magnesium	16.5	FALSE	FALSE
G53D	3/15/2022	Sodium	51.3	FALSE	FALSE
G53D	3/15/2022	Potassium	0.317	FALSE	FALSE
G53D	3/15/2022	Chloride	18	FALSE	FALSE
G53D	3/15/2022	Sulfate	74	FALSE	FALSE
G53D	3/15/2022	Fluoride	0.71	FALSE	FALSE
G53D	3/15/2022	Barium	0.0922	FALSE	FALSE
G53D	3/15/2022	Boron	0.332	FALSE	FALSE
G53D	3/15/2022	Cobalt	0.0022	FALSE	FALSE
G53D	3/15/2022	Iron	1.69	TRUE	NA
G53D	3/15/2022	Manganese	0.0334	TRUE	NA
G53D	3/15/2022	H+	0.000000316	FALSE	FALSE
G53D	7/25/2022	Alkalinity, bicarbonate	149	FALSE	FALSE
G53D	7/25/2022	Calcium	39.7	FALSE	FALSE
G53D	7/25/2022	Magnesium	17	FALSE	FALSE
G53D	7/25/2022	Sodium	49.4	FALSE	FALSE
G53D	7/25/2022	Potassium	0.3	FALSE	FALSE
G53D	7/25/2022	Chloride	19	FALSE	FALSE
G53D	7/25/2022	Sulfate	77	FALSE	FALSE
G53D	7/25/2022	Fluoride	0.72	FALSE	FALSE
G53D	7/25/2022	Barium	0.0913	FALSE	FALSE
G53D	7/25/2022	Boron	0.341	FALSE	FALSE
G53D	7/25/2022	Cobalt	0.0021	FALSE	FALSE
G53D	7/25/2022	Iron	0.281	FALSE	FALSE
G53D	7/25/2022	Manganese	0.137	FALSE	FALSE
G53D	7/25/2022	H+	1.32E-08	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G53D	3/9/2023	Alkalinity, bicarbonate	177	FALSE	FALSE
G53D	3/9/2023	Calcium	38.3	FALSE	FALSE
G53D	3/9/2023	Magnesium	16.4	FALSE	FALSE
G53D	3/9/2023	Sodium	49.2	FALSE	FALSE
G53D	3/9/2023	Potassium	0.355	FALSE	FALSE
G53D	3/9/2023	Chloride	17	FALSE	FALSE
G53D	3/9/2023	Sulfate	72	FALSE	FALSE
G53D	3/9/2023	Fluoride	0.59	FALSE	FALSE
G53D	3/9/2023	Barium	0.101	FALSE	FALSE
G53D	3/9/2023	Boron	0.37	FALSE	FALSE
G53D	3/9/2023	Cobalt	0.0022	FALSE	FALSE
G53D	3/9/2023	Iron	2.25	TRUE	NA
G53D	3/9/2023	Manganese	0.0334	TRUE	NA
G53D	3/9/2023	H+	0.000000347	FALSE	FALSE
G54D	3/24/2021	Alkalinity, bicarbonate	214	FALSE	FALSE
G54D	3/24/2021	Calcium	78.1	FALSE	FALSE
G54D	3/24/2021	Magnesium	24.2	FALSE	FALSE
G54D	3/24/2021	Sodium	62.4	FALSE	FALSE
G54D	3/24/2021	Potassium	1.12	FALSE	FALSE
G54D	3/24/2021	Chloride	23	FALSE	FALSE
G54D	3/24/2021	Sulfate	186	FALSE	FALSE
G54D	3/24/2021	Fluoride	0.32	FALSE	FALSE
G54D	3/24/2021	Barium	0.0941	FALSE	FALSE
G54D	3/24/2021	Boron	0.404	FALSE	FALSE
G54D	3/24/2021	Cobalt	0.0045	FALSE	FALSE
G54D	3/24/2021	Iron	5.11	TRUE	NA
G54D	3/24/2021	Manganese	3.87	TRUE	NA
G54D	3/24/2021	H+	0.000000275	FALSE	FALSE
G54D	9/20/2021	Alkalinity, bicarbonate	207	FALSE	FALSE
G54D	9/20/2021	Calcium	72.8	FALSE	FALSE
G54D	9/20/2021	Magnesium	24.1	TRUE	NA
G54D	9/20/2021	Sodium	49.2	TRUE	NA
G54D	9/20/2021	Potassium	1.12	TRUE	NA
G54D	9/20/2021	Chloride	24	FALSE	FALSE
G54D	9/20/2021	Sulfate	175	FALSE	FALSE
G54D	9/20/2021	Fluoride	0.29	FALSE	FALSE
G54D	9/20/2021	Barium	0.0879	FALSE	FALSE
G54D	9/20/2021	Boron	0.35	FALSE	FALSE
G54D	9/20/2021	Cobalt	0.0083	FALSE	FALSE
G54D	9/20/2021	Iron	5.11	TRUE	NA
G54D	9/20/2021	Manganese	3.87	TRUE	NA
G54D	9/20/2021	H+	0.000000331	FALSE	FALSE
G54D	3/15/2022	Alkalinity, bicarbonate	208	FALSE	FALSE
G54D	3/15/2022	Calcium	83.4	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G54D	3/15/2022	Magnesium	25.8	FALSE	FALSE
G54D	3/15/2022	Sodium	54.2	FALSE	FALSE
G54D	3/15/2022	Potassium	1.21	FALSE	FALSE
G54D	3/15/2022	Chloride	21	FALSE	FALSE
G54D	3/15/2022	Sulfate	213	FALSE	FALSE
G54D	3/15/2022	Fluoride	0.31	FALSE	FALSE
G54D	3/15/2022	Barium	0.064	FALSE	FALSE
G54D	3/15/2022	Boron	0.451	FALSE	FALSE
G54D	3/15/2022	Cobalt	0.011	FALSE	FALSE
G54D	3/15/2022	Iron	5.11	TRUE	NA
G54D	3/15/2022	Manganese	3.87	TRUE	NA
G54D	3/15/2022	H+	0.000000245	FALSE	FALSE
G54D	9/20/2022	Alkalinity, bicarbonate	171	TRUE	NA
G54D	9/20/2022	Calcium	69.7	FALSE	FALSE
G54D	9/20/2022	Magnesium	19.4	TRUE	NA
G54D	9/20/2022	Sodium	49.2	TRUE	NA
G54D	9/20/2022	Potassium	0.355	TRUE	NA
G54D	9/20/2022	Chloride	22	FALSE	FALSE
G54D	9/20/2022	Sulfate	218	FALSE	FALSE
G54D	9/20/2022	Fluoride	0.27	FALSE	FALSE
G54D	9/20/2022	Barium	0.0768	FALSE	FALSE
G54D	9/20/2022	Boron	0.252	FALSE	FALSE
G54D	9/20/2022	Cobalt	0.0048	FALSE	FALSE
G54D	9/20/2022	Iron	5.11	TRUE	NA
G54D	9/20/2022	Manganese	3.87	TRUE	NA
G54D	9/20/2022	H+	0.000000316	FALSE	FALSE
G54D	5/3/2023	Alkalinity, bicarbonate	206	FALSE	FALSE
G54D	5/3/2023	Calcium	81.5	FALSE	FALSE
G54D	5/3/2023	Magnesium	26.4	FALSE	FALSE
G54D	5/3/2023	Sodium	57	FALSE	FALSE
G54D	5/3/2023	Potassium	1.21	FALSE	FALSE
G54D	5/3/2023	Chloride	22	FALSE	FALSE
G54D	5/3/2023	Sulfate	194	FALSE	FALSE
G54D	5/3/2023	Fluoride	0.3	FALSE	FALSE
G54D	5/3/2023	Barium	0.0794	FALSE	FALSE
G54D	5/3/2023	Boron	0.555	FALSE	FALSE
G54D	5/3/2023	Cobalt	0.0106	FALSE	FALSE
G54D	5/3/2023	Iron	1.39	FALSE	FALSE
G54D	5/3/2023	Manganese	1.19	FALSE	FALSE
G54D	5/3/2023	H+	0.000000158	FALSE	FALSE
XPW01	3/5/2021	Alkalinity, bicarbonate	155	FALSE	FALSE
XPW01	3/5/2021	Calcium	162	FALSE	FALSE
XPW01	3/5/2021	Magnesium	2.25	FALSE	FALSE
XPW01	3/5/2021	Sodium	35.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	3/5/2021	Potassium	31.1	FALSE	FALSE
XPW01	3/5/2021	Chloride	10	FALSE	FALSE
XPW01	3/5/2021	Sulfate	345	FALSE	FALSE
XPW01	3/5/2021	Fluoride	0.67	FALSE	FALSE
XPW01	3/5/2021	Barium	0.165	FALSE	FALSE
XPW01	3/5/2021	Boron	10.4	FALSE	FALSE
XPW01	3/5/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	3/5/2021	Iron	2.18	FALSE	FALSE
XPW01	3/5/2021	Manganese	1.24	FALSE	FALSE
XPW01	3/5/2021	H+	0.00000001	FALSE	FALSE
XPW01	3/24/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
XPW01	3/24/2021	Calcium	158	FALSE	FALSE
XPW01	3/24/2021	Magnesium	1.7	FALSE	FALSE
XPW01	3/24/2021	Sodium	37.2	FALSE	FALSE
XPW01	3/24/2021	Potassium	38.1	FALSE	FALSE
XPW01	3/24/2021	Chloride	9	FALSE	FALSE
XPW01	3/24/2021	Sulfate	355	FALSE	FALSE
XPW01	3/24/2021	Fluoride	0.55	FALSE	FALSE
XPW01	3/24/2021	Barium	0.161	FALSE	FALSE
XPW01	3/24/2021	Boron	9.58	FALSE	FALSE
XPW01	3/24/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	3/24/2021	Iron	1.18	FALSE	FALSE
XPW01	3/24/2021	Manganese	0.59	FALSE	FALSE
XPW01	3/24/2021	H+	3.98E-09	FALSE	FALSE
XPW01	4/14/2021	Alkalinity, bicarbonate	136	FALSE	FALSE
XPW01	4/14/2021	Calcium	156	FALSE	FALSE
XPW01	4/14/2021	Magnesium	1.28	FALSE	FALSE
XPW01	4/14/2021	Sodium	28.3	FALSE	FALSE
XPW01	4/14/2021	Potassium	34.7	FALSE	FALSE
XPW01	4/14/2021	Chloride	7	FALSE	FALSE
XPW01	4/14/2021	Sulfate	355	FALSE	FALSE
XPW01	4/14/2021	Fluoride	0.57	FALSE	FALSE
XPW01	4/14/2021	Barium	0.154	FALSE	FALSE
XPW01	4/14/2021	Boron	9.42	FALSE	FALSE
XPW01	4/14/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	4/14/2021	Iron	1.36	FALSE	FALSE
XPW01	4/14/2021	Manganese	0.725	FALSE	FALSE
XPW01	4/14/2021	H+	6.31E-09	FALSE	FALSE
XPW01	5/12/2021	Alkalinity, bicarbonate	145	FALSE	FALSE
XPW01	5/12/2021	Calcium	166	FALSE	FALSE
XPW01	5/12/2021	Magnesium	1.31	FALSE	FALSE
XPW01	5/12/2021	Sodium	29.3	FALSE	FALSE
XPW01	5/12/2021	Potassium	36.9	FALSE	FALSE
XPW01	5/12/2021	Chloride	6	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	5/12/2021	Sulfate	309	FALSE	FALSE
XPW01	5/12/2021	Fluoride	0.62	FALSE	FALSE
XPW01	5/12/2021	Barium	0.162	FALSE	FALSE
XPW01	5/12/2021	Boron	10.2	FALSE	FALSE
XPW01	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	5/12/2021	Iron	1.98	FALSE	FALSE
XPW01	5/12/2021	Manganese	1.09	FALSE	FALSE
XPW01	5/12/2021	H+	3.98E-09	FALSE	FALSE
XPW01	3/15/2022	Alkalinity, bicarbonate	104	FALSE	FALSE
XPW01	3/15/2022	Calcium	159	FALSE	FALSE
XPW01	3/15/2022	Magnesium	0.443	FALSE	FALSE
XPW01	3/15/2022	Sodium	27.4	FALSE	FALSE
XPW01	3/15/2022	Potassium	36.9	FALSE	FALSE
XPW01	3/15/2022	Chloride	5	FALSE	FALSE
XPW01	3/15/2022	Sulfate	360	FALSE	FALSE
XPW01	3/15/2022	Fluoride	0.25	FALSE	FALSE
XPW01	3/15/2022	Barium	0.113	FALSE	FALSE
XPW01	3/15/2022	Boron	10.4	FALSE	FALSE
XPW01	3/15/2022	Cobalt	0.0316	FALSE	TRUE
XPW01	3/15/2022	Iron	1.36	TRUE	NA
XPW01	3/15/2022	Manganese	0.725	TRUE	NA
XPW01	3/15/2022	H+	4.68E-09	FALSE	FALSE
XPW01	3/8/2023	Alkalinity, bicarbonate	64	FALSE	FALSE
XPW01	3/8/2023	Calcium	164	FALSE	FALSE
XPW01	3/8/2023	Magnesium	0.254	FALSE	FALSE
XPW01	3/8/2023	Sodium	27.2	FALSE	FALSE
XPW01	3/8/2023	Potassium	37.2	FALSE	FALSE
XPW01	3/8/2023	Chloride	11	FALSE	FALSE
XPW01	3/8/2023	Sulfate	414	FALSE	FALSE
XPW01	3/8/2023	Fluoride	0.16	FALSE	FALSE
XPW01	3/8/2023	Barium	0.128	FALSE	FALSE
XPW01	3/8/2023	Boron	8.79	FALSE	FALSE
XPW01	3/8/2023	Cobalt	0.0002	FALSE	FALSE
XPW01	3/8/2023	Iron	1.36	TRUE	NA
XPW01	3/8/2023	Manganese	0.725	TRUE	NA
XPW01	3/8/2023	H+	3.39E-09	FALSE	FALSE
XPW01	5/3/2023	Alkalinity, bicarbonate	130	FALSE	FALSE
XPW01	5/3/2023	Calcium	151	FALSE	FALSE
XPW01	5/3/2023	Magnesium	0.405	FALSE	FALSE
XPW01	5/3/2023	Sodium	27	FALSE	FALSE
XPW01	5/3/2023	Potassium	38.5	FALSE	FALSE
XPW01	5/3/2023	Chloride	14	FALSE	FALSE
XPW01	5/3/2023	Sulfate	345	FALSE	FALSE
XPW01	5/3/2023	Fluoride	0.34	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	5/3/2023	Barium	0.137	FALSE	FALSE
XPW01	5/3/2023	Boron	10.6	FALSE	FALSE
XPW01	5/3/2023	Cobalt	0.0002	FALSE	FALSE
XPW01	5/3/2023	Iron	1	FALSE	FALSE
XPW01	5/3/2023	Manganese	0.544	FALSE	FALSE
XPW01	5/3/2023	H+	3.89E-09	FALSE	FALSE
XPW02	3/4/2021	Alkalinity, bicarbonate	121	FALSE	FALSE
XPW02	3/4/2021	Calcium	591	FALSE	FALSE
XPW02	3/4/2021	Magnesium	10.9	FALSE	FALSE
XPW02	3/4/2021	Sodium	888	FALSE	FALSE
XPW02	3/4/2021	Potassium	23.4	FALSE	FALSE
XPW02	3/4/2021	Chloride	130	FALSE	FALSE
XPW02	3/4/2021	Sulfate	2380	FALSE	FALSE
XPW02	3/4/2021	Fluoride	0.42	FALSE	FALSE
XPW02	3/4/2021	Barium	0.0342	FALSE	FALSE
XPW02	3/4/2021	Boron	12.1	FALSE	FALSE
XPW02	3/4/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	3/4/2021	Iron	1.63	FALSE	FALSE
XPW02	3/4/2021	Manganese	0.47	FALSE	FALSE
XPW02	3/4/2021	H+	0.00000001	FALSE	FALSE
XPW02	3/24/2021	Alkalinity, bicarbonate	128	FALSE	FALSE
XPW02	3/24/2021	Calcium	484	FALSE	FALSE
XPW02	3/24/2021	Magnesium	11.3	FALSE	FALSE
XPW02	3/24/2021	Sodium	798	FALSE	FALSE
XPW02	3/24/2021	Potassium	26.3	FALSE	FALSE
XPW02	3/24/2021	Chloride	176	FALSE	FALSE
XPW02	3/24/2021	Sulfate	2830	FALSE	FALSE
XPW02	3/24/2021	Fluoride	0.45	FALSE	FALSE
XPW02	3/24/2021	Barium	0.0271	FALSE	FALSE
XPW02	3/24/2021	Boron	12.2	FALSE	FALSE
XPW02	3/24/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	3/24/2021	Iron	1.25	FALSE	FALSE
XPW02	3/24/2021	Manganese	0.499	FALSE	FALSE
XPW02	3/24/2021	H+	0.00000001	FALSE	FALSE
XPW02	4/14/2021	Alkalinity, bicarbonate	128	FALSE	FALSE
XPW02	4/14/2021	Calcium	551	FALSE	FALSE
XPW02	4/14/2021	Magnesium	11.3	FALSE	FALSE
XPW02	4/14/2021	Sodium	705	FALSE	FALSE
XPW02	4/14/2021	Potassium	25.3	FALSE	FALSE
XPW02	4/14/2021	Chloride	110	FALSE	FALSE
XPW02	4/14/2021	Sulfate	2410	FALSE	FALSE
XPW02	4/14/2021	Fluoride	0.44	FALSE	FALSE
XPW02	4/14/2021	Barium	0.0283	FALSE	FALSE
XPW02	4/14/2021	Boron	11.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW02	4/14/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	4/14/2021	Iron	1.69	FALSE	FALSE
XPW02	4/14/2021	Manganese	0.583	FALSE	FALSE
XPW02	4/14/2021	H+	1.26E-08	FALSE	FALSE
XPW02	5/12/2021	Alkalinity, bicarbonate	123	FALSE	FALSE
XPW02	5/12/2021	Calcium	495	FALSE	FALSE
XPW02	5/12/2021	Magnesium	11.8	FALSE	FALSE
XPW02	5/12/2021	Sodium	641	FALSE	FALSE
XPW02	5/12/2021	Potassium	24.5	FALSE	FALSE
XPW02	5/12/2021	Chloride	134	FALSE	FALSE
XPW02	5/12/2021	Sulfate	2410	FALSE	FALSE
XPW02	5/12/2021	Fluoride	0.41	FALSE	FALSE
XPW02	5/12/2021	Barium	0.0287	FALSE	FALSE
XPW02	5/12/2021	Boron	10.8	FALSE	FALSE
XPW02	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	5/12/2021	Iron	2.15	FALSE	FALSE
XPW02	5/12/2021	Manganese	0.632	FALSE	FALSE
XPW02	5/12/2021	H+	1.41E-08	FALSE	FALSE
XPW02	7/21/2021	Alkalinity, bicarbonate	139	FALSE	FALSE
XPW02	7/21/2021	Calcium	494	FALSE	FALSE
XPW02	7/21/2021	Magnesium	11.1	FALSE	FALSE
XPW02	7/21/2021	Sodium	762	FALSE	FALSE
XPW02	7/21/2021	Potassium	24.7	FALSE	FALSE
XPW02	7/21/2021	Chloride	179	FALSE	FALSE
XPW02	7/21/2021	Sulfate	2330	FALSE	FALSE
XPW02	7/21/2021	Fluoride	0.4	FALSE	FALSE
XPW02	7/21/2021	Barium	0.0226	FALSE	FALSE
XPW02	7/21/2021	Boron	12	FALSE	FALSE
XPW02	7/21/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	7/21/2021	Iron	2.7	FALSE	FALSE
XPW02	7/21/2021	Manganese	0.744	FALSE	FALSE
XPW02	7/21/2021	H+	1.74E-08	FALSE	FALSE
XPW02	3/15/2022	Alkalinity, bicarbonate	144	FALSE	FALSE
XPW02	3/15/2022	Calcium	483	FALSE	FALSE
XPW02	3/15/2022	Magnesium	10.7	FALSE	FALSE
XPW02	3/15/2022	Sodium	828	FALSE	FALSE
XPW02	3/15/2022	Potassium	27.1	FALSE	FALSE
XPW02	3/15/2022	Chloride	115	FALSE	FALSE
XPW02	3/15/2022	Sulfate	2590	FALSE	FALSE
XPW02	3/15/2022	Fluoride	0.48	FALSE	FALSE
XPW02	3/15/2022	Barium	0.023	FALSE	FALSE
XPW02	3/15/2022	Boron	16	FALSE	FALSE
XPW02	3/15/2022	Cobalt	0.0316	FALSE	TRUE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW02	3/15/2022	Iron	1.69	TRUE	NA
XPW02	3/15/2022	Manganese	0.583	TRUE	NA
XPW02	3/15/2022	H+	1.82E-08	FALSE	FALSE
XPW02	5/3/2023	Alkalinity, bicarbonate	139	FALSE	FALSE
XPW02	5/3/2023	Calcium	451	FALSE	FALSE
XPW02	5/3/2023	Magnesium	12.3	FALSE	FALSE
XPW02	5/3/2023	Sodium	953	FALSE	FALSE
XPW02	5/3/2023	Potassium	27.4	FALSE	FALSE
XPW02	5/3/2023	Chloride	104	FALSE	FALSE
XPW02	5/3/2023	Sulfate	2650	FALSE	FALSE
XPW02	5/3/2023	Fluoride	0.48	FALSE	FALSE
XPW02	5/3/2023	Barium	0.0212	FALSE	FALSE
XPW02	5/3/2023	Boron	13.4	FALSE	FALSE
XPW02	5/3/2023	Cobalt	0.0002	FALSE	FALSE
XPW02	5/3/2023	Iron	3.49	FALSE	FALSE
XPW02	5/3/2023	Manganese	0.748	FALSE	FALSE
XPW02	5/3/2023	H+	1.91E-08	FALSE	FALSE
XPW03	5/12/2021	Alkalinity, bicarbonate	141	TRUE	FALSE
XPW03	5/12/2021	Calcium	16.4	FALSE	FALSE
XPW03	5/12/2021	Magnesium	0.316	FALSE	TRUE
XPW03	5/12/2021	Sodium	113	FALSE	FALSE
XPW03	5/12/2021	Potassium	27.5	FALSE	FALSE
XPW03	5/12/2021	Chloride	25	FALSE	FALSE
XPW03	5/12/2021	Sulfate	155	FALSE	FALSE
XPW03	5/12/2021	Fluoride	0.25	FALSE	FALSE
XPW03	5/12/2021	Barium	0.012	FALSE	FALSE
XPW03	5/12/2021	Boron	11.7	FALSE	FALSE
XPW03	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW03	5/12/2021	Iron	0.316	FALSE	TRUE
XPW03	5/12/2021	Manganese	0.0707	FALSE	TRUE
XPW03	5/12/2021	H+	2E-11	FALSE	FALSE
XPW03	7/21/2021	Alkalinity, bicarbonate	141	TRUE	FALSE
XPW03	7/21/2021	Calcium	15.3	FALSE	FALSE
XPW03	7/21/2021	Magnesium	0.224	FALSE	TRUE
XPW03	7/21/2021	Sodium	104	FALSE	FALSE
XPW03	7/21/2021	Potassium	26.9	FALSE	FALSE
XPW03	7/21/2021	Chloride	26	FALSE	FALSE
XPW03	7/21/2021	Sulfate	148	FALSE	FALSE
XPW03	7/21/2021	Fluoride	0.26	FALSE	FALSE
XPW03	7/21/2021	Barium	0.0114	FALSE	FALSE
XPW03	7/21/2021	Boron	11.6	FALSE	FALSE
XPW03	7/21/2021	Cobalt	0.0316	FALSE	TRUE
XPW03	7/21/2021	Iron	0.158	FALSE	TRUE
XPW03	7/21/2021	Manganese	0.0447	FALSE	TRUE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW03	7/21/2021	H+	1.07E-10	FALSE	FALSE

Note:
mg/L = milligrams per liter
RL = reporting limit

APPENDIX C
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
G03	Compliance	06/15/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	07/06/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	07/21/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	06/15/2021	Manganese, total	0.0330	mg/L
G03	Compliance	07/06/2021	Manganese, total	0.0226	mg/L
G03	Compliance	07/21/2021	Manganese, total	0.0334	mg/L
G05	Compliance	03/04/2021	Boron, total	0.181	mg/L
G05	Compliance	03/24/2021	Boron, total	0.195	mg/L
G05	Compliance	04/13/2021	Boron, total	0.190	mg/L
G05	Compliance	05/11/2021	Boron, total	0.158	mg/L
G05	Compliance	06/01/2021	Boron, total	0.157	mg/L
G05	Compliance	06/15/2021	Boron, total	0.140	mg/L
G05	Compliance	07/06/2021	Boron, total	0.148	mg/L
G05	Compliance	07/20/2021	Boron, total	0.131	mg/L
G05	Compliance	07/26/2022	Boron, total	0.0645	mg/L
G05	Compliance	03/09/2023	Boron, total	0.0541	mg/L
G05	Compliance	05/03/2023	Boron, total	0.0478	mg/L
G05	Compliance	03/04/2021	Cobalt, total	0.0101	mg/L
G05	Compliance	03/24/2021	Cobalt, total	0.00960	mg/L
G05	Compliance	04/13/2021	Cobalt, total	0.00950	mg/L
G05	Compliance	05/11/2021	Cobalt, total	0.00870	mg/L
G05	Compliance	06/01/2021	Cobalt, total	0.00780	mg/L
G05	Compliance	06/15/2021	Cobalt, total	0.00570	mg/L
G05	Compliance	07/06/2021	Cobalt, total	0.00910	mg/L
G05	Compliance	07/20/2021	Cobalt, total	0.00590	mg/L
G05	Compliance	07/26/2022	Cobalt, total	0.00750	mg/L
G05	Compliance	03/09/2023	Cobalt, total	0.00740	mg/L
G05	Compliance	05/03/2023	Cobalt, total	0.0103	mg/L
G05	Compliance	03/04/2021	Manganese, total	0.227	mg/L
G05	Compliance	04/13/2021	Manganese, total	0.294	mg/L
G05	Compliance	05/11/2021	Manganese, total	0.256	mg/L
G05	Compliance	06/01/2021	Manganese, total	0.254	mg/L
G05	Compliance	06/15/2021	Manganese, total	0.187	mg/L
G05	Compliance	07/06/2021	Manganese, total	0.270	mg/L
G05	Compliance	07/20/2021	Manganese, total	0.204	mg/L
G05	Compliance	07/26/2022	Manganese, total	0.176	mg/L
G05	Compliance	05/03/2023	Manganese, total	0.191	mg/L
G05	Compliance	03/04/2021	Sulfate, total	94.0	mg/L
G05	Compliance	03/24/2021	Sulfate, total	92.0	mg/L
G05	Compliance	04/13/2021	Sulfate, total	95.0	mg/L
G05	Compliance	05/11/2021	Sulfate, total	109	mg/L
G05	Compliance	06/01/2021	Sulfate, total	83.0	mg/L
G05	Compliance	06/15/2021	Sulfate, total	91.0	mg/L
G05	Compliance	07/06/2021	Sulfate, total	90.0	mg/L
G05	Compliance	07/20/2021	Sulfate, total	87.0	mg/L
G05	Compliance	07/26/2022	Sulfate, total	68.0	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
G05	Compliance	03/09/2023	Sulfate, total	90.0	mg/L
G05	Compliance	05/03/2023	Sulfate, total	112	mg/L
G53D	Compliance	07/25/2022	Cobalt, total	0.00210	mg/L
G53D	Compliance	05/03/2023	Cobalt, total	0.00180	mg/L
G53D	Compliance	07/25/2022	Manganese, total	0.137	mg/L
G53D	Compliance	05/03/2023	Manganese, total	0.133	mg/L
XPW01	Porewater	03/05/2021	Boron, total	10.4	mg/L
XPW01	Porewater	03/24/2021	Boron, total	9.58	mg/L
XPW01	Porewater	04/14/2021	Boron, total	9.42	mg/L
XPW01	Porewater	05/12/2021	Boron, total	10.2	mg/L
XPW01	Porewater	07/21/2021	Boron, total	10.1	mg/L
XPW01	Porewater	03/15/2022	Boron, total	10.4	mg/L
XPW01	Porewater	03/08/2023	Boron, total	8.79	mg/L
XPW01	Porewater	05/03/2023	Boron, total	10.6	mg/L
XPW01	Porewater	03/05/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/08/2023	Cobalt, total	0.0002 J	mg/L
XPW01	Porewater	05/03/2023	Cobalt, total	0.0002 J	mg/L
XPW01	Porewater	03/05/2021	Sulfate, total	345	mg/L
XPW01	Porewater	03/24/2021	Sulfate, total	355	mg/L
XPW01	Porewater	04/14/2021	Sulfate, total	355	mg/L
XPW01	Porewater	05/12/2021	Sulfate, total	309	mg/L
XPW01	Porewater	07/21/2021	Sulfate, total	328	mg/L
XPW01	Porewater	03/15/2022	Sulfate, total	360	mg/L
XPW01	Porewater	03/08/2023	Sulfate, total	414	mg/L
XPW01	Porewater	05/03/2023	Sulfate, total	345	mg/L
XPW02	Porewater	03/04/2021	Boron, total	12.1	mg/L
XPW02	Porewater	03/24/2021	Boron, total	12.2	mg/L
XPW02	Porewater	04/14/2021	Boron, total	11.5	mg/L
XPW02	Porewater	05/12/2021	Boron, total	10.8	mg/L
XPW02	Porewater	07/21/2021	Boron, total	12.0	mg/L
XPW02	Porewater	03/15/2022	Boron, total	16.0	mg/L
XPW02	Porewater	03/08/2023	Boron, total	10.8	mg/L
XPW02	Porewater	05/03/2023	Boron, total	13.4	mg/L
XPW02	Porewater	03/04/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/08/2023	Cobalt, total	0.0003 J	mg/L
XPW02	Porewater	05/03/2023	Cobalt, total	0.0002 J	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
XPW02	Porewater	03/04/2021	Sulfate, total	2,380	mg/L
XPW02	Porewater	03/24/2021	Sulfate, total	2,830	mg/L
XPW02	Porewater	04/14/2021	Sulfate, total	2,410	mg/L
XPW02	Porewater	05/12/2021	Sulfate, total	2,410	mg/L
XPW02	Porewater	07/21/2021	Sulfate, total	2,330	mg/L
XPW02	Porewater	03/15/2022	Sulfate, total	2,590	mg/L
XPW02	Porewater	03/08/2023	Sulfate, total	2,450	mg/L
XPW02	Porewater	05/03/2023	Sulfate, total	2,650	mg/L
XPW03	Porewater	03/04/2021	Boron, total	12.2	mg/L
XPW03	Porewater	03/24/2021	Boron, total	11.6	mg/L
XPW03	Porewater	04/14/2021	Boron, total	9.30	mg/L
XPW03	Porewater	05/12/2021	Boron, total	11.7	mg/L
XPW03	Porewater	07/21/2021	Boron, total	11.6	mg/L
XPW03	Porewater	03/15/2022	Boron, total	11.1	mg/L
XPW03	Porewater	03/09/2023	Boron, total	8.06	mg/L
XPW03	Porewater	05/03/2023	Boron, total	9.22	mg/L
XPW03	Porewater	03/04/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/09/2023	Cobalt, total	0.0001 U	mg/L
XPW03	Porewater	05/03/2023	Cobalt, total	0.0001 U	mg/L
XPW03	Porewater	03/04/2021	Sulfate, total	133	mg/L
XPW03	Porewater	03/24/2021	Sulfate, total	138	mg/L
XPW03	Porewater	04/14/2021	Sulfate, total	152	mg/L
XPW03	Porewater	05/12/2021	Sulfate, total	155	mg/L
XPW03	Porewater	07/21/2021	Sulfate, total	148	mg/L
XPW03	Porewater	03/15/2022	Sulfate, total	152	mg/L
XPW03	Porewater	03/09/2023	Sulfate, total	142	mg/L
XPW03	Porewater	05/03/2023	Sulfate, total	144	mg/L

APPENDIXC.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Notes:
mg/L = milligrams per liter
J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.
U = The analyte was analyzed for, but was not detected above the level of the adjusted detection limit or quantitation limit, as appropriate.

APPENDIX D
GEOCHEMICAL ANALYSIS OF JOPPA EAST ASH POND GROUNDWATER IN SUPPORT OF AN ALTERNATIVE SOURCE DEMONSTRATION (LIFE CYCLE GEO, LLC, 2023)

TECHNICAL MEMORANDUM

DATE October 21, 2023 **Reference No.** 23RAM01-1

TO Brian G. Hennings - Ramboll
Frances Ackerman - Ramboll
Allison Kreinberg - Geosyntec

CC Stu Cravens - Vistra

FROM Shannon Zahuranec, Allie Wyman, Tom Meuzelaar **EMAIL:** shannon@lifecyclegeo.com

GEOCHEMICAL ANALYSIS OF JOPPA EAST ASH POND GROUNDWATER IN SUPPORT OF AN ALTERNATIVE SOURCE DEMONSTRATION

1.0 EXECUTIVE SUMMARY

This document serves as an Appendix to the October 21, 2023, Alternative Source Demonstration (ASD) for Joppa (JOP) Power Plant East Ash Pond (EAP) for monitoring Event 1 (E001) (referred to as the E001 ASD), completed to fulfill the requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e). Life Cycle Geo, LLC (LCG) has completed a review of geochemical conditions to evaluate the feasibility of an ASD at monitoring wells G11 and G51D associated with the JOP EAP. Compliance wells G11 and G51D monitor conditions in the Uppermost Aquifer (UA) to the west of the EAP and currently exhibit pH levels lower than the groundwater protection standard (GWPS) range for pH. This technical evaluation considered all available groundwater and solid-phase chemical analyses and utilized multivariate statistical analysis to conclude that low pH levels at G11 and G51D are not attributed to influence from the EAP. Further, observed pH levels are likely the result of the oxidation of dissolved iron released from chemically reducing conditions in the upgradient area to the north and west of the G11 and G51D monitoring wells (also referred to in this document as exceedance wells). Oxidation of dissolved ferrous iron and subsequent precipitation of solid-phase iron generates acidity through fundamentally established geochemical reactions discussed in Section 4.0. This scope of work was executed by subcontract to Ramboll Americas Engineering Solutions, Inc. (Ramboll) on behalf of Electric Energy, Inc.

2.0 HYDROGEOLOGY AND GROUNDWATER CONDITION

Monitoring wells G11 and G51D are screened in the UA. The UA is composed predominantly of sand and is overlain by the upper confining unit (UCU), a clay-rich, low permeability stratigraphic unit (Ramboll, 2021). Monitoring wells G11 and G51D are on the western border of the EAP, hydraulically upgradient of the EAP and the other EAP monitoring wells (Attachment 1). Monitoring wells G11 and G51D are downgradient of the northernmost part of the JOP West Ash Pond (WAP), and the sewage treatment pond (Attachment 2) situated on the northwest corner of the WAP.

Table 1: Concentration Ranges for Select Constituents in Joppa Groundwater and CCR Ponds.

	pH	Boron (mg/L)	Magnesium (mg/L)
G11	5.78-6.33	0.25-0.42	27.8-72.4
G51D	5.30-6.92	0.03-0.96	12.3-14.4
CCR porewater	6.76-11.1	4.02-34.3	ND-27.8
Western Groundwater*	5.04-7.4	ND-24.7	4.0-126
Eastern Groundwater	5.62-7.88	ND-5.43	7.1-49.3
TPZ120	2.77-3.63	2.08-3.55	52.4-63.5

ND=Not Detected
Data provided in Appendix D-1
*Western groundwater ranges presented do not include TPZ120, which is listed separately.

From March 2021 through May 2023, pH at G11 and G51D is generally below the GWPS lower limit of 6.0 standard pH units (SU) (Attachment 3). Groundwater pH elsewhere at the site has been measured as low as 5.0 SU (Table 1) but is typically between 6 and 8 SU (Attachment 3; Appendix D-1). The UCU monitoring well TPZ120 is an exception with a much lower groundwater pH (less than 4.0 SU).

This analysis focused predominantly on assessing the source of acidity in G11 and G51D as originating from either east or west of the exceedance wells to determine if the EAP (east of the exceedance wells) is the source of the low pH levels observed. To this end, monitoring wells to the east of the exceedance wells are discussed as the Eastern Wells and the monitoring wells to the west are discussed as the Western Wells. The Eastern Wells include the EAP porewater wells [XPW01, XPW02, and XPW03] as an endmember for evaluation, EAP compliance-based groundwater wells [G03, G05, G06, G07, G08, G09, G10, G52D, G53D, and G54D], and two EAP monitoring wells [G04 and G06S] that are not included in the regulatory network but are in close proximity to the compliance EAP monitoring wells. While most of these wells are downgradient of G11 and G51D, they provide a necessary comparison for assessing potential EAP impacts to G11 and G51D. The Western Wells are hydraulically upgradient or side-gradient of G11 and G51D and are used to evaluate potential alternate sources for the pH exceedances originating to the west. Western Wells included in this analysis are installed in the UA [TPZ118D, TPZ118DD, TPZ119D, TPZ119DD, TPZ120D, TPZ123, and TPZ124D] and UCU [TPZ118, TPZ120, and TPZ124], as well as the WAP porewater wells [XTPW01, XTPW02, XTPW03, and XTPW04]. The upgradient background wells G01D and G02D are assessed as the upgradient endmember reflective of groundwater uninfluenced by activity at the JOP site. This selection of Eastern and Western wells provides the best analysis of geochemical conditions and potential sources in the immediate area of G11 and G51D. Potential sources of acidity (which could drive the observed low pH levels at G11 and G51D) are assessed through comprehensive geochemical analysis, including time series analysis, correlation plots (scatterplot comparisons), Principal Components Analysis (PCA), and spatial and chemical distribution of iron.

3.0 GEOCHEMICAL ANALYSIS

3.1 CCR INDICATOR CONSTITUENT BORON

Boron is commonly used as an indicator parameter for contaminant transport of CCR because: (i) it is commonly present at elevated concentrations in coal ash leachate; (ii) it is mobile and typically not very

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

reactive but conservative (i.e., low rates of sorption or degradation) in groundwater; and (iii) it is less likely than other constituents to be present at elevated concentrations in background groundwater from natural or other anthropogenic sources. Boron is often assessed in groundwater to identify possible end-member sources of influence in downgradient areas that could be attributed to CCR. Porewater samples collected from both the EAP and WAP exhibit elevated concentrations of boron, whereas boron concentrations in monitoring wells G11 and G51D are low relative to CCR porewater and most groundwater monitoring wells located both to the east and west (Attachment 3). While boron concentrations suggest no immediate influence from either of the CCR units, it is not otherwise relied upon for distinguishing influence as originating from either the east (i.e., EAP) or west.

3.2 OTHER PERTINENT CHEMICAL TRACERS OF INFLUENCE

Magnesium is not commonly used as a CCR indicator, yet the substantial range in magnesium concentrations observed in groundwater to the west relative to east makes it a particularly useful tracer of influence (Attachment 3). Table 1 presents the range in magnesium measured for several different endmember components assessed for influence in relation to exceedance wells G11 and G51D.

Magnesium concentrations are notably elevated in several of the western groundwater monitoring wells, both within the UA and UCU stratigraphic units. Magnesium concentrations in G11 are similarly elevated when contrasted with groundwater concentrations measured to the east. Concentrations of magnesium at G51D are more similar to background (i.e., overall low). While some Eastern Wells do exhibit magnesium concentrations above background, the range is substantially lower than G11 and the Western Wells overall. The low magnesium concentrations observed in background groundwater, eastern groundwater, and CCR porewater lead in the direction of the western groundwater as a source of high magnesium to, and therefore a dominant influence on, the exceedance wells (G11 in particular).

A strong linear relationship is observed between sulfate and magnesium in groundwater (Attachment 4; Appendix D-1), except TPZ120, which appears as an outlier for the JOP groundwater. The linear relationship between magnesium and sulfate is observed in both western and eastern groundwaters, though the magnitude of measured concentrations in the Western Wells extends beyond that of the Eastern Wells, as discussed in the previous paragraph. Concentrations from monitoring well G11 plot among the Western Wells and are distinctly separate from Eastern Wells. Furthermore, the G11 magnesium-sulfate relationship is similar to Western UCU wells. This data suggests that G11 groundwater chemistry is more similar to western groundwater chemistry than eastern groundwater chemistry. Conditions at G51D are suspected to be under the same influence from the western groundwater chemistry, but are simultaneously influenced from upgradient background groundwater, discussed further in Section 4.0. This mixing of groundwaters produces a lower magnesium concentration in G51D relative to G11.

3.3 MULTIVARIATE DATA ANALYSIS

3.3.1 METHOD

Groundwater chemistry data are by nature multivariate datasets given the high number of parameters observed per sampling location and within a given timeframe. With such a large number of variables, advanced statistical analysis of multivariate groundwater data can provide important insights into spatial,

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

temporal, and chemical relationships influencing constituent distribution and compliance in groundwater. The multivariate technique Principal Component Analysis (PCA) is used to interrogate the groundwater chemistry around the exceedance wells.

PCA is a multivariate technique that reduces dataset dimensionality to its principal, independent components thereby revealing the inner structure of the dataset. Multivariate techniques such as PCA are valuable because they identify variables that are highly dependent on each other but do not inherently provide insights into water origin, type, or evolution. Reducing multivariate data dimensionality reduces redundant information, revealing inner structures in the data that might otherwise be obscured by these dependencies. These structures might include groups of related variables, chemical evolution through time, or spatial locations with similar chemical signatures.

PCA results are most easily viewed on a biplot (such as those provided in Attachment 5), which depicts the sample population plotted on two axes, each representing a principal component. The principal components are created from a linear combination of the original variables in the dataset and variance in the data. For natural compositional datasets, approximately 70% of the population variance can often be expressed in the first three or four principal components (in some cases less and in others, more), each representing decreasing amounts of variance in the data while remaining uncorrelated to previous principal components. The first two principal components often represent the majority of the dataset and are visualized using biplots with the variables expressed as vectors; the location of groups of samples (i.e., factor scores) relative to component vectors provides insight into geochemical relationships among groups of variables and samples.

3.3.2 DATA PREPARATION

When conducting multivariate analysis, it is first necessary to prepare the dataset. Raw chemical data requires preparation prior to analysis because the data often contains values in two forms unsuitable for advanced analytics: 1) measurements reported below a method detection limit (MDL), referred to as censored data, and 2) missing values. For this work, any sample or analyte with a high percentage (≥40%) of missing and/or censored data was assessed for meaningful statistical variance. If overall analyte variance was determined to be low, the analyte was removed, otherwise the data was included in the analysis. Any remaining censored data was converted to half the MDL. Remaining missing values were imputed, a method of assigning an estimated value that accounts for the entire distribution of the material's composition (Sanford et al., 1993) and also takes into consideration the values associated with samples of similar composition. Imputation was done with a nearest neighbor algorithm (Troyanskaya, 2001) and resulting values were checked against the overall data distribution for both the analyte and sample to ensure representative results. Imputed data represents 1.9% or less of the overall dataset in the PCA biplots presented here. Processed data for the PCA are presented in Electronic Attachment 1 and 2.

PCA also requires transformation of the dataset to address the numeric closure problem inherent within chemical compositional datasets (Aitchison, 1986). Numeric closure can often occur in water quality data since water quality concentrations are not completely independent. To address this issue, all data was converted to the same units (mg/L) and the centered-log ratio transformation (CLR; Aitchison 1986; Egozcue et al. 2011) was applied to the cleaned dataset. In practice, closure only significantly affects elements present in large concentrations (e.g., major ions in typical water quality samples), but for consistency the entire dataset (i.e., including trace metals) was CLR-transformed.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

The resulting dataset includes both compliance wells and other monitoring wells and spans sampling events from 2017 through 2023. The dataset contains 18 measured analytes, including the hydrogen ion (H+), which represents acidity in groundwater and is proportional to pH. This data represents both the most recent data measured at JOP as well as the most complete set of regularly measured and detectable analytes. All data preparation was conducted using python programming language. Only total concentrations of major ions and metals were used in this analysis as those data are both relatively complete and consistent across the wells on site and are the parameters of interest for regulatory purposes.

3.3.3 RESULTS

Biplots showing principal components 1 and 2 (PC1 and PC2) are provided in Attachment 5. The PC1 and PC2 are represented on the X and Y axis and explain approximately 30% and 25% of the statistical variance in the water quality dataset, respectively. For each biplot, the first three components explain over 65% variance in the dataset, while the first four explain over 70%. Constituent variables are expressed as vectors. The grouping of samples relative to the component vectors is useful for providing immediate insight into geochemical relationships among groups of variables and samples.

Two iterations of biplots are provided; Attachment 5a depicts all Western and Eastern Wells and porewater locations with sufficient data. Attachment 5b depicts all potential endmember influences on the pH exceedances at G11 and G51D, as represented by background groundwater, EAP porewater, WAP porewater, and hydraulically upgradient groundwater wells (all of which exist to the north and west). Side-gradient western well TPZ120 is also included as it represents a geochemical endmember. While constituent vectors are arranged in a similar orientation across both biplots, biplot 5A which includes the downgradient eastern groundwater contains more noise in the dataset making it difficult to decipher meaningful inter-well trends. This biplot is provided as a reference but is not discussed further. The remaining analysis focuses on biplot 5B which contains hydraulically upgradient wells, background wells, and porewater wells as geochemical endmembers of G11 and G51D (Attachment 5b). This biplot exhibits the following key features:

- Exceedance wells G51D and G11 exhibit a high degree of similarity with the Western Wells screened in the UA.
- Groundwater samples are distributed linearly from the bottom right to the middle of the upper left quadrant, with clear separation between stratigraphic units within the spread of data. Background data plots as an endmember in the lower right quadrant, transitions into UA wells in the lower left quadrant, and continues through the UCU wells in the middle upper left quadrant.
- The EAP and WAP porewaters dominate the upper right quadrant and are distinctly separate from the groundwater samples. There is also a clear separation between EAP and WAP porewaters. The WAP porewater has a strong association with the boron and lithium vectors whereas the EAP porewater is more closely associated with arsenic, potassium, molybdenum, and selenium.
- The WAP UCU monitoring well TPZ120 plots alone in the upper left corner of the plot at the far end of the iron vector, indicating (a) iron is a key contributor to the variance associated with this location and (b) TPZ120 has a distinct chemical composition relative to the other groundwater compositions considered.

The linear spread of groundwater data suggests chemical evolution and/or communication within the aquifer system. The western UCU groundwater composition is dominated by redox sensitive vectors such as manganese, iron, and sulfate. The UA groundwater is observed to undergo a gradual chemical evolution from the UCU redox-sensitive composition endmember back to background conditions, which are dominated by

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

alkalinity, sodium, chloride, and fluoride. The exceedance wells plot among the western UA groundwater, suggesting geochemistry is broadly similar in these wells. Furthermore, the exceedance wells plot in near association with the background groundwater wells, also indicating some multi-variate geochemical similarity to background. This positioning may indicate potential mixing between reduced upgradient groundwaters from the northwest with oxidized background water from the north, discussed further in Section 4.0. Exceedance wells G51D and G11 do not demonstrate association with the EAP porewater composition, supporting the conclusion that the EAP porewater is not a primary influence on the groundwater composition observed at G51D and G11, and is therefore not found to be responsible for the pH exceedances.

4.0 POTENTIAL ALTERNATE SOURCES

This technical review identified the likely source of acidity contributing to the low pH levels at G11 and G51D is dissolved iron in groundwater under reducing conditions and the redox transition that occurs in groundwater immediately upgradient of the G11 and G51D monitoring wells. This is demonstrated in Attachment 6, which includes figures depicting the redox condition at the site. The map included in Attachment 6A (Appendix D-2) demonstrates a distinct redox transition from more reducing conditions in upgradient waters and more oxidizing conditions near the exceedance wells. The reducing upgradient waters are characterized by lower oxidation reduction potential (ORP) and higher iron concentrations, while downgradient waters are largely the opposite with higher ORP and lower iron concentrations. This spatial gradient in redox conditions is also reflected in the Pourbaix diagram for the upgradient western groundwater network (Attachment 6B; Appendix D-3). This diagram demonstrates the predominant iron species and mineral forms under changing pH and Eh conditions (Eh is calculated from field measurements of ORP using the AquaTROLL conversion rate). There is a clear gradient from more reducing conditions in the north and west to more oxidized conditions in G11 and G51D with dissolved iron (Fe^{++}) and iron hydroxide ($Fe(OH)_3$) as the dominant forms of iron. Simultaneously, there is a drop in pH as conditions become more oxidizing.

The source of the dissolved iron and reducing condition could be attributed to three possible upgradient influences existing to the west and north of the two exceedance wells: 1) low pH and relatively high dissolved iron existing in the general area around Western Well TPZ120, 2) the WAP, and 3) the sewage treatment pond. Results of the PCA suggest groundwater monitored in the area of Western Well TPZ120 and the WAP are both potential geochemical endmembers of the chemical evolution observed upgradient and to the west (Attachment 5). Monitoring well TPZ120 has an average iron concentration of 1.2 mg/L (determined from samples with turbidity <10 NTU) and is near enough in proximity to the exceedance wells to suggest cross-gradient flow between these wells may be possible (Attachment 2). The WAP and the sewage treatment pond are both upgradient sources of reduced groundwater, though high turbidity in field samples limits the use of existing iron data for full understanding of transport and speciation of dissolved iron in response to the redox gradient. These three locations represent possible alternate sources of reduced iron to the exceedance wells.

This change in redox condition is the likely source of acidity in G11 and G51D. It is interpreted that dissolved iron is released from the sediments through the process of reductive dissolution by upgradient waters, in response to the reducing conditions (as observed by low ORP). The dissolved iron is transported downgradient with groundwater and subsequently oxidizes and precipitates when it moves into an area with sufficient dissolved oxygen to drive the oxidation reaction.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

The oxidation of dissolved iron to iron hydroxide is known to produce acidity via the following reactions:

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

Acidity is highlighted in red, and the equations demonstrate a net increase in acidity through iron oxidation and precipitation. In this way, reduced upgradient waters from the north and west provides the constituent (i.e., reduced iron) necessary to cause a drop in pH (i.e., through iron oxidation) in G11 and G51D. The oxidized environment near the exceedance wells results from sufficient mixing with the upgradient oxidized background groundwater. This is particularly evident in G51D, which has a more immediate influence of dissolved iron from reduced upgradient wells and has a compositional similarity to background wells (as seen in PCA and magnesium concentrations) resulting in the lowest pH in the JOP EAP groundwater network.

5.0 CONCLUSIONS

This technical review presents evidence that demonstrates the EAP is not the source of pH exceedances at compliance wells G11 and G51D. Results of the geochemical and multivariate analysis (i.e., PCA) demonstrate that groundwater associated with monitoring wells G11 and G51D are more similar to upgradient groundwater to the north and west than the EAP porewater. This analysis was supported by examination of magnesium concentrations and the magnesium-sulfate relationship, both of which indicate G11 and G51D have a chemical signature indicative of western groundwater and background groundwater. The pH exceedances are found to be the result of chemically reduced upgradient waters carrying dissolved iron (released from the aquifer solids through the geochemical process of reductive dissolution) subsequently mixing with oxidized background groundwater in the area of G51D and G11. Further analysis revealed three potential sources of dissolved iron to the north and west of the exceedance locations; however, this investigation did not attempt to identify the primary or singular source of dissolved iron driving the pH exceedances. Upon mixing, the dissolved iron originating from more reducing groundwater subsequently oxidizes and precipitates as iron hydroxide, consequently generating acidity and lowering the groundwater pH in this specific area. The information and analysis presented thus rules out the EAP as the source of the acidity, and therefore pH exceedances, in this area.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

6.0 ABBREVIATIONS

Alk	Total Alkalinity
As	Arsenic
B	Boron
Ca	Calcium
CCR	Coal combustion residual
Cl	Chloride
Co	Cobalt
Cr	Chromium
EAP	East Ash Pond
F	Fluoride
Fe	Iron
H+	Hydrogen ion, represents acidity in groundwater
JOP	Joppa
K	Potassium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
ORP	Oxidation reduction potential
PCA	Principal components analysis
Redox	Oxidation-Reduction
Se	Selenium
SO4	Sulfate
UA	Upper Aquifer
UCU	Upper confining unit
WAP	West Ash Pond

729 Main Street, Longmont, CO 80501 720 550 0745 contact@lifecyclegeo.com www.lifecyclegeo.com

7.0 REFERENCES

Aitchison, J. 1986. The Statistical Analysis of Compositional Data. Chapman and Hall. London

Egozcue J.J. and V. Pawlowsky-Glahn. 2011. Basic concepts and procedures.In: Pawlowsky-Glahn V, Buccianti A, editors. Compositional data analysis: theory and applications. Chichester: Wiley; 2011. pp. 12–28.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. Hydrogeologic Site Characterization Report. East Ash Pond. Joppa Power Plant. Joppa, Illinois.

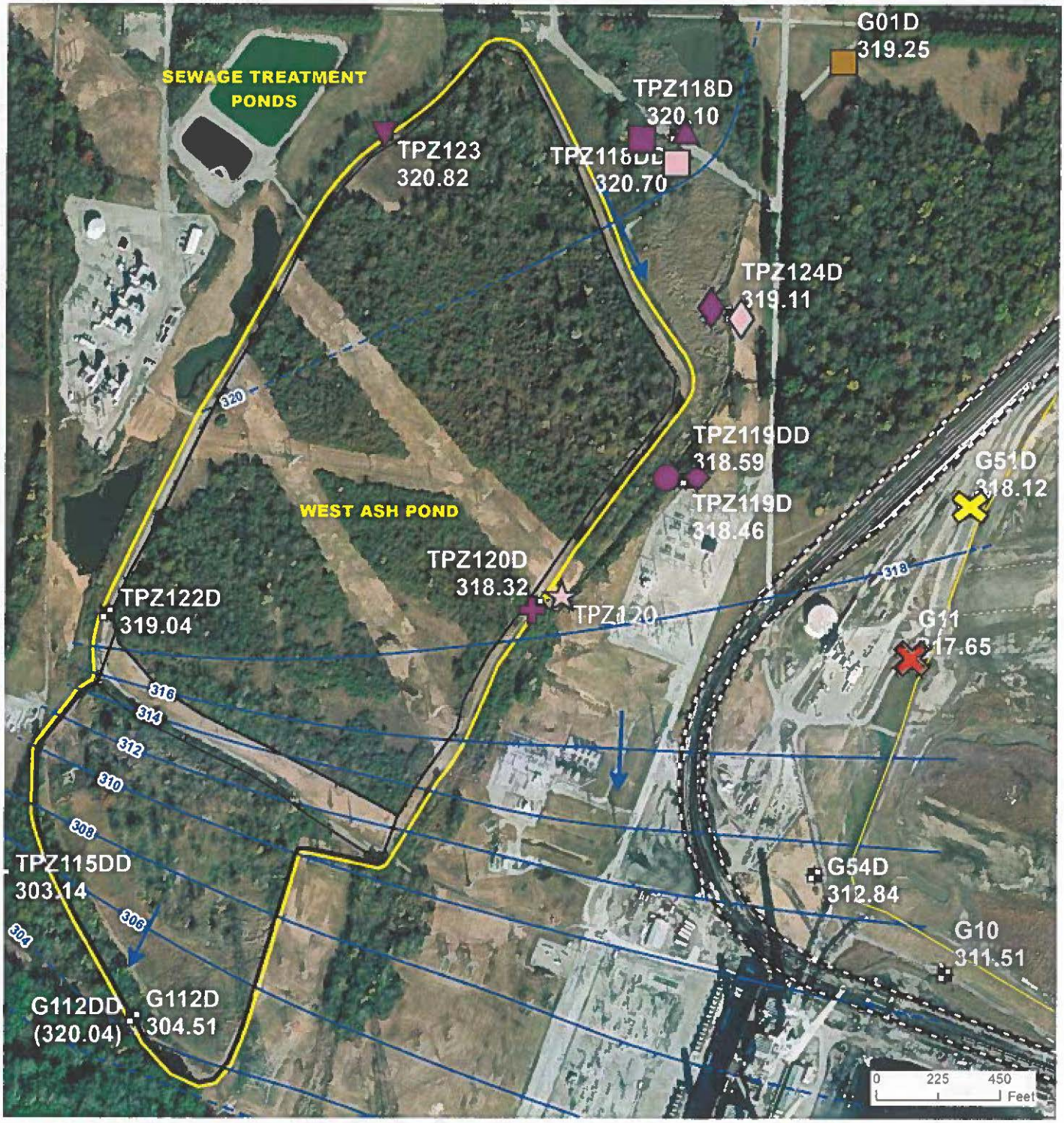
Olga Troyanskaya, Michael Cantor, Gavin Sherlock, Pat Brown, Trevor Hastie, Robert Tibshirani, David Botstein and Russ B. Altman, Missing value estimation methods for DNA microarrays, BIOINFORMATICS Vol. 17 no. 6, 2001 Pages 520-525.

Sanford, R. F., C.T. Pierson, and R.A. Crovelli. 1993. An objective replacement method for censored geochemical data: Math. Geol., 2S(1), p. 59–80.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

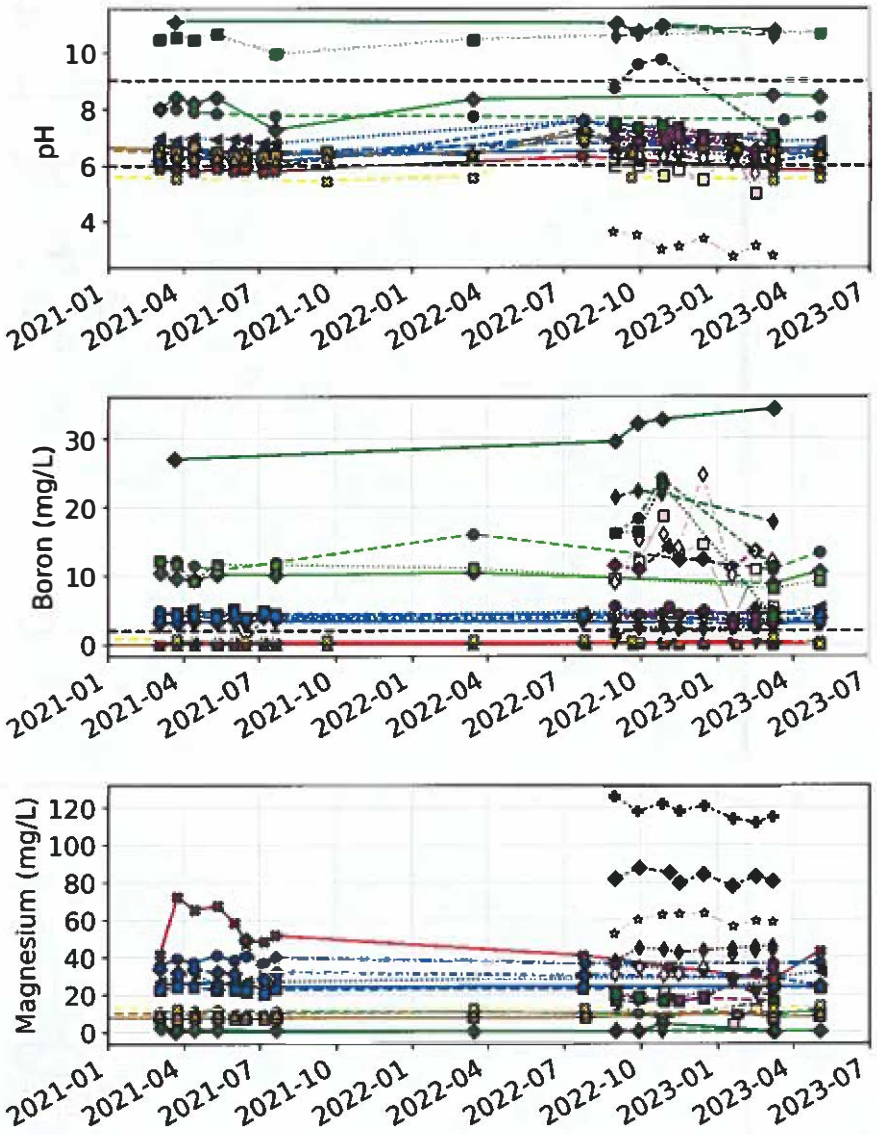
Notes:
Wells with pH exceedances are shown with an X.
East ash pond compliance wells are light blue and monitoring wells are dark blue.
Western monitoring wells are purple (UA) and pink (UCU).
Background wells are brown. Ash ponds are outlined in yellow.
Contours are from March 2023.

LIFECYCLEGEO	Title: Joppa East Ash Pond Well Locations and Hydrology		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 1
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	



Notes:
Wells with pH exceedances are shown with an X.
Western wells are purple (UA) and pink (UCU).
Background wells are brown. Ash ponds are outlined in yellow.
Contours are from September 2022.

LIFECYCLEGEO	Title: Joppa West Ash Pond Well Locations and Upper Aquifer Groundwater Elevation		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 2
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	



Notes:
Data is colored according to well classification.
All data shown is for eastern compliance wells, upgradient western upgradient wells, background, and porewaters

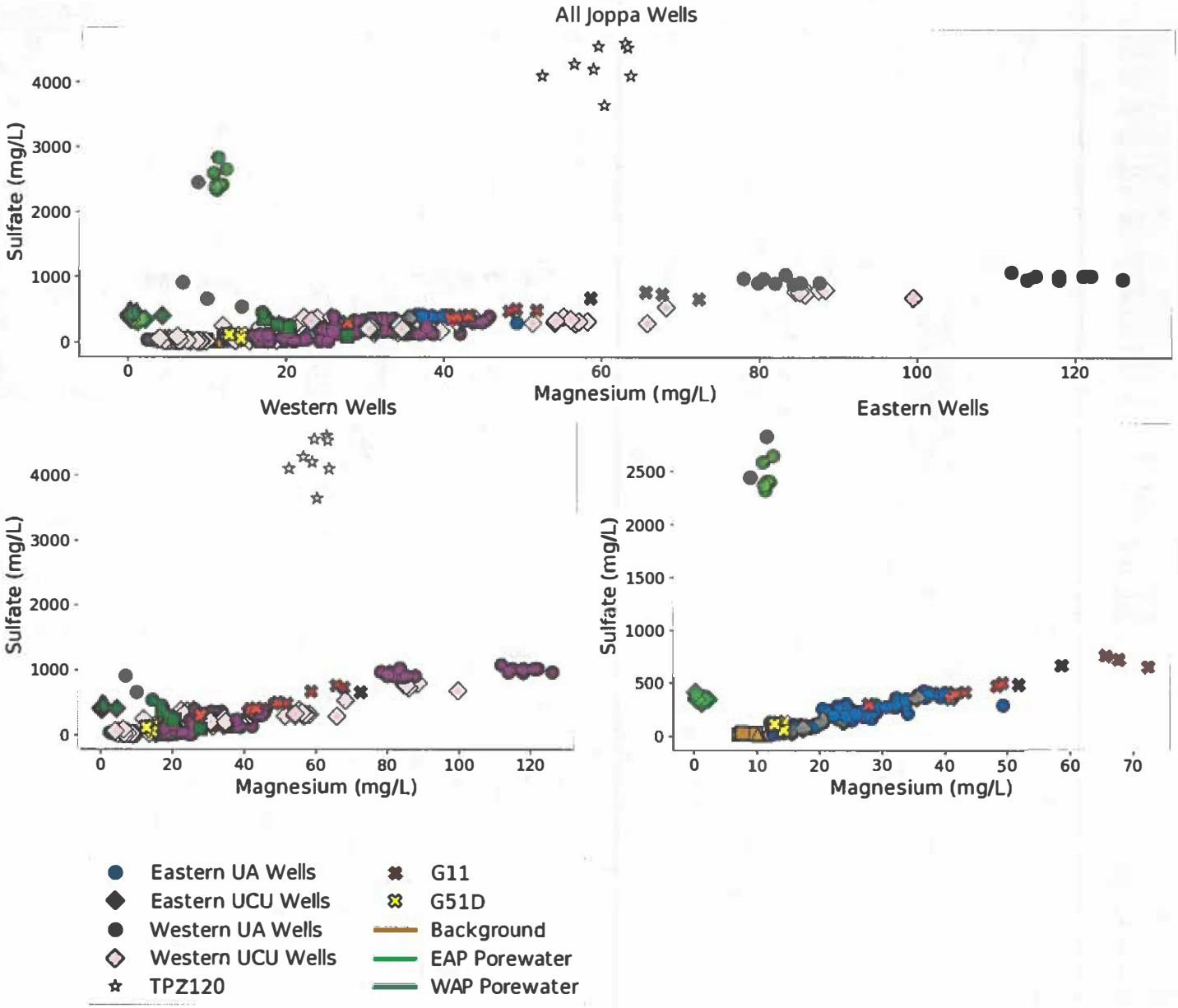
Well ID

G06	TPZ118DD	XTPW01
G07	TPZ119D	XTPW02
G08	TPZ119DD	XTPW03
G09	TPZ120	XTPW04
G10	TPZ120D	G01D
XPW01	TPZ123	G02D
XPW02	TPZ124	G11
XPW03	TPZ124D	G51D
TPZ118		

- Background
- Eastern Compliance Well
- Western UA Well
- Western UCU Well
- EAP Porewater
- WAP Porewater
- GWPS
- Exceedance

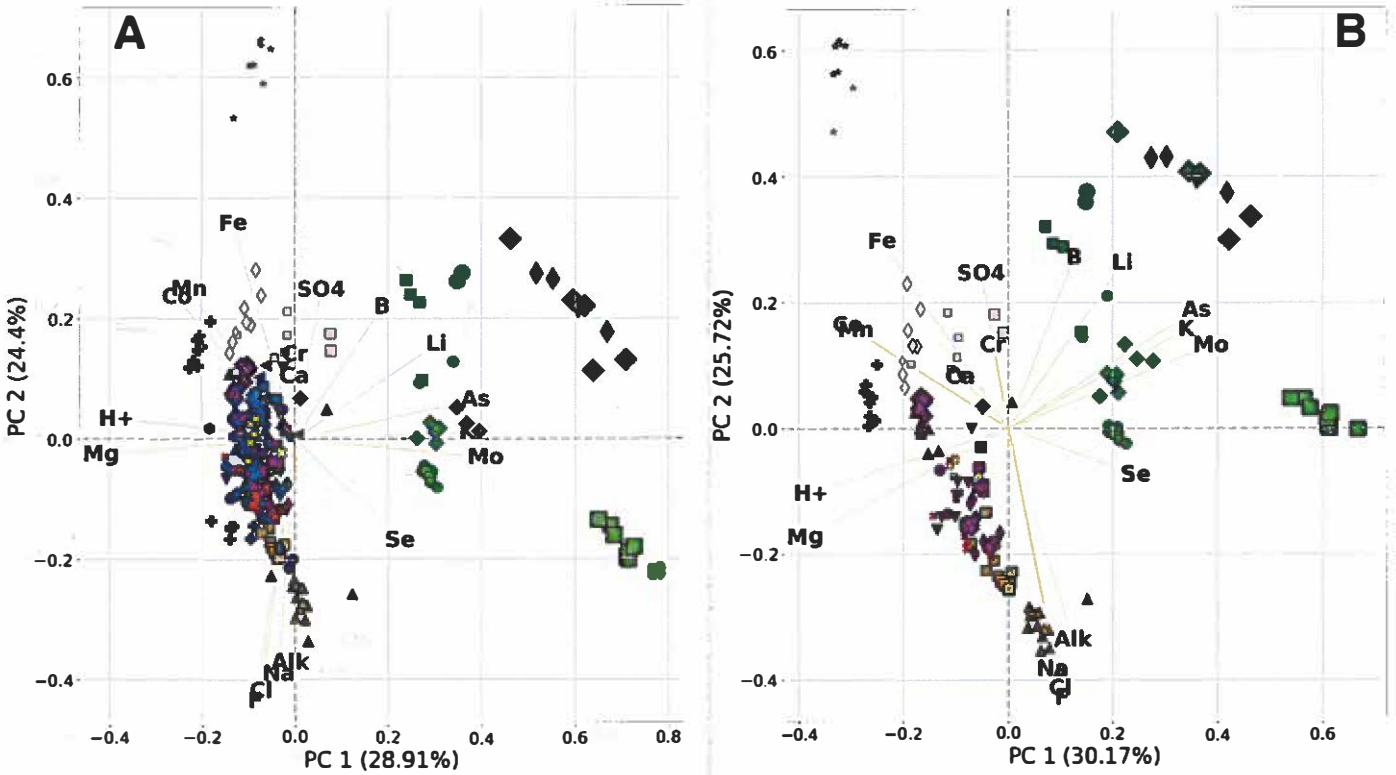
LIFECYCLEGEO

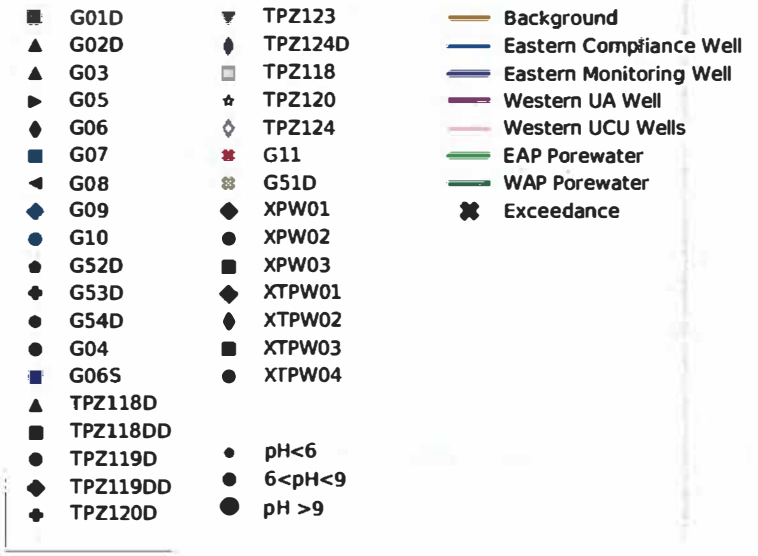
Title: Time Series for pH, Boron, and Magnesium			
Project Name: Joppa- East Ash Pond Evaluation		Project Number: [23RAM01-1] Vistra CCR	Attachment: 3
Client Name: Ramboll Americas Engineering Solutions, Inc.		Date: 10/21/2023	



Scatterplots of magnesium and sulfate for all Joppa wells (top), the western wells (bottom left) and eastern wells (bottom right).

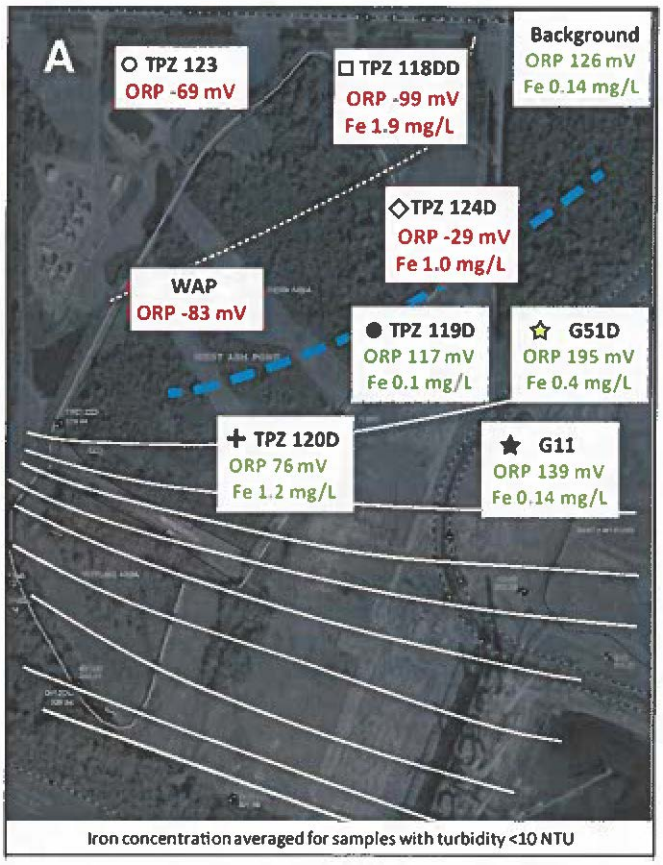
LIFECYCLEGEO	Title: Joppa Magnesium-Sulfate Scatterplot		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 4
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	

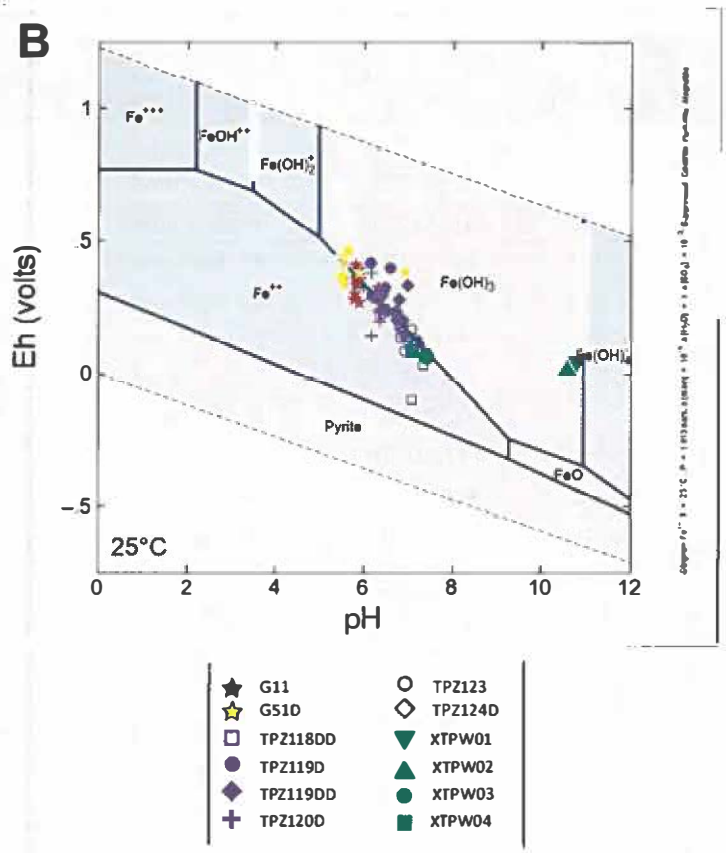




Notes:
Data is colored according to well classification and sized according to pH. See abbreviations list for complete analyte and unit names.
A) PCA with all eastern and western wells, including porewater.
B) PCA with only western wells, background, and porewater.

LIFECYCLEGEO	Title: Joppa Principal Components Analysis Results		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 5
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	





Notes:

A) Redox conditions upgradient of G11 and G51D. White lines are upper aquifer groundwater contours, blue line indicates where conditions change from reducing to oxidizing. Contours from September 2022. Iron concentration not shown where turbidity >10 NTU.

B) Pourbaix diagram depicting iron solubility upgradient of G11 and G51D. WAP porewater is shown in green, western monitoring wells are shown in purple, G11 is red, and G51D is yellow. Blue areas are indicate aqueous phase iron; brown areas indicate solid phase iron.

LIFECYCLEGEO	Title: Joppa Oxidation Reduction Conditions		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 6
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	

LIFECYCLEGEO

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G01D	12/3/2015	Background	6.7	<0.025	--	20
G01D	3/15/2016	Background	6.7	0.036	--	126
G01D	6/15/2016	Background	6.9	0.0296	--	157
G01D	9/14/2016	Background	6.8	0.0416	--	129
G01D	12/14/2016	Background	6.8	<0.025	--	53
G01D	3/7/2017	Background	6.2	<0.025	--	72
G01D	6/15/2017	Background	6.7	<0.025	--	56
G01D	7/20/2017	Background	6.8	<0.025	9.87	31
G01D	11/30/2017	Background	6.8	<0.025	--	117
G01D	6/19/2018	Background	6.8	<0.025	--	70
G01D	9/5/2018	Background	7	<0.025	--	94
G01D	3/27/2019	Background	6.7	<0.025	--	30
G01D	9/9/2019	Background	6.4	<0.025	--	37
G01D	3/30/2020	Background	6.8	<0.025	7.6	35
G01D	9/23/2020	Background	6.72	<0.025	--	34
G02D	7/6/2021	Background	6.17	0.0431	9.77	22
G02D	7/21/2021	Background	6.18	0.0329	10.1	20
G02D	6/1/2021	Background	6.23	0.0433	9.39	23
G02D	4/14/2021	Background	6.3	0.0318	9.39	19
G02D	9/20/2021	Background	6.32	0.0313	--	19
G01D	7/6/2021	Background	6.33	<0.025	7.18	20
G01D	6/1/2021	Background	6.34	<0.025	7.36	18
G01D	5/2/2023	Background	6.34	0.021	8.43	26
G02D	3/24/2021	Background	6.35	0.033	9.76	18
G02D	5/12/2021	Background	6.35	0.0356	10.4	27
G02D	6/14/2021	Background	6.36	0.0352	9.84	23
G01D	7/21/2021	Background	6.37	<0.025	7.54	18
G01D	3/14/2022	Background	6.37	<0.025	7.77	22
G02D	5/3/2023	Background	6.46	0.0412	10.4	13
G01D	6/14/2021	Background	6.46	<0.025	7.41	20
G02D	12/3/2015	Background	6.7	0.0536	--	16
G02D	3/15/2016	Background	6.6	0.0494	--	17
G02D	6/15/2016	Background	6.8	0.0508	--	15
G02D	9/14/2016	Background	6.6	0.0534	--	22
G02D	12/14/2016	Background	6.3	0.0552	--	22
G02D	7/20/2017	Background	6.7	0.044	11.4	12
G02D	11/30/2017	Background	6.9	0.0496	--	17
G02D	6/19/2018	Background	6.7	0.0404	--	17
G02D	9/5/2018	Background	6.6	0.0468	--	19

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G02D	3/27/2019	Background	6.6	0.0473	--	20
G02D	9/9/2019	Background	6.5	0.0429	--	20
G02D	3/30/2020	Background	6.59	0.0449	9.96	22
G02D	9/23/2020	Background	6.62	0.0442	--	22
G02D	3/14/2022	Background	6.47	0.0283	10.6	11
G02D	9/21/2022	Background	6.48	0.0266	--	15
G01D	5/12/2021	Background	6.49	0.0167	7.55	20
G01D	3/24/2021	Background	6.49	<0.025	7.06	21
G02D	3/3/2021	Background	6.5	0.0296	9.98	21
G01D	9/20/2022	Background	6.5	<0.014	--	23
G01D	9/20/2021	Background	6.51	<0.025	--	18
G01D	3/7/2023	Background	6.53	0.029	7.66	36
G02D	3/8/2023	Background	6.56	0.027	10.3	11
G01D	3/3/2021	Background	6.6	<0.025	7.79	18
G01D	1/24/2023	Background	6.62	<0.022	9.75	24
G02D	3/8/2017	Background	6.9	0.0546	--	18
G02D	6/14/2017	Background	6.3	0.0467	--	20
G02D	1/24/2023	Background	6.64	0.0311	10.2	12
G01D	4/14/2021	Background	6.7	<0.025	7.56	39
G01D	7/26/2022	Background	7.17	<0.015	7.74	36
G02D	7/27/2022	Background	7.35	0.0322	10.1	19
G03	3/24/2021	Eastern Compliance	6.3	0.343	17.6	104
G03	4/14/2021	Eastern Compliance	6.2	0.603	28.3	168
G03	5/12/2021	Eastern Compliance	6.39	0.26	15.8	112
G03	6/1/2021	Eastern Compliance	6.35	0.232	14.9	73
G03	7/6/2021	Eastern Compliance	6.34	0.235	14	77
G03	7/21/2021	Eastern Compliance	6.36	0.294	15.7	92
G03	7/26/2022	Eastern Compliance	6.51	0.532	22.9	164
G03	5/3/2023	Eastern Compliance	6.18	0.38	16.6	97
G03	3/5/2021	Eastern Compliance	6.4	0.213	15.1	66
G03	6/15/2021	Eastern Compliance	6.24	0.225	15.1	79
G03	3/9/2023	Eastern Compliance	6.23	0.33	15.2	82
G04	3/24/2021	Eastern Monitoring	6.5	<0.025	14.6	41
G04	7/26/2022	Eastern Monitoring	6.82	<0.0092	34.1	216
G04	3/4/2021	Eastern Monitoring	6.5	<0.025	12.6	21
G04	4/13/2021	Eastern Monitoring	6.5	<0.025	17.3	63
G04	5/11/2021	Eastern Monitoring	6.28	0.0157	17.6	73
G04	7/20/2021	Eastern Monitoring	6.33	<0.025	20.6	131
G05	3/24/2021	Eastern Compliance	6.4	0.195	18.8	92

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G05	6/1/2021	Eastern Compliance	6.48	0.157	18.6	83
G05	7/6/2021	Eastern Compliance	6.42	0.148	17.6	90
G05	7/26/2022	Eastern Compliance	6.63	0.0645	17.6	68
G05	5/3/2023	Eastern Compliance	6.49	0.0478	19.3	112
G05	6/15/2021	Eastern Compliance	6.34	0.14	18.4	91
G05	3/9/2023	Eastern Compliance	6.5	0.0541	19.4	90
G05	3/4/2021	Eastern Compliance	6.5	0.181	17.2	94
G05	4/13/2021	Eastern Compliance	6.5	0.19	19.5	95
G05	5/11/2021	Eastern Compliance	6.38	0.158	19.4	109
G05	7/20/2021	Eastern Compliance	6.35	0.131	18.5	87
G06	3/24/2021	Eastern Compliance	6.6	3.4	26.6	215
G06	6/1/2021	Eastern Compliance	6.56	3.56	25.3	216
G06	7/6/2021	Eastern Compliance	6.32	3.93	23.7	223
G06	5/3/2023	Eastern Compliance	6.63	3.28	24.4	208
G06	6/15/2021	Eastern Compliance	6.51	2.97	25.2	230
G06	3/9/2023	Eastern Compliance	6.57	2.95	24.1	221
G06	3/4/2021	Eastern Compliance	6.7	2.9	25.1	250
G06	4/13/2021	Eastern Compliance	6.6	3.27	26	229
G06	5/11/2021	Eastern Compliance	6.43	3.37	26.8	219
G06	7/20/2021	Eastern Compliance	6.41	3.41	24.4	213
G06	7/23/2022	Eastern Compliance	--	3.29	24.5	216
G06S	3/24/2021	Eastern Monitoring	5.8	0.253	13.5	31
G06S	3/4/2021	Eastern Monitoring	6.2	0.229	12.9	35
G06S	4/13/2021	Eastern Monitoring	5.8	0.265	14.3	30
G06S	5/11/2021	Eastern Monitoring	5.62	0.245	15.6	31
G06S	7/20/2021	Eastern Monitoring	5.73	0.248	13	30
G06S	7/23/2022	Eastern Monitoring	6.54	0.269	13.5	30
G07	3/24/2021	Eastern Compliance	6.4	4.67	24.2	258
G07	6/1/2021	Eastern Compliance	6.25	5.23	22.9	257
G07	7/6/2021	Eastern Compliance	5.98	4.95	20.5	258
G07	5/3/2023	Eastern Compliance	6.38	4.27	23.4	260
G07	6/15/2021	Eastern Compliance	6.25	3.91	21.8	246
G07	3/9/2023	Eastern Compliance	6.42	4.55	24.3	308
G07	3/4/2021	Eastern Compliance	6.5	4.37	22.9	285
G07	4/13/2021	Eastern Compliance	6.3	5.04	24.4	274
G07	5/11/2021	Eastern Compliance	6.28	4.55	22.9	248
G07	7/20/2021	Eastern Compliance	6.14	4.48	23	252
G07	7/23/2022	Eastern Compliance	7.06	4.35	23.2	246
G08	3/24/2021	Eastern Compliance	6.9	4.39	29	225

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G08	6/1/2021	Eastern Compliance	6.96	4.63	27.2	204
G08	7/6/2021	Eastern Compliance	6.81	4.56	26.2	227
G08	5/3/2023	Eastern Compliance	6.88	5.43	32.2	363
G08	6/15/2021	Eastern Compliance	6.94	3.97	27.2	226
G08	3/9/2023	Eastern Compliance	6.85	4.33	28.9	297
G08	3/4/2021	Eastern Compliance	7	4.53	27.2	241
G08	4/13/2021	Eastern Compliance	7	5.25	31.9	286
G08	5/11/2021	Eastern Compliance	6.94	3.77	25.4	203
G08	7/20/2021	Eastern Compliance	6.81	3.98	27.1	227
G08	7/23/2022	Eastern Compliance	7.59	4.74	29	229
G09	4/14/2021	Eastern Compliance	6.3	3.48	33.7	297
G09	5/12/2021	Eastern Compliance	6.45	3.26	32.1	272
G09	6/1/2021	Eastern Compliance	6.24	3.65	31.4	284
G09	7/6/2021	Eastern Compliance	6.29	4.05	28.7	289
G09	7/21/2021	Eastern Compliance	5.99	3.75	32	286
G09	5/3/2023	Eastern Compliance	6.37	3.87	24.7	241
G09	6/15/2021	Eastern Compliance	5.97	0.282	49.3	294
G09	3/9/2023	Eastern Compliance	6.13	3.49	28.9	295
G09	3/4/2021	Eastern Compliance	6.2	3.19	33.8	351
G09	3/25/2021	Eastern Compliance	6.3	3.15	32	286
G09	7/24/2022	Eastern Compliance	7.57	3.89	30.6	278
G10	3/24/2021	Eastern Compliance	6.7	4.31	39.3	369
G10	6/1/2021	Eastern Compliance	6.5	4.73	38.5	401
G10	7/6/2021	Eastern Compliance	6.51	4.81	37.3	415
G10	7/26/2022	Eastern Compliance	6.81	4.4	36.6	388
G10	3/8/2023	Eastern Compliance	6.55	3.28	36.6	425
G10	5/3/2023	Eastern Compliance	6.6	3.08	36.9	365
G10	6/15/2021	Eastern Compliance	6.46	3.74	40.8	407
G10	3/4/2021	Eastern Compliance	6.7	4.98	35.7	391
G10	4/13/2021	Eastern Compliance	6.6	4.26	37.2	382
G10	5/11/2021	Eastern Compliance	6.34	3.95	41.1	364
G10	7/20/2021	Eastern Compliance	6.49	4.2	40	410
G11	3/8/2023	Exceedance	5.87	0.327	27.8	303
G11	7/23/2022	Exceedance	6.33	0.31	40.9	352
G11	3/4/2021	Exceedance	5.9	0.247	41.6	400
G11	5/3/2023	Exceedance	5.82	0.373	43.2	416
G11	7/6/2021	Exceedance	5.78	0.358	48.3	474
G11	7/20/2021	Exceedance	5.82	0.302	51.8	487
G11	6/14/2021	Exceedance	5.86	0.266	49.2	505

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G11	3/24/2021	Exceedance	5.9	0.42	72.4	658
G11	6/1/2021	Exceedance	5.82	0.309	58.6	671
G11	5/12/2021	Exceedance	5.9	0.321	67.7	730
G11	4/14/2021	Exceedance	5.8	0.411	65.6	761
G51D	12/3/2015	Exceedance	6.2	0.117	--	117
G51D	3/15/2016	Exceedance	5.9	0.184	--	145
G51D	6/15/2016	Exceedance	5.8	0.213	--	139
G51D	9/14/2016	Exceedance	5.6	0.263	--	136
G51D	12/14/2016	Exceedance	5.9	0.171	--	101
G51D	6/15/2017	Exceedance	5.6	0.58	--	149
G51D	7/20/2017	Exceedance	5.9	0.332	14.4	140
G51D	11/30/2017	Exceedance	5.6	0.302	--	138
G51D	6/19/2018	Exceedance	5.7	0.337	--	124
G51D	9/5/2018	Exceedance	6	0.263	--	134
G51D	3/27/2019	Exceedance	5.7	0.778	--	125
G51D	9/9/2019	Exceedance	5.3	0.501	--	109
G51D	3/30/2020	Exceedance	5.62	0.697	13.4	130
G51D	9/23/2020	Exceedance	5.72	0.863	--	121
G51D	9/20/2021	Exceedance	5.46	0.689	--	131
G51D	3/8/2023	Exceedance	5.49	0.963	12.3	131
G51D	3/24/2021	Exceedance	5.56	0.786	12.5	122
G51D	3/8/2017	Exceedance	6.2	0.309	--	146
G51D	5/3/2023	Exceedance	5.57	0.0297	14.3	59
G51D	3/15/2022	Exceedance	5.57	0.689	12.9	123
G51D	9/20/2022	Exceedance	5.58	0.551	--	125
G51D	7/25/2022	Exceedance	6.92	0.663	12.8	116
G52D	12/3/2015	Eastern Compliance	6.5	<0.025	--	65
G52D	3/15/2016	Eastern Compliance	6.3	<0.025	--	99
G52D	6/15/2016	Eastern Compliance	6.6	<0.025	--	88
G52D	9/14/2016	Eastern Compliance	6.4	<0.025	--	84
G52D	12/14/2016	Eastern Compliance	6.7	<0.025	--	82
G52D	3/7/2017	Eastern Compliance	5.9	<0.025	--	115
G52D	11/30/2017	Eastern Compliance	6	<0.025	--	97
G52D	6/19/2018	Eastern Compliance	6.4	<0.025	--	97
G52D	9/5/2018	Eastern Compliance	6.3	<0.025	--	101
G52D	3/27/2019	Eastern Compliance	6.4	<0.025	--	81
G52D	9/9/2019	Eastern Compliance	6	<0.025	--	78
G52D	3/30/2020	Eastern Compliance	6.38	<0.025	15.3	84
G52D	9/23/2020	Eastern Compliance	6.54	<0.025	--	84

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field), (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G52D	9/20/2021	Eastern Compliance	6.29	<0.025	--	83
G52D	6/14/2017	Eastern Compliance	6.2	<0.025	--	112
G52D	9/21/2022	Eastern Compliance	6.26	<0.011	--	72
G52D	5/3/2023	Eastern Compliance	6.31	0.682	12.1	129
G52D	3/25/2021	Eastern Compliance	6.25	<0.025	14.6	75
G52D	3/15/2022	Eastern Compliance	6.22	<0.025	15.1	68
G52D	3/10/2023	Eastern Compliance	6.54	0.0319	15.3	74
G52D	7/19/2017	Eastern Compliance	6.4	<0.025	17	108
G53D	12/3/2015	Eastern Compliance	6.8	0.332	--	103
G53D	3/15/2016	Eastern Compliance	6.7	0.334	--	107
G53D	6/15/2016	Eastern Compliance	6.6	0.342	--	107
G53D	9/14/2016	Eastern Compliance	6.5	0.368	--	104
G53D	12/14/2016	Eastern Compliance	6.8	0.364	--	106
G53D	6/15/2017	Eastern Compliance	6.6	0.309	--	79
G53D	7/20/2017	Eastern Compliance	6.8	0.366	19.2	94
G53D	11/30/2017	Eastern Compliance	6.6	0.427	--	98
G53D	6/19/2018	Eastern Compliance	6.6	0.361	--	84
G53D	9/5/2018	Eastern Compliance	6.8	0.392	--	81
G53D	3/27/2019	Eastern Compliance	6.6	0.269	--	54
G53D	9/9/2019	Eastern Compliance	6.2	0.385	--	80
G53D	3/30/2020	Eastern Compliance	6.7	0.334	15.7	66
G53D	9/23/2020	Eastern Compliance	6.67	0.411	--	79
G53D	9/20/2021	Eastern Compliance	6.27	0.402	--	78
G53D	9/20/2022	Eastern Compliance	6.48	0.431	--	79
G53D	3/8/2017	Eastern Compliance	7.2	0.138	--	35
G53D	5/3/2023	Eastern Compliance	6.48	0.367	15.3	68
G53D	3/9/2023	Eastern Compliance	6.46	0.37	16.4	72
G53D	3/25/2021	Eastern Compliance	6.53	0.355	15.7	71
G53D	7/25/2022	Eastern Compliance	7.88	0.341	17	77
G53D	3/15/2022	Eastern Compliance	6.5	0.332	16.5	74
G54D	12/3/2015	Eastern Compliance	7	0.663	--	191
G54D	3/15/2016	Eastern Compliance	6.8	0.513	--	176
G54D	6/15/2016	Eastern Compliance	6.6	0.508	--	160
G54D	9/14/2016	Eastern Compliance	6.6	0.557	--	149
G54D	12/14/2016	Eastern Compliance	6.7	0.564	--	144
G54D	6/15/2017	Eastern Compliance	6.8	0.685	--	170
G54D	7/20/2017	Eastern Compliance	6.8	0.58	25.2	151
G54D	11/30/2017	Eastern Compliance	6.7	0.646	--	136
G54D	6/19/2018	Eastern Compliance	6.7	0.631	--	146

LIFECYCLEGEO

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G54D	9/5/2018	Eastern Compliance	6.5	0.66	--	152
G54D	3/27/2019	Eastern Compliance	6.8	1.03	--	142
G54D	9/9/2019	Eastern Compliance	6.4	0.614	--	136
G54D	3/30/2020	Eastern Compliance	6.78	0.766	27.1	184
G54D	9/23/2020	Eastern Compliance	6.7	0.819	--	173
G54D	3/24/2021	Eastern Compliance	6.56	0.404	24.2	186
G54D	9/20/2021	Eastern Compliance	6.48	0.35	--	175
G54D	7/26/2022	Eastern Compliance	7.09	0.178	22.3	188
G54D	9/20/2022	Eastern Compliance	6.5	0.252	--	218
G54D	3/8/2017	Eastern Compliance	7.1	0.499	--	131
G54D	5/3/2023	Eastern Compliance	6.8	0.555	26.4	194
G54D	3/9/2023	Eastern Compliance	6.52	0.555	26.4	231
G54D	3/15/2022	Eastern Compliance	6.61	0.451	25.8	213
G101	7/26/2022	Other	7.31	<0.0092	5.09	30
G101	3/7/2023	Other	6.58	0.0294	5.4	28
G101	3/22/2021	Other	6.99	<0.02	7.65	39
G101	8/31/2022	Other	6.64	<0.0092	5.88	37
G101	9/28/2022	Other	6.49	<0.019	5.77	30
G101	10/26/2022	Other	6.9	0.0366	5.21	56
G101	11/15/2022	Other	6.85	<0.0092	5.51	37
G101	12/14/2022	Other	6.63	<0.0092	5.19	37
G101	1/18/2023	Other	6.58	<0.0092	5.01	32
G101	2/14/2023	Other	6.24	<0.0092	5.29	41
G101	12/14/2016	Other	6.7	<0.025	--	35
G101	3/7/2017	Other	6	<0.025	--	37
G101	11/30/2017	Other	6.6	<0.025	--	35
G101	6/19/2018	Other	6.7	<0.025	--	49
G101	3/27/2019	Other	6.7	<0.025	--	46
G101	9/9/2019	Other	6.3	<0.025	--	35
G101	3/30/2020	Other	6.76	<0.025	3.79	41
G101	9/23/2020	Other	6.51	<0.025	--	37
G101	9/20/2021	Other	6.4	<0.025	--	36
G101	3/14/2022	Other	6.48	<0.025	4.34	38
G101	9/20/2022	Other	6.58	<0.0092	--	38
G101	6/14/2017	Other	6.4	<0.025	--	51
G101	3/25/2021	Other	6.51	<0.025	4.36	37
G101	7/19/2017	Other	6.7	<0.025	4.68	52
G101	12/22/2015	Other	6.5	<0.025	--	33
G101	3/16/2016	Other	6.6	<0.025	--	86

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G101	6/14/2016	Other	6.3	<0.025	--	53
G101	9/13/2016	Other	6.4	<0.025	--	47
G101	12/6/2018	Other	6.7	<0.025	--	54
G101	3/21/2023	Other	6.59	0.0525	13.2	49
G102	3/7/2017	Other	5.8	<0.025	--	22
G102	11/30/2017	Other	6.3	<0.025	--	20
G102	6/19/2018	Other	6.5	<0.025	--	50
G102	3/27/2019	Other	6.5	<0.025	--	44
G102	9/9/2019	Other	6.1	<0.025	--	34
G102	3/30/2020	Other	6.48	<0.025	2.5	38
G102	9/23/2020	Other	6.24	<0.025	--	34
G102	9/20/2021	Other	6.38	<0.025	--	38
G102	3/14/2022	Other	6.37	<0.025	3.21	30
G102	9/20/2022	Other	6.44	<0.0092	--	41
G102	6/14/2017	Other	6.1	<0.025	--	27
G102	3/25/2021	Other	6.46	<0.025	2.64	35
G102	3/10/2023	Other	6.31	<0.02	3.6	40
G102	7/19/2017	Other	6.4	<0.025	3.3	28
G102	12/22/2015	Other	6.9	<0.025	--	15
G102	3/16/2016	Other	6.4	<0.025	--	58
G102	6/14/2016	Other	6.1	<0.025	--	65
G102	9/13/2016	Other	5.8	<0.025	--	49
G102	12/6/2018	Other	6.4	<0.025	--	28
G102	12/15/2016	Other	6.2	<0.025	--	24
G103	12/23/2015	Other	7.25	--	--	--
G104	6/23/2014	Other	6.8	<0.02	--	<50.0
G104	9/9/2014	Other	6.89	<0.02	--	<50.0
G104	12/9/2014	Other	6.9	0.0837	--	<50.0
G104	3/20/2015	Other	6.29	<0.02	--	--
G105	3/7/2017	Other	5.7	<0.025	--	12
G105	11/30/2017	Other	6.3	<0.025	--	12
G105	6/19/2018	Other	6.3	<0.025	--	12
G105	3/27/2019	Other	6.3	<0.025	--	11
G105	9/9/2019	Other	6.1	<0.025	--	12
G105	3/30/2020	Other	6.32	<0.025	9.11	13
G105	9/23/2020	Other	6.22	<0.025	--	16
G105	9/20/2021	Other	6.06	<0.025	--	13
G105	3/14/2022	Other	6.18	<0.025	8.95	12
G105	9/20/2022	Other	6.14	<0.0092	--	11

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G105	6/14/2017	Other	6.1	<0.025	--	16
G105	3/25/2021	Other	6.13	<0.025	8.53	12
G105	3/10/2023	Other	6.03	<0.011	8.78	12
G105	7/19/2017	Other	6.4	<0.025	8.8	13
G105	12/22/2015	Other	6.6	<0.025	--	12
G105	3/16/2016	Other	6.4	<0.025	--	11
G105	6/14/2016	Other	6.4	<0.025	--	12
G105	9/13/2016	Other	6.4	<0.025	--	13
G105	12/6/2018	Other	6.2	<0.025	--	11
G105	12/15/2016	Other	6.2	<0.025	--	11
G106	12/23/2015	Other	6.34	--	--	--
G107	3/7/2017	Other	6.1	<0.025	--	93
G107	11/30/2017	Other	6.5	0.0295	--	88
G107	6/19/2018	Other	6.6	<0.025	--	77
G107	3/27/2019	Other	6.4	<0.025	--	30
G107	9/9/2019	Other	6.5	0.0373	--	112
G107	3/30/2020	Other	6.68	<0.025	24.8	89
G107	9/23/2020	Other	6.73	0.0353	--	101
G107	9/20/2021	Other	6.64	0.0282	--	67
G107	3/14/2022	Other	6.42	<0.025	21.3	40
G107	9/20/2022	Other	6.59	<0.023	--	49
G107	6/14/2017	Other	6.4	<0.025	--	50
G107	3/25/2021	Other	6.48	0.0291	19.5	54
G107	3/10/2023	Other	6.42	<0.023	20.6	42
G107	7/19/2017	Other	6.8	<0.025	26.7	123
G107	12/22/2015	Other	6.9	0.0365	--	29
G107	3/16/2016	Other	6.3	<0.025	--	11
G107	6/14/2016	Other	6.9	0.0311	--	58
G107	9/13/2016	Other	6.7	<0.025	--	127
G107	12/6/2018	Other	6.6	0.027	--	72
G107	12/15/2016	Other	6.6	<0.025	--	67
G108	12/23/2015	Other	7.04	--	--	--
G109	3/7/2017	Other	6	<0.025	--	37
G109	11/30/2017	Other	6.5	<0.025	--	48
G109	6/19/2018	Other	6.9	0.0277	--	100
G109	9/5/2018	Other	7	--	--	77
G109	3/27/2019	Other	6.7	0.0309	--	55
G109	9/9/2019	Other	6.5	0.0255	--	59
G109	3/30/2020	Other	6.76	0.0272	8.21	41

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G109	9/23/2020	Other	6.6	<0.025	--	42
G109	9/20/2021	Other	6.54	<0.025	--	27
G109	3/14/2022	Other	6.55	<0.025	7.91	30
G109	9/20/2022	Other	6.49	<0.014	--	21
G109	6/14/2017	Other	6.5	<0.025	--	68
G109	3/25/2021	Other	6.35	<0.025	6.16	32
G109	3/10/2023	Other	6.32	<0.018	7.7	37
G109	7/19/2017	Other	6.7	<0.025	7.34	65
G109	12/22/2015	Other	6.7	0.0315	--	23
G109	3/16/2016	Other	6.5	<0.025	--	22
G109	6/14/2016	Other	6.4	<0.025	--	29
G109	9/13/2016	Other	6.5	<0.025	--	41
G109	12/6/2018	Other	6.7	<0.025	--	68
G109	12/15/2016	Other	6.5	<0.025	--	33
G110	12/23/2015	Other	6.87	--	--	--
G111	3/7/2023	Other	7.05	<0.0092	8.94	16
G111	3/22/2021	Other	7.34	<0.02	9.48	17
G111	1/18/2023	Other	6.88	<0.0092	8.76	14
G111	9/1/2022	Other	7.02	0.0873	9.92	16
G111	9/27/2022	Other	7.03	0.0341	9	14
G111	10/28/2022	Other	6.9	0.0389	9.32	13
G111	11/16/2022	Other	7.11	<0.0092	8.67	16
G111	12/15/2022	Other	6.89	<0.0092	8.89	15
G111	2/15/2023	Other	6.48	<0.0092	9.14	16
G111	3/7/2017	Other	6.2	0.0308	--	29
G111	11/30/2017	Other	6.7	<0.025	--	<10.0
G111	6/19/2018	Other	6.8	<0.025	--	40
G111	3/27/2019	Other	6.8	0.0256	--	46
G111	9/9/2019	Other	5.9	0.0258	--	33
G111	3/30/2020	Other	6.68	0.03	7.49	44
G111	9/23/2020	Other	6.63	<0.025	--	31
G111	9/20/2021	Other	6.51	<0.025	--	21
G111	3/14/2022	Other	6.49	<0.025	6.03	29
G111	9/20/2022	Other	6.53	<0.013	--	19
G111	6/14/2017	Other	6.6	<0.025	--	37
G111	3/25/2021	Other	6.4	<0.025	6.06	33
G111	7/19/2017	Other	6.8	<0.025	5.97	29
G111	12/22/2015	Other	6.5	<0.025	--	27
G111	3/16/2016	Other	6.5	<0.025	--	37

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G111	6/14/2016	Other	6.7	0.0265	--	39
G111	9/13/2016	Other	6.8	0.0251	--	23
G111	12/6/2018	Other	6.5	0.0404	--	32
G111	3/21/2023	Other	6.56	0.047	4.71	23
G111	12/15/2016	Other	6.8	<0.025	--	13
G112C	3/8/2023	Other	6.41	4.8	85.6	822
G112C	3/22/2021	Other	6.85	4.25	68.2	532
G112C	9/28/2022	Other	6.31	4.82	99.5	682
G112C	10/26/2022	Other	6.69	4.86	84.7	820
G112C	12/14/2022	Other	6.63	4.99	87.5	791
G112C	1/18/2023	Other	6.49	4.31	84.6	769
G112C	2/15/2023	Other	6.26	5.04	88.4	797
G112C	8/30/2022	Other	6.62	4.26	85.8	726
G112C	11/17/2022	Other	6.76	4.6	85.1	764
G112D	3/8/2023	Other	6.62	0.0464	24.3	13
G112D	9/28/2022	Other	6.8	0.101	26	<8.0
G112D	10/26/2022	Other	6.97	0.0457	24.3	<8.0
G112D	12/14/2022	Other	6.81	<0.0092	24.7	<6.0
G112D	1/18/2023	Other	6.71	0.0268	24.3	11
G112D	2/15/2023	Other	6.49	<0.0092	25.4	13
G112D	8/30/2022	Other	6.89	0.0367	24.8	<9.0
G112D	11/17/2022	Other	6.95	<0.012	24	<8.0
G112DD	3/8/2023	Other	7.03	0.104	17.7	10
G112DD	9/28/2022	Other	7.24	0.162	21	12
G112DD	10/26/2022	Other	7.42	0.12	18.6	13
G112DD	12/14/2022	Other	8.06	0.116	18.3	10
G112DD	8/30/2022	Other	7.31	0.109	19.9	12
G112DD	11/17/2022	Other	7.41	0.135	17.5	11
G113	3/7/2023	Other	6.53	<0.013	55.2	386
G113	3/22/2021	Other	6.86	<0.02	51.3	292
G113	9/28/2022	Other	6.36	0.0258	65.8	289
G113	10/26/2022	Other	6.57	0.0919	56.7	288
G113	9/1/2022	Other	6.6	<0.022	58.2	316
G113	11/16/2022	Other	6.58	<0.014	54.1	296
G113	12/15/2022	Other	6.38	<0.0092	57.1	314
G113	2/15/2023	Other	6.21	<0.0092	56.1	346
G113	1/19/2023	Other	6.32	<0.0092	54.2	327
TPZ114	3/10/2023	Other	6.15	<0.024	6.82	20
TPZ114	3/22/2021	Other	7.42	0.177	15.4	19

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ114	9/1/2022	Other	6.32	0.0746	7.86	13
TPZ114	9/27/2022	Other	6.02	0.0451	7.95	19
TPZ114	11/16/2022	Other	6.51	0.0269	8.71	21
TPZ114	12/15/2022	Other	6.22	<0.0092	7.5	24
TPZ114	2/15/2023	Other	6.09	0.0254	6.36	24
TPZ114	1/19/2023	Other	6.26	<0.0092	6.42	19
TPZ114	10/27/2022	Other	6.21	0.0251	6.52	21
TPZ115	3/8/2023	Other	6.96	<0.015	38.4	197
TPZ115	1/18/2023	Other	6.93	<0.0092	36.6	178
TPZ115	9/27/2022	Other	6.91	0.0383	34.2	147
TPZ115	12/15/2022	Other	6.87	<0.0092	38.1	180
TPZ115	2/15/2023	Other	6.68	<0.0092	37.6	179
TPZ115	8/30/2022	Other	7.12	0.0354	31.2	135
TPZ115	11/17/2022	Other	7.16	<0.013	35.5	181
TPZ115	10/27/2022	Other	6.93	0.0267	39.6	170
TPZ115D	3/8/2023	Other	7.11	0.356	21.8	37
TPZ115D	1/18/2023	Other	7.13	0.349	20.8	37
TPZ115D	9/27/2022	Other	7.24	0.467	22.5	35
TPZ115D	12/15/2022	Other	7.1	0.387	22.4	39
TPZ115D	2/15/2023	Other	6.79	0.4	22.3	37
TPZ115D	8/30/2022	Other	7.13	0.382	21.9	38
TPZ115D	11/17/2022	Other	7.37	0.387	20.9	37
TPZ115D	10/27/2022	Other	7.13	0.421	22.6	36
TPZ115DD	3/8/2023	Other	7.18	0.0915	17	13
TPZ115DD	9/27/2022	Other	7.34	0.0563	17.6	11
TPZ115DD	12/15/2022	Other	7.2	0.0657	19.2	12
TPZ115DD	8/30/2022	Other	7.36	0.0423	17.7	<8.0
TPZ115DD	11/17/2022	Other	7.36	0.0684	16.4	11
TPZ115DD	10/27/2022	Other	7.24	0.0847	18.3	11
TPZ116	3/22/2021	Other	6.99	<0.02	13.6	24
TPZ117	3/22/2021	Other	6.67	<0.02	18.8	32
TPZ117D	3/7/2023	Other	6.54	0.724	29.3	228
TPZ117D	7/27/2022	Other	7.56	0.409	36.3	134
TPZ117D	3/22/2021	Other	7.09	0.0763	19.3	187
TPZ117D	11/15/2022	Other	6.7	0.36	35.6	133
TPZ117D	12/14/2022	Other	6.53	0.353	37	127
TPZ117D	1/18/2023	Other	6.48	0.495	29.8	186
TPZ117D	9/1/2022	Other	6.62	0.41	38.7	124
TPZ117D	2/15/2023	Other	6.29	0.331	35.1	126

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ117D	9/29/2022	Other	6.57	0.394	42.1	130
TPZ117D	11/4/2022	Other	6.69	0.423	35.2	135
TPZ118	3/8/2023	Western UCU	6.56	5.44	6.3	88
TPZ118	8/31/2022	Western UCU	5.97	9.54	21.6	242
TPZ118	11/15/2022	Western UCU	5.84	13.1	16.7	233
TPZ118	12/14/2022	Western UCU	5.52	14.6	19.1	263
TPZ118	10/28/2022	Western UCU	5.65	18.7	21.1	259
TPZ118	2/15/2023	Western UCU	5.04	10.9	12	250
TPZ118	1/19/2023	Western UCU	6.41	3.35	4.04	63
TPZ118	9/29/2022	Western UCU	5.99	12.1	18.6	215
TPZ118D	3/8/2023	Western UA	6.28	7.44	30.7	358
TPZ118D	8/31/2022	Western UA	6.3	5.41	32.7	351
TPZ118D	11/15/2022	Western UA	6.55	6.13	29.8	332
TPZ118D	12/14/2022	Western UA	6.6	5.85	27.1	300
TPZ118D	10/28/2022	Western UA	6.35	7.08	31.3	352
TPZ118D	2/15/2023	Western UA	6.07	7.56	30.8	329
TPZ118D	1/19/2023	Western UA	6.31	6.35	28.7	329
TPZ118D	9/29/2022	Western UA	6.17	5.74	33.6	357
TPZ118DD	3/8/2023	Western UA	7.09	0.0776	16.8	10
TPZ118DD	8/31/2022	Western UA	7.4	0.831	19.5	73
TPZ118DD	11/15/2022	Western UA	7.34	0.054	16.4	12
TPZ118DD	12/14/2022	Western UA	7.08	0.122	17.9	12
TPZ118DD	10/28/2022	Western UA	7.26	0.112	16.5	10
TPZ118DD	9/29/2022	Western UA	6.84	0.146	17.9	17
TPZ119D	3/7/2023	Western UA	6.34	4.76	33.7	175
TPZ119D	8/31/2022	Western UA	6.49	5.58	35.5	192
TPZ119D	12/14/2022	Western UA	6.44	4.59	33.6	156
TPZ119D	1/18/2023	Western UA	6.35	3.32	29	142
TPZ119D	11/16/2022	Western UA	6.48	4.35	32.4	159
TPZ119D	2/15/2023	Western UA	6.16	4.22	31.2	154
TPZ119D	9/29/2022	Western UA	6.19	4.37	35	186
TPZ119D	11/4/2022	Western UA	6.61	5.48	33.7	156
TPZ119DD	3/7/2023	Western UA	6.76	11.8	80.5	969
TPZ119DD	8/31/2022	Western UA	6.9	11.5	82	899
TPZ119DD	12/14/2022	Western UA	6.81	12.4	84.3	886
TPZ119DD	1/18/2023	Western UA	6.74	11.1	78	972
TPZ119DD	11/16/2022	Western UA	6.94	12.3	79.8	906
TPZ119DD	2/15/2023	Western UA	6.54	13.6	83.3	1030
TPZ119DD	9/29/2022	Western UA	6.88	10.9	87.6	907

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ119DD	11/4/2022	Western UA	7	14.2	85.2	906
TPZ120	3/7/2023	Western UCU	2.8	2.36	58.8	4200
TPZ120	10/26/2022	Western UCU	3.02	3.13	62.8	4600
TPZ120	9/27/2022	Western UCU	3.53	2.53	60.2	3650
TPZ120	11/16/2022	Western UCU	3.13	2.21	63.1	4530
TPZ120	12/15/2022	Western UCU	3.4	3.55	63.5	4100
TPZ120	2/15/2023	Western UCU	3.14	2.1	59.4	4550
TPZ120	8/30/2022	Western UCU	3.63	2.08	52.4	4100
TPZ120	1/19/2023	Western UCU	2.77	2.1	56.4	4280
TPZ120D	3/7/2023	Western UA	6.2	4.77	115	1020
TPZ120D	10/26/2022	Western UA	6.35	4.51	122	1020
TPZ120D	9/27/2022	Western UA	6.37	4.14	118	960
TPZ120D	11/16/2022	Western UA	6.37	4.39	118	1020
TPZ120D	12/15/2022	Western UA	6.16	5.09	121	1020
TPZ120D	2/15/2023	Western UA	6.01	5.31	112	1080
TPZ120D	8/30/2022	Western UA	6.18	3.52	126	967
TPZ120D	1/19/2023	Western UA	6.17	3.9	114	964
TPZ122	3/7/2023	Other	6.77	5.15	27	214
TPZ122	8/31/2022	Other	6.52	0.806	19.7	234
TPZ122	1/18/2023	Other	6.12	1.17	22.3	379
TPZ122	9/27/2022	Other	6.46	1.16	18.2	270
TPZ122	11/16/2022	Other	6.35	0.945	23.4	332
TPZ122	12/15/2022	Other	6.2	1.32	24	367
TPZ122	2/15/2023	Other	5.73	1.34	25.8	381
TPZ122	10/27/2022	Other	6.24	0.988	23.2	325
TPZ122D	3/7/2023	Other	6.11	1.32	26.1	395
TPZ122D	8/31/2022	Other	6.95	4.66	26.4	193
TPZ122D	1/18/2023	Other	6.77	4.36	24.7	225
TPZ122D	9/27/2022	Other	6.65	5.43	25.7	193
TPZ122D	11/16/2022	Other	6.94	5.25	25.4	193
TPZ122D	12/15/2022	Other	6.76	4.92	25.9	213
TPZ122D	2/15/2023	Other	6.46	5.54	26.8	215
TPZ122D	10/27/2022	Other	6.78	6.6	27.7	191
TPZ123	3/7/2023	Western UA	6.84	<0.023	20.5	156
TPZ123	11/3/2022	Western UA	7.2	0.027	17.6	102
TPZ123	8/31/2022	Western UA	7.21	0.0691	17.1	85
TPZ123	1/18/2023	Western UA	6.93	0.0384	26	163
TPZ123	9/27/2022	Western UA	7.2	0.0934	15.9	89
TPZ123	11/16/2022	Western UA	7.11	<0.015	16.8	121

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ123	12/15/2022	Western UA	6.95	0.0457	17.8	122
TPZ123	2/15/2023	Western UA	6.38	0.0337	20.2	166
TPZ124	3/7/2023	Western UCU	6.17	12.2	44	357
TPZ124	8/31/2022	Western UCU	6.27	8.99	30.8	219
TPZ124	11/15/2022	Western UCU	6.57	14.1	30.8	221
TPZ124	12/14/2022	Western UCU	6.25	24.7	34.4	257
TPZ124	1/18/2023	Western UCU	6.09	10	41.6	311
TPZ124	2/14/2023	Western UCU	5.71	13.6	43.6	331
TPZ124	10/28/2022	Western UCU	6.31	16	30.5	205
TPZ124	9/29/2022	Western UCU	6.35	15.2	34.7	202
TPZ124D	3/7/2023	Western UA	6.77	2.88	45.8	394
TPZ124D	8/31/2022	Western UA	7.04	1.31	37.8	238
TPZ124D	11/15/2022	Western UA	7.07	2.21	42.5	321
TPZ124D	12/14/2022	Western UA	6.88	2.22	43.6	314
TPZ124D	1/18/2023	Western UA	6.8	2.41	44.7	313
TPZ124D	2/14/2023	Western UA	6.4	2.59	45.4	341
TPZ124D	10/28/2022	Western UA	6.84	2.46	43.9	306
TPZ124D	9/29/2022	Western UA	6.91	2.34	44.9	303
XPW01	7/21/2021	Eastern Porewater	7.27	10.1	0.917	328
XPW02	3/21/2023	Eastern Porewater	7.6	--	--	--
XPW02	5/3/2023	Eastern Porewater	7.72	13.4	12.3	2650
XPW02	3/15/2022	Eastern Porewater	7.74	16	10.7	2590
XPW02	7/21/2021	Eastern Porewater	7.76	12	11.1	2330
XPW02	5/12/2021	Eastern Porewater	7.85	10.8	11.8	2410
XPW02	4/14/2021	Eastern Porewater	7.9	11.5	11.3	2410
XPW01	3/5/2021	Eastern Porewater	8	10.4	2.25	345
XPW02	3/4/2021	Eastern Porewater	8	12.1	10.9	2380
XPW02	3/24/2021	Eastern Porewater	8	12.2	11.3	2830
XPW01	4/14/2021	Eastern Porewater	8.2	9.42	1.28	355
XPW01	3/15/2022	Eastern Porewater	8.33	10.4	0.443	360
XPW01	5/12/2021	Eastern Porewater	8.4	10.2	1.31	309
XPW01	3/24/2021	Eastern Porewater	8.4	9.58	1.7	355
XPW01	5/3/2023	Eastern Porewater	8.41	10.6	0.405	345
XPW01	3/8/2023	Eastern Porewater	8.47	8.79	0.254	414
XPW03	7/21/2021	Eastern Porewater	9.97	11.6	<0.05	148
XPW03	3/4/2021	Eastern Porewater	10.5	12.2	<0.05	133
XPW03	3/15/2022	Eastern Porewater	10.5	11.1	<0.05	152
XPW03	4/14/2021	Eastern Porewater	10.5	9.3	<0.05	152
XPW03	3/24/2021	Eastern Porewater	10.6	11.6	<0.05	138

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
XPW03	3/9/2023	Eastern Porewater	10.7	8.06	<0.021	142
XPW03	5/3/2023	Eastern Porewater	10.7	9.22	<0.03	144
XPW03	5/12/2021	Eastern Porewater	10.7	11.7	<0.1	155
XPW02	3/8/2023	Eastern Porewater	--	10.8	8.75	2450
XTPW01	3/10/2023	Western Porewater	10.8	34.3	0.0986	420
XTPW01	3/22/2021	Western Porewater	11.13	27	0.122	387
XTPW01	9/28/2022	Western Porewater	10.71	32.1	0.29	395
XTPW01	9/1/2022	Western Porewater	11.03	29.5	0.292	402
XTPW01	10/27/2022	Western Porewater	10.95	32.7	4.36	403
XTPW02	3/8/2023	Western Porewater	10.6	17.8	0.123	462
XTPW02	9/28/2022	Western Porewater	10.65	22.3	0.7	427
XTPW02	10/26/2022	Western Porewater	10.91	21.9	0.381	478
XTPW02	9/1/2022	Western Porewater	10.56	21.4	1.1	461
XTPW03	3/7/2023	Western Porewater	6.76	4.02	27.8	89
XTPW03	9/28/2022	Western Porewater	7.33	16.4	18.9	269
XTPW03	9/1/2022	Western Porewater	7.5	16.2	20.4	234
XTPW03	10/27/2022	Western Porewater	7.42	23.3	17.2	356
XTPW04	3/8/2023	Western Porewater	7.09	11.3	17	452
XTPW04	9/28/2022	Western Porewater	9.58	18.3	10	658
XTPW04	10/26/2022	Western Porewater	9.77	24.2	6.91	907
XTPW04	9/1/2022	Western Porewater	8.73	16.2	14.4	539

Notes:

mg/L = milligrams per liter

SU= standard units

< = less than analytical detection limit; data not included in Attachment 3 and 4 analyses.

-- = data not measured

Well Type: Western and Eastern as defined in main text, UA=uppermost aquifer, UCU= upper confining unit

Attachment 3: pH, boron, and magnesium data from March 2021 to May 2023. See Attachment 3 legend for full list of included wells.

Attachment 4: Magnesium and sulfate data for all sampling dates and all wells listed here.

Table 1: Inline Table 1 presents pH, boron, and magnesium data for G11, G51D, CCR Porewater, Western Groundwater, Eastern Groundwater, and TPZ120. G11, G51D, and TPZ120 data are from from March 2021 to May 2023 for those individual wells. For the same time frame, CCR Porewater includes both eastern and western porewater; Western Groundwater includes all Western UA and UCU wells except TPZ120; Eastern Groundwater includes all Eastern Compliance and Background Wells.

LIFECYCLEGEO

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G11	2021/07/06	0.071	78
G11	2021/04/14	0.084	100
G11	2021/07/20	0.036	135
G11	2023/05/03	*3.35*	207
G11	2021/06/01	0.086	159
G11	2021/06/14	0.052	149
G11	2023/03/08	--	166
G11	2021/03/04	0.51	69.0
G11	2021/03/24	<0.025	154
G11	2021/05/12	<0.1	194
G11	2022/07/23	0.16	122
G51D	2023/03/08	--	167
G51D	2021/03/24	--	136
G51D	2022/07/25	0.41	178
G51D	2022/03/15	--	165
G51D	2020/03/30	--	261
G51D	2023/05/03	*0.82*	214
G51D	2017/07/20	--	180
G51D	2019/09/09	--	157
G51D	2021/09/20	--	238
G51D	2022/09/20	--	215
G51D	2016/09/14	--	231
G51D	2017/06/15	--	168
G51D	2017/11/30	--	168
G51D	2018/06/19	--	247
G51D	2019/03/27	--	130
G51D	2020/09/23	--	292
G51D	2016/06/15	--	213
G51D	2016/12/14	--	134
G51D	2016/03/15	--	122
G51D	2018/09/05	--	217
G51D	2015/12/03	--	133
G51D	2017/03/08	--	282
TPZ118DD	2022/09/29	*0.97*	-65.5
TPZ118DD	2022/12/14	2.07	<-300.0
TPZ118DD	2023/03/08	*2.11*	-36.2
TPZ118DD	2022/10/28	1.88	-103
TPZ118DD	2022/11/15	1.60	-168

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
TPZ118DD	2022/08/31	*1.70*	-124
TPZ119D	2023/02/15	0.10	217
TPZ119D	2022/09/29	0.12	90.1
TPZ119D	2023/03/07	0.051	104
TPZ119D	2023/01/18	0.12	76.0
TPZ119D	2022/12/14	0.095	96.0
TPZ119D	2022/11/16	*0.086*	38.0
TPZ119D	2022/08/31	*0.80*	123
TPZ119D	2022/11/04	--	196
TPZ120D	2023/02/15	0.89	123
TPZ120D	2022/12/15	1.30	212
TPZ120D	2023/01/19	1.30	178
TPZ120D	2022/08/30	*16.5*	-59.2
TPZ120D	2023/03/07	*1.30*	83.1
TPZ120D	2022/10/26	1.51	32.0
TPZ120D	2022/11/16	1.32	-3.20
TPZ120D	2022/09/27	2.68	43.2
TPZ123	2022/08/31	*31.9*	-78.4
TPZ123	2022/11/03	--	-89.2
TPZ123	2022/09/27	*5.11*	-81.7
TPZ123	2023/03/07	*2.74*	-24.2
TPZ123	2023/01/18	*102*	-116
TPZ123	2022/11/16	*2.46*	-116
TPZ123	2022/12/15	*5.56*	-64.0
TPZ123	2023/02/15	*2.17*	21.0
TPZ124D	2023/02/14	0.40	35.0
TPZ124D	2023/03/07	0.32	11.6
TPZ124D	2023/01/18	0.32	-8.00
TPZ124D	2022/10/28	1.13	-32.9
TPZ124D	2022/12/14	0.76	-24.0
TPZ124D	2022/09/29	*1.71*	-42.7
TPZ124D	2022/08/31	3.14	-63.7
TPZ124D	2022/11/15	0.82	-106
G01D	2017/03/07	--	80.0
G01D	2021/07/06	*1.79*	139
G01D	2023/05/02	*4.09*	145

LIFECYCLEGEO

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G01D	2021/06/01	*1.92*	164
G01D	2021/07/21	*1.35*	122
G01D	2022/03/14	--	117
G01D	2019/09/09	--	193
G01D	2021/06/14	*0.83*	160
G01D	2021/03/24	*1.15*	160
G01D	2021/05/12	*0.65*	180
G01D	2022/09/20	--	173
G01D	2021/09/20	--	170
G01D	2023/03/07	--	195
G01D	2021/03/03	*1.09*	145
G01D	2023/01/24	*7.38*	114
G01D	2016/03/15	--	-103
G01D	2017/06/15	--	123
G01D	2015/12/03	--	60.0
G01D	2019/03/27	--	118
G01D	2021/04/14	0.70	134
G01D	2020/09/23	--	202
G01D	2016/09/14	--	-26.0
G01D	2017/11/30	--	21.0
G01D	2016/12/14	--	113
G01D	2018/06/19	--	29.0
G01D	2017/07/20	--	102
G01D	2020/03/30	--	138
G01D	2016/06/15	--	-110
G01D	2018/09/05	--	131
G01D	2022/07/26	*1.85*	15.5
G02D	2021/07/06	<0.025	128
G02D	2021/07/21	0.059	100
G02D	2021/06/01	0.043	140
G02D	2017/06/14	--	95.0
G02D	2021/04/14	<0.025	151
G02D	2016/12/14	--	218
G02D	2021/09/20	--	191
G02D	2021/03/24	0.026	175
G02D	2021/05/12	<0.1	183

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G02D	2021/06/14	0.071	169
G02D	2023/05/03	0.049	182
G02D	2022/03/14	--	138
G02D	2022/09/21	--	199
G02D	2021/03/03	0.11	151
G02D	2019/09/09	--	186
G02D	2023/03/08	--	49.1
G02D	2020/03/30	--	179
G02D	2016/03/15	--	28.0
G02D	2016/09/14	--	69.0
G02D	2018/09/05	--	169
G02D	2019/03/27	--	130
G02D	2020/09/23	--	246
G02D	2023/01/24	<0.0115	109.8
G02D	2015/12/03	--	146
G02D	2018/06/19	--	187
G02D	2017/07/20	--	132
G02D	2016/06/15	--	82.0
G02D	2017/03/08	--	254
G02D	2017/11/30	--	70.0
G02D	2022/07/27	0.03	97.3
XTPW03	2023/03/07	*0.49*	50.0
XTPW03	2022/09/28	*12.8*	-69.5
XTPW03	2022/10/27	*5.64*	-136
XTPW03	2022/09/01	*18.7*	-174

Notes:

mg/L = milligrams per liter

mV = millivolts ; V = volts

Italicized samples not included in average iron presented in Attachment 6a due to turbidity >10NTU

WAP: West ash pond, represented by data from XTPW03

Backgroud: Represented by data from G01D and G02D

LIFECYCLEGEO

Appendix D-3. Supporting groundwater analytical data for Attachment 6B.

Well ID	Date	pH (SU)	Temperature (Celcius)	Oxidation Reduction Potential (mV)	Eh (V)
G11	3/4/2021	5.90	16.30	69.0	0.276
G11	3/24/2021	5.90	16.50	154	0.361
G11	4/14/2021	5.80	16.10	100	0.307
G11	5/12/2021	5.90	16.50	194	0.401
G11	6/1/2021	5.82	16.40	159	0.366
G11	6/14/2021	5.86	16.60	149	0.355
G11	7/6/2021	5.78	16.70	78.0	0.284
G11	7/20/2021	5.82	16.90	135	0.341
G11	7/23/2022	6.33	17.32	122	0.328
G11	3/8/2023	5.87	16.00	166	0.373
G11	5/3/2023	5.82	16.50	207	0.414
G51D	7/20/2017	5.90	18.92	180	0.384
G51D	3/30/2020	5.62	16.40	261	0.468
G51D	3/24/2021	5.56	17.00	136	0.342
G51D	9/20/2021	5.46	17.70	238	0.443
G51D	3/15/2022	5.57	16.10	165	0.372
G51D	7/25/2022	6.92	18.07	178	0.383
G51D	3/8/2023	5.49	15.90	167	0.374
G51D	5/3/2023	5.57	16.30	214	0.421
TPZ118DD	8/31/2022	7.40	15.94	-124	0.083
TPZ118DD	9/29/2022	6.84	15.83	-65.5	0.142
TPZ118DD	10/28/2022	7.26	15.70	-103	0.104
TPZ118DD	11/15/2022	7.34	14.77	-168	0.040
TPZ118DD	12/14/2022	7.08	14.80	-300	-0.092
TPZ118DD	3/8/2023	7.09	14.70	-36.2	0.172
TPZ119D	8/31/2022	6.49	16.55	123	0.329
TPZ119D	9/29/2022	6.19	16.92	90.1	0.296
TPZ119D	11/4/2022	6.61	16.12	196	0.403
TPZ119D	11/16/2022	6.48	14.41	38.0	0.246
TPZ119D	12/14/2022	6.44	14.80	96.0	0.304
TPZ119D	1/18/2023	6.35	14.30	76.0	0.285
TPZ119D	2/15/2023	6.16	15.10	217	0.425
TPZ119D	3/7/2023	6.34	14.90	104	0.312
TPZ119DD	8/31/2022	6.90	17.25	-1.3	0.205
TPZ119DD	9/29/2022	6.88	18.56	-3.0	0.202
TPZ119DD	11/4/2022	7.00	17.05	131	0.337
TPZ119DD	11/16/2022	6.94	12.75	-54.0	0.156
TPZ119DD	12/14/2022	6.81	14.60	76.0	0.284
TPZ119DD	1/18/2023	6.74	14.00	32.0	0.241

Appendix D-3. Supporting groundwater analytical data for Attachment 6B.

Well ID	Date	pH (SU)	Temperature (Celcius)	Oxidation Reduction Potential (mV)	Eh (V)
TPZ119DD	2/15/2023	6.54	14.90	36.0	0.244
TPZ119DD	3/7/2023	6.76	14.60	2.0	0.210
TPZ120D	8/30/2022	6.18	16.31	-59.2	0.148
TPZ120D	9/27/2022	6.37	17.00	43.2	0.249
TPZ120D	10/26/2022	6.35	17.60	32.0	0.238
TPZ120D	11/16/2022	6.37	15.23	-3.2	0.204
TPZ120D	12/15/2022	6.16	14.70	212	0.420
TPZ120D	1/19/2023	6.17	14.80	178	0.386
TPZ120D	2/15/2023	6.01	15.50	123	0.330
TPZ120D	3/7/2023	6.20	14.90	83.1	0.291
TPZ123	8/31/2022	7.21	17.13	-78.4	0.128
TPZ123	9/27/2022	7.20	16.42	-81.7	0.125
TPZ123	11/3/2022	7.20	19.43	-89.2	0.115
TPZ123	11/16/2022	7.11	13.87	-116	0.093
TPZ123	12/15/2022	6.95	14.70	-64.0	0.144
TPZ123	1/18/2023	6.93	14.30	-116	0.093
TPZ123	2/15/2023	6.38	14.70	21.0	0.229
TPZ123	3/7/2023	6.84	14.60	-24.2	0.184
TPZ124D	8/31/2022	7.04	16.98	-63.7	0.142
TPZ124D	9/29/2022	6.91	16.40	-42.7	0.164
TPZ124D	10/28/2022	6.84	14.80	-32.9	0.175
TPZ124D	11/15/2022	7.07	13.82	-106	0.103
TPZ124D	12/14/2022	6.88	14.50	-24.0	0.184
TPZ124D	1/18/2023	6.80	14.00	-8.0	0.201
TPZ124D	2/14/2023	6.40	14.00	35.0	0.244
TPZ124D	3/7/2023	6.77	14.40	11.6	0.220
XTPW01	3/10/2023	10.80	14.00	-156	0.053
XTPW02	3/8/2023	10.60	13.90	-182	0.027
XTPW03	10/27/2022	7.42	14.40	-136	0.072
XTPW04	3/8/2023	7.09	13.50	-118	0.091

Notes:

SU= standard units

mV = millivolts ; V = volts

DOCUMENT 14

Strauss, Rebecca Y.

From: Seif, Josiah <Josiah.Seif@Illinois.gov>
Sent: Monday, October 23, 2023 8:33 AM
To: Hunt, Lauren; MacDonna, Keegan; Mullenax, Heather; Bierwagen, Justin
Cc: LeCrone, Darin; Dunaway, Lynn; Summers, Michael
Subject: Joppa EastAsh ASD Letter

Hard copy of the **Joppa EastAsh ASD Letter** has been received, scanned to the N:Drive, hard copy placed in the Impoundment. If you have any questions, please let me know.

Thank you,

Josiah M. Seif

Josiah M. Seif
CCR Office Coordinator
Bureau of Water
Illinois Environmental Protection Agency
217-782-0610
Josiah.Seif@illinois.gov

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 15

Rees, Jeromy

Subject: ASD Discussions--Newton and Joppa
Location: EPA.Water.SanKotyAquifer.Conference

Start: Thu 10/26/2023 9:30 AM
End: Thu 10/26/2023 10:30 AM

Recurrence: (none)

Meeting Status: Accepted

Organizer: Hunt, Lauren
Required Attendees Dunaway, Lynn; Mullenax, Heather; Bierwagen, Justin; Garee, Matthew J.
Optional Attendees: Summers, Michael
Resources: EPA.Water.SanKotyAquifer.Conference

Categories: Meetings for EPA

Added a draft Joppa letter to discuss.

Hi all.
Let's discuss the ASDs for Newton (letter due by November 5th) and Joppa (letter due by November 19th).
The ASDs are attached.
We will need to discuss the following in depth to get the team up to speed on general subjects we will see a lot of coming soon:

1. Geochemistry
2. Alternative source data submittal requirements
3. Other items the team is curious about or needs to brush up on.

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.

Luminant

Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234

RECEIVED
OCT 06 2023
IEPA
BOW/WPC/PERMIT SECTION

October 6, 2023
Illinois Environmental Protection Agency
DWPC – Permits MC#15
Attn: 35 I.A.C. § 845.610 Quarterly Report Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Re: Newton Power Plant Primary Ash Pond; IEPA ID # W0798070001-01

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 exceedances observed from the Quarter 2 2023 sampling event at the Newton Power Plant Primary Ash Pond, identified by Illinois Environmental Protection Agency (IEPA) ID No. W0798070001-01.

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,

Phil Morris, PE
Senior Director, Environmental

Enclosures
Alternate Source Demonstration, Quarter 2 2023, Primary Ash Pond Newton Power Plant, Newton Illinois

Intended for
Illinois Power Generating Company

Date
October 6, 2023

Project No.
1940103649-013

35 I.A.C. § 845.650(E): ALTERNATIVE SOURCE DEMONSTRATION

PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

IEPA ID: W0798070001-1

RAMBOLL Bright ideas. Sustainable change.

CERTIFICATIONS

I, Anne Frances Ackerman, a qualified professional engineer in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Anne Frances Ackerman
Qualified Professional Engineer
062-060586
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 6, 2023

I, Brian G. Hennings, a professional geologist in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Brian G. Hennings
Professional Geologist
196-001482
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 6, 2023

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA
T 414-837-3607
F 414-837-3608
https://ramboll.com

CONTENTS

1.	**Introduction**	**3**
2.	**Background**	**4**
2.1	Site Location and Description	4
2.2	Description of Primary Ash Pond CCR Unit	4
2.3	Geology and Hydrogeology	4
2.3.1	Site Hydrogeology	4
2.3.2	Regional Bedrock Geology	5
2.3.3	Water Table Elevation and Groundwater Flow Direction	5
2.4	Groundwater and PAP Monitoring	6
3.	**Alternative Source Demonstration: Lines of Evidence**	**7**
3.1	LOE #1: The PAP is Separated from the UA at APW15 by a Thick Layer of Low Permeability Glacial Till (UCU)	7
3.2	LOE #2: Concentrations of Primary CCR Indicators in APW15 Do Not Exceed Background Limits and are Not Increasing	7
3.3	LOE #3: Concentrations of Chloride at APW15 are Greater than Source Concentrations	8
4.	**Conclusions**	**9**
5.	**References**	**10**

TABLES (IN TEXT)

Table A	Summary Statistics for Chloride in APW15 and PAP Porewater (February 2021 to April 2023)

FIGURES (ATTACHED)

Figure 1	Sampling Locations and Potentiometric Surface Map - April 24, 2023

APPENDICES

Appendix A	Soil Boring B141 Location and Boring Log
Appendix B	Supporting Materials for LOE #1
Appendix C	Supplemental Analytical Data

ACRONYMS AND ABBREVIATIONS

35 I.A.C.	Title 35 of the Illinois Administrative Code
ASD	Alternative Source Demonstration
bgs	below ground surface
CCR	coal combustion residuals
cm/s	centimeters per second
E001	Event 1
GWPS	groundwater protection standard
LCU	lower confining unit
LF2	Landfill 2
LOE(s)	Line(s) of evidence
M-K	Mann-Kendall
mg/L	milligrams per liter
NAVD88	North American Vertical Datum of 1988
NPDES	National Pollutant Discharge Elimination System
NPP	Newton Power Plant
NRT/OBG	Natural Resource Technology, an OBG Company
PAP	Primary Ash Pond
PMP	primary migration pathway
Ramboll	Ramboll Americas Engineering Solutions, Inc.
Rapps	Rapps Engineering and Applied Science
TDS	total dissolved solids
UA	uppermost aquifer
UCU	upper confining unit
UD	upper drift
UTL	Upper Tolerance Limit

1. INTRODUCTION

Under Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e), 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, an owner or operator of a coal combustion residuals (CCR) surface impoundment may complete a written 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 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 (Alternative Source Demonstration [ASD]).

This ASD has been prepared on behalf of Illinois Power Generating Company, by Ramboll Americas Engineering Solutions, Inc (Ramboll), to provide pertinent information pursuant to 35 I.A.C. § 845.650(e) for the Newton Power Plant (NPP) Primary Ash Pond (PAP) located near Newton, Illinois.

The most recent quarterly sampling event (Event 1 [E001]) was completed on April 28, 2023, and analytical data were received on June 8, 2023. In accordance with 35 I.A.C. § 845.610(b)(3)(C), comparison of statistically derived values with the GWPSs described in 35 I.A.C. § 845.600 to determine exceedances of the GWPS was completed by August 7, 2023, within 60 days of receipt of the analytical data (Ramboll, 2023). The statistical determination identified the following GWPS exceedances at compliance groundwater monitoring wells:

- Chloride at well APW15
- Lithium at well APW02
- Sulfate at wells APW02, APW04, APW05S, and APW10
- Total dissolved solids (TDS) at wells APW02, APW04, and APW05S

Pursuant to 35 I.A.C. § 845.650(e), the lines of evidence (LOEs) presented in **Section 3** demonstrate that sources other than the PAP were the cause of the chloride GWPS exceedance listed above. This ASD was completed by October 6, 2023, within 60 days of determination of the exceedances (August 7, 2023), as required by 35 I.A.C. § 845.650(e).

Lithium, sulfate, and TDS exceedances will be addressed in accordance with 35 I.A.C. § 845.660.

2. BACKGROUND

2.1 Site Location and Description

The NPP is located in Jasper County in the southeastern part of central Illinois, approximately 7 miles southwest of the town of Newton. The plant is located on the north side of Newton Lake. The area is bounded by Newton Lake and agricultural land to the west, south, and east, and agricultural land to the north. Beyond the lake is additional agricultural land.

2.2 Description of Primary Ash Pond CCR Unit

The NPP's sole CCR surface impoundment, the PAP, was constructed in 1977 and has a design capacity of approximately 9,715 acre-feet. The PAP has a surface area of 400 acres and a height of approximately 71 feet above grade. The PAP currently receives bottom ash, fly ash, and low-volume wastewater from the plant's two coal-fired boilers, and is operated per National Pollutant Discharge Elimination System (NPDES) Permit IL0049191, Outfall 001. The PAP was not excavated during construction, except for native borrow materials used to build the containment berms.

2.3 Geology and Hydrogeology

2.3.1 Site Hydrogeology

The information used to describe the hydrogeology is based on the local geology obtained from published sources, hydrogeologic investigation data, and boring data collected during site investigations conducted from 1997 to 2021 (Natural Resource Technology, an OBG Company [NRT/OBG], 2017; Ramboll, 2021a).

Quaternary deposits in the Newton area consist mainly of diamictons and outwash deposits that were deposited during Illinoian and Pre-Illinoian glaciations (Lineback, 1979; Willman et al., 1975). The unconsolidated deposits include the following units (beginning at the ground surface):

- **Upper Drift (UD)/ Potential Migration Pathway (PMP):** The upper drift is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member. The hydraulic conductivity of this unit, calculated from field hydraulic test data from monitoring wells screened between 8 and 36 feet below ground surface (bgs), was observed to range from 2.4 x 10^{-6} to 6.1 x 10^{-5} centimeters per second (cm/s) with a geometric mean of 1.3 x 10^{-5} cm/s (Rapps Engineering and Applied Science [Rapps], 1997).
    - **Hagarstown Member/PMP**: The Hagarstown Member consists of the discontinuous, sandier deposits of the UD where present and overlies the Vandalia Till. Results of field hydraulic conductivity tests in wells screened within the Hagarstown PMP (APW05S and APW12) ranged from 6.1 x 10^{-4} to 1.5 x 10^{-2} cm/s, with a geometric mean hydraulic conductivity of 3.1 x 10^{-3} cm/s (Ramboll, 2021a).
- **Upper Confining Unit (UCU)**: The UCU consists of a thick package of the low permeability clay and silt of the Vandalia Till Member. This unit is a laterally continuous layer between the base of the upper drift and the top of the uppermost aquifer (UA). The hydraulic conductivity of this unit was observed to range from 6.3 x 10^{-9} to 2.1 x 10^{-8} cm/s with a geometric mean of 1.1 x 10^{-8} cm/s (Rapps, 1997).

- **Uppermost Aquifer (UA):** The UA is composed of the Mulberry Grove Member, which has been classified as poorly graded sand, silty sand, clayey sand, and gravel. The top of the UA is highest in elevation in the north and east portions of the unit and slopes downward toward APW15. The top of unit elevations range from approximately 482 feet (APW05 and APW10) to 425 feet (APW15) North American Vertical Datum of 1988 (NAVD88). Field hydraulic conductivity tests conducted in 2021 at monitoring wells screened in the UA ranged from 2.0 x 10^{-4} to 1.5 x 10^{-1} cm/s with a geometric mean hydraulic conductivity of 6.8 x 10^{-3} cm/s. The highest conductivities are measured in APW15, APW16, and APW17 (Ramboll, 2021a).
- **Lower Confining Unit (LCU):** The LCU is comprised of low permeability silt and clay of the Smithboro Till Member and the Banner Formation. The hydraulic conductivity of this unit was observed to be 1.4 x 10^{-7} cm/s (Rapps, 1997).
- **Bedrock Unit:** Shale bedrock of the Pennsylvanian-age Mattoon Formation (Willman et al., 1967) was encountered at the NPP during recent and historical investigations. Based on boring logs, the bedrock surface elevation at the NPP ranges from 408 feet NAVD88 (B141) (**Appendix A**) to 445 feet NAVD88 (APW13) (Ramboll, 2021a). Bedrock was not encountered at APW15, which was advanced to approximately 412 feet NAVD88 (Ramboll, 2021a). This indicates that APW15, which is screened within the UA from 424 to 419 feet NAVD88, is located in close proximity to the bedrock surface.

2.3.2 Regional Bedrock Geology

Regional investigations of the Illinois Basin have identified bedrock (specifically brines within the bedrock formations) as a source of chloride in groundwater (Kelley et al, 2012; Panno et al, 2018). Studies by Cartwright (1970) and Siegel (1989) indicate that groundwater migrates toward the center of the Illinois Basin and discharges upward through overlying confining units. The "Saline groundwater and brines can be brought near or to the land surface by natural conditions, such as migrating up prominent fractures and/or faults in bedrock, or by anthropogenic activities, such as exploration for and exploitation of petroleum. The mixing of upward-migrating saline groundwater with fresh groundwater from shallow aquifers can make groundwater from private wells undrinkable and can present a very expensive problem for municipalities (Panno and Hackley, 2010). "A saline spring was identified in Clay County (Kelley et al, 2012) approximately 10 miles south of the NPP and is adjacent to the Clay City Anticline which runs north into Jasper County and east of the NPP. Concentrations of chloride in groundwater collected from the Pennsylvanian shale in Jasper County range from 100 to 5,000 milligrams per liter (mg/L) (Panno et al, 2017).

2.3.3 Water Table Elevation and Groundwater Flow Direction

Groundwater elevations in the UA (referenced to NAVD88) across the PAP ranged from approximately 491 to 530 feet during E001 (**Figure 1**). Depth to groundwater measurements used to generate the groundwater elevation contours shown on **Figure 1** were collected on April 24, 2023. Groundwater flow in the UA beneath the eastern portion of the PAP is generally to the south, with flow direction diverging to the southwest beneath the western portion of the PAP, toward Landfill 2 (LF2), where groundwater flow in the area is converging along the major axis of LF2 Cells 1 and 2.

2.4 Groundwater and PAP Monitoring

The monitoring system for the PAP is shown on **Figure 1** and consists of two background monitoring wells (APW05 and APW06), 16 compliance monitoring wells (APW02, APW03, APW04, APW05S, APW07, APW08, APW09, APW10, APW11, APW12, APW13, APW14, APW15, APW16, APW17, and APW18), and two temporary water level only surface water staff gages (XSG01 and SG02) to monitor potential impacts from the PAP (Ramboll, 2021b). These monitoring wells are screened within the UD (APW02, APW03, APW04, APW05S, and APW12) and the UA (APW05, APW06, APW07, APW08, APW09, APW10, APW11, APW13, APW14, APW15, APW16, APW17, and APW18) along the perimeter of the PAP. Porewater samples are collected from locations XPW01 and XPW02 on the northern side of the PAP, and from XPW03 and XPW04 on the northeastern side of the PAP (**Figure 1**).

3. ALTERNATIVE SOURCE DEMONSTRATION: LINES OF EVIDENCE

As allowed by 35 I.A.C. § 845.650(e), this ASD demonstrates that sources other than the PAP (the CCR unit) caused the chloride exceedance at APW15. LOEs supporting this ASD include the following:

1. The PAP is separated from the UA at APW15 by a thick layer of low permeability glacial till (UCU).
2. Concentrations of primary CCR indicators in APW15 do not exceed background limits and are not increasing.
3. Concentrations of chloride at APW15 are greater than source concentrations.

These LOEs are described and supported in greater detail below.

3.1 LOE #1: The PAP is Separated from the UA at APW15 by a Thick Layer of Low Permeability Glacial Till (UCU)

Based on the boring log for monitoring well APW15, the top elevation of the UA is 424.9 feet NAVD88 (Ramboll, 2021a), which corresponds to 97.2 feet bgs on the boring log. At this location, the UA is overlain by the UCU, a low permeability (6.3×10^{-9} to 2.1×10^{-8} cm/s) glacial till. The bottom of the PAP, as presented in drawing S-69, is situated within the UCU, generally consistent with ground surface topography at the time the PAP was constructed (AECOM, 2022). The estimated bottom elevation of CCR presented on profile B-B' of sheet 00C302 (HDR, 2022), which bisects the axis of a former drainage feature, is 485 feet and has been interpreted to be the minimum base of ash elevation across the PAP. Thus, separation between the UA and the base of ash is approximately 60 feet, which represents the thickness of the low permeability glacial till that comprises the UCU. Based upon these observations, there is no complete pathway for transport of CCR constituents to APW15, and the PAP is not the source of the chloride exceedance at that well. **Appendix B** includes the boring log for APW15, drawing S-69, and sheet 00C302 to support this LOE.

3.2 LOE #2: Concentrations of Primary CCR Indicators in APW15 Do Not Exceed Background Limits and are Not Increasing

Boron and sulfate can be indicators of CCR impacts to groundwater due to their leachability from CCR and mobility in groundwater. Porewater in the NPP PAP is elevated in both boron and sulfate, indicating that these parameters are site-specific key indicators for CCR. If the groundwater in APW15 had been impacted by CCR from the unit, boron and sulfate concentrations would be expected to be elevated above their respective background Upper Tolerance Limits (UTLs). The UTL is an upper bound on background concentrations calculated for the purpose of comparing compliance measurements to background.

Mann-Kendall (M-K) trend analysis tests were performed to determine whether there are trends in the boron and sulfate concentrations in each well. If groundwater downgradient of the PAP was being affected by CCR but boron and sulfate did not yet exceed background concentrations, boron and sulfate concentrations would be expected to be increasing. No trends in boron or sulfate concentrations were identified by the M-K tests in compliance well APW15.

The concentration of boron in compliance well APW15 (0.13 mg/L) is less than the boron UTL (0.26 mg/L) and the concentration of sulfate in APW15 (0.40 mg/L) is also less than the sulfate UTL (35.84 mg/L), and the lack of increasing trends in boron and sulfate concentrations at monitoring well APW15 indicate that this well has not been affected by CCR impacts from the NPP PAP (Ramboll 2021b; Ramboll 2023). Analytical data to support this LOE are included in **Appendix C**.

3.3 LOE #3: Concentrations of Chloride at APW15 are Greater than Source Concentrations

Table A below provides summary statistics for chloride in APW15 and PAP porewater collected from XPW01, XPW02, XPW03, and XPW04.

Table A. Summary Statistics for Chloride in APW15 and PAP Porewater (February 2021 to April 2023)

Sample Location	Chloride (mg/L)		
	Minimum	Maximum	Median
Composite Porewater[1]	8.1	62.0	12.5
APW15	130	270	235

[1] Composite Porewater includes summary statistics of data collected at porewater locations XPW01, XPW02, XPW03, and XPW04

The following observations can be made from **Table A**:

- Concentrations of chloride in compliance monitoring well APW15 ranged from 130 mg/L to 270 mg/L, with a median chloride concentration of 235 mg/L.
- Concentrations of chloride within PAP porewater ranged from 8.1 mg/L to 62.0 mg/L, with a median chloride concentration of 12.5 mg/L.
- The median chloride concentration observed in porewater is an order of magnitude lower than the median chloride concentrations observed in compliance monitoring well APW15.
- The maximum observed chloride concentration in compliance monitoring well APW15 is approximately four times the concentration observed in porewater.

Analytical data to support the summary statistics presented in **Table A** are included in **Appendix C**. If the PAP was the source of chloride in downgradient groundwater, chloride concentrations in PAP porewater would be expected to be greater than the groundwater concentrations. However, the median chloride concentration observed in compliance groundwater monitoring well APW15 is greater than the median chloride concentrations observed porewater, indicating that chloride concentrations are not related to the PAP.

4. CONCLUSIONS

Based on the three LOEs presented below and described in the previous section, it has been demonstrated that the GWPS exceedance of chloride at APW15 is not due to the PAP but is from a source other than the CCR unit.

1. The PAP is separated from the UA at APW15 by a thick layer of low permeability glacial till (UCU).
2. Concentrations of primary CCR indicators in APW15 do not exceed background limits and are not increasing.
3. Concentrations of chloride at APW15 are greater than source concentrations.

Given the preponderance of evidence demonstrating that the PAP is not the source of elevated chloride in groundwater compliance well APW15, regional literature was reviewed to identify an alternative source. Based on the literature discussed in **Section 2.3.2**, elevated chloride concentrations (ranging 100 to 5,000 mg/L) are present in bedrock at concentrations above those detected in APW15. The UA was encountered at the lowest elevation onsite at APW15 (~425 feet NAVD88), and the screened elevation of this well (424 to 419 feet NAVD88) indicates that it is in close proximity to the bedrock surface, which is known to range between 408 and 445 feet NAVD88 at the NPP. Upward migration of chloride-containing groundwater from the shale bedrock into the overlying unlithified materials above the bedrock valley has the potential to impact groundwater within the UA.

Based on the review of regional literature and site-specific bedrock conditions, chloride concentrations in bedrock groundwater are a likely source of chloride observed in APW15 for the following reasons:

- Chloride is present in Pennsylvanian shale in Jasper County at concentrations ranging from 100 to 5,000 mg/L.
- Upward vertical hydraulic gradients and fractures near geologic features provide conduits for these chloride-rich waters to migrate. The Clay City Anticline is present east of the PAP and a saline spring has been mapped adjacent to this anticline approximately 10 miles south of the PAP in Clay County.
- Well APW15 is located in close proximity to bedrock and screened at a lower elevation than other wells monitoring the UA which could explain why this is the only affected well. The screened interval is estimated to be 10 to 15 feet lower than the top of bedrock in adjacent wells. The high hydraulic conductivity of the UA relative to the low hydraulic conductivity of underlying bedrock (Mehnert et al, 1990) at this location provides a potential pathway for interaction with upward-migrating chloride-containing bedrock groundwater.

This information serves as the written ASD prepared in accordance with 35 I.A.C. § 845.650(e), demonstrating that the chloride exceedance observed at APW15 during the E001 sampling event was not due to the PAP. Therefore, assessment of corrective measures is not required for chloride at the PAP.

Lithium, sulfate, and TDS exceedances will be addressed in accordance with 35 I.A.C. § 845.660.

5. REFERENCES

AECOM, 2016. Drawing S-69, Ash Pond and SO2 Disposal Pond, included in the Construction Permit Application submitted to IEPA for Newton Power Plant Primary Ash Pond. July 28, 2022.

Cartwright, K., 1970. Groundwater discharge in the Illinois Basin as suggested by temperature anomalies. Water Resources Research 6, No. 3: 912-918.

Kelley, Walton R., Samuel V. Panno, and Keith Hackley, 2012. The Sources, Distribution, and Trends of Chloride in the Waters of Illinois. Prairie Research Institute. University of Illinois at Urbana-Champaign. March 2012.

HDR, 2022. Sheet 00C302, Cross Section B-B, Closure Drawing for Illinois Power Generating Company Newton Power Plant Primary Ash Pond Closure, included in the Construction Permit Application submitted to IEPA for Newton Power Plant Primary Ash Pond. July 28, 2022.

Lineback, J., 1979. Quaternary Deposits of Illinois: Illinois State Geological Survey map, scale 1:500,000.

Mehnert, Edward, Craig R. Gendron, and Ross D. Brower, 1990. Investigation of the Hydraulic Effects of Deep-Well Injection of Industrial Wastes. Champaign, Illinois: Illinois State Geological Survey.

Natural Resource Technology, an OBG Company (NRT/OBG), 2017. Hydrogeologic Monitoring Plan, Newton Primary Ash Pond – CCR Unit ID 501, Newton Landfill 2 – CCR Unit ID 502, Newton Power Station, Canton, Illinois, Illinois Power Generating Company. October 17, 2017.

Panno, S.V., and K.C. Hackley, 2010. Geologic influences on water quality. In *Geology of Illinois*, ed. D.R. Kolata and C.K. Nimz, 337-350. Champaign, Illinois: Illinois State Geological Survey.

Panno, S.V., Askari, Z., Kelly, W.R., Parris, T.M. and Hackley, K.C., 2018. Recharge and Groundwater Flow Within an Intracratonic Basin, Midwestern United States. Groundwater, 56: 32-45.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021a. Hydrogeologic Site Characterization Report. Newton Power Plant, Primary Ash Pond, Newton, Illinois. Illinois Power Generating Company. October 25, 2021.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021b. *Groundwater Monitoring Plan, Newton Power Plant, Primary Ash Pond, Newton, Illinois, Illinois Power Generating Company*. October 25, 2021.Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2023. *35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances, 2023 Quarter 2, Primary Ash Pond, Newton Power Plant," Newton, Illinois*. August 7, 2023.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2023. 35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances, 2023 Quarter 2, Primary Ash Pond, Newton Power Plant, Newton, Illinois. August 7, 2023.

Rapps Engineering and Applied Science (Rapps), 1997. Hydrogeologic Investigation and Groundwater Monitoring, CIPS – Newton Power Station Landfill, Jasper County, Illinois, in Newton Power Station Landfill, Application for Landfill Permit.

Siegel, D.I., 1989. Geochemistry of the Cambrian-Ordovician Aquifer System in the Northern Midwest, U.S. Geological Survey Professional Paper 1405-D, 76p.

Willman, H.B., J.C. Frye, J.A. Simon, K.E. Clegg, D.H. Swann, E. Atherton, C. Collinson, J.A. Lineback, T.C. Buschbach, and H.B. Willman, 1967. *Geologic Map of Illinois: Illinois State Geological Survey map, scale 1:500,000.*

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975. *Handbook of Illinois Stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.*

Figures

- COMPLIANCE MONITORING WELL
- BACKGROUND MONITORING WELL
- MONITORING WELL
- PORE WATER WELL
- LEACHATE WELL
- STAFF GAGE, CCR UNIT
- STAFF GAGE, LAKE
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION
- GROUNDWATER FLOW DIRECTION
- REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

NOTES:
1 ELEVATIONS IN PARENTHESES WERE NOT USED FOR CONTOURING
2 ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

0 400 800
Feet

SAMPLING LOCATIONS AND POTENTIOMETRIC SURFACE MAP APRIL 24, 2023

ALTERNATIVE SOURCE DEMONSTRATION
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

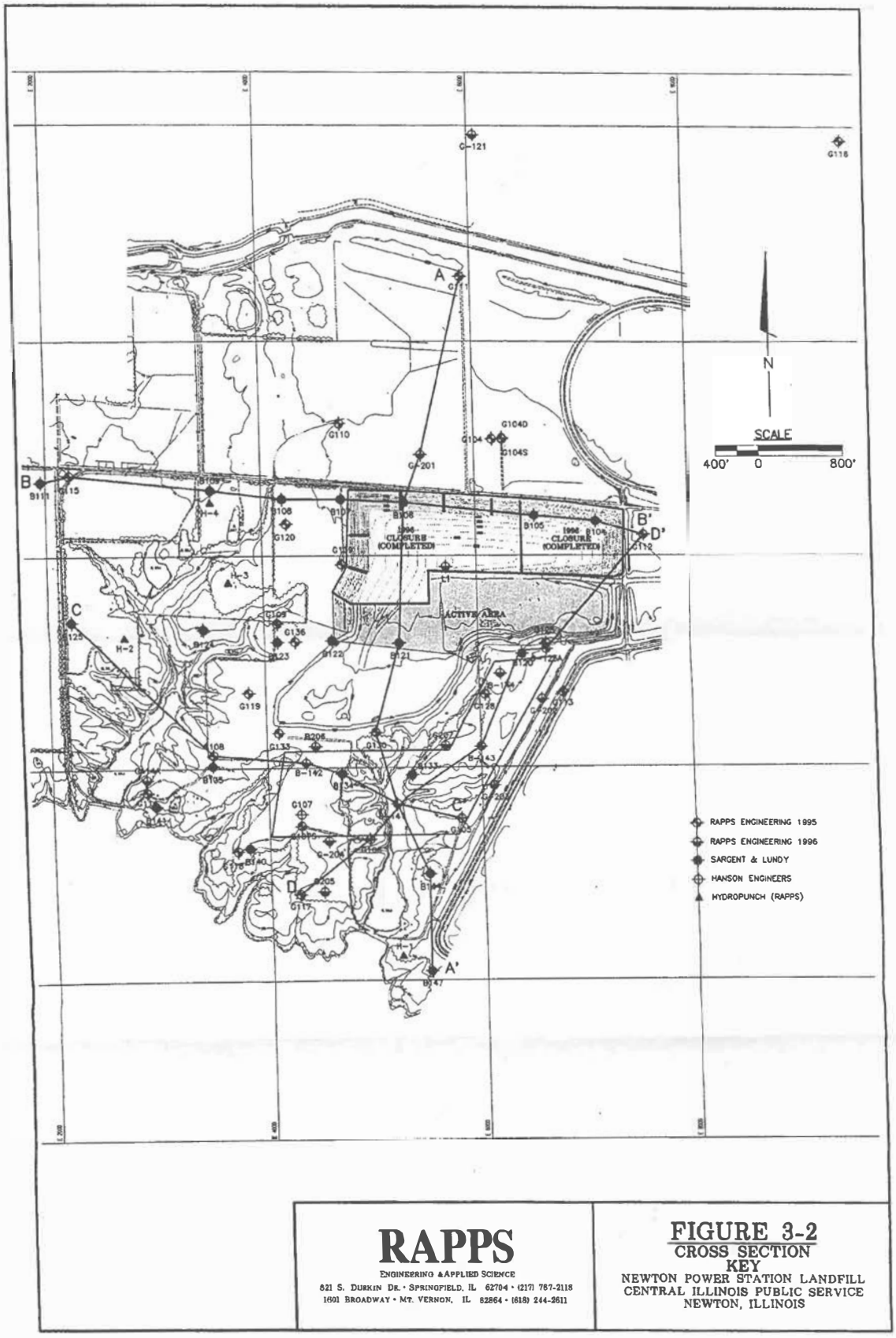
RAMBOLL

R001518

Appendix A

Soil Boring B141 Location and Boring Log

RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA96083\FIGURES\XSECKEY



RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. Durkin Dr. • Springfield, IL 62704 • (217) 787-2118
1601 Broadway • Mt. Vernon, IL 62864 • (618) 244-2611

FIGURE 3-2
CROSS SECTION KEY
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

R001521

RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY
Location of Borings NEWTON, ILLINOIS
Date FEBRUARY 14, 19 74 Job No. 68-21241-K1
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 141

GROUND SURFACE

525	ELEV. 524.5'		0.0'
	LIGHT GREY SILTY TOP SOIL		0.5'
520	BROWN CLAYEY SILT	20	
515		9	
	FINE SAND & SMALL TO MEDIUM GRAVEL		11.3'
	BROWN CLAYEY SANDY SILT		11.5'
510	BROWN SANDY SILT	43	14.5'
			15.0'
505	BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL	60/6	
500		44	
	SMALL TO M.D. GRAVEL & SAND		22.0'
			22.9'
495	BROWN SANDY SILTY CLAY TR. GRAVEL	36	
	SMALL TO MED. GRAVEL & SAND		32.0'
	BROWN SANDY SILTY CLAY		33.1'
490		34	34.4'
485		38	
480	GREY SANDY	47	
475	CLAYEY SILT	55	
470	TR. GRAVEL	47	
465		35	

No. 142

GROUND SURFACE

	ELEV. 534.8'		0
	GREY SILTY TOP SOIL		0.5
	BROWN & GREY SILTY CLAY	6	
		14	
	FINE SAND & GRAVEL		11
			11
	BROWN & GREY SILTY CLAY	22	
			16.0
	SAND & GRAVEL		18.0
	BROWN COMPACT FINE SAND	60/9	
			22.0
	FINE TO COURSE SAND & MED. TO LARGE GRAVEL	60/11	25.0
		60	
	GREY COMPACT SANDY CLAYEY SILT TR. GRAVEL SOME SAND SEAMS	60/11	
		39	
		39	
			48.0
		43	
	BROWN & GREY SANDY SILTY CLAY TR. GRAVEL	51	
			56.0
	GREY COMPACT SANDY CLAYEY SILT TR. GRAVEL		57.0
	FINE SAND & SMALL TO MED. GRAVEL SEAM	41	58.0
		43	
	GREY COMPACT	44	

			68.3'
5	SAND & SMALL TO MED. GRAVEL	60/9	69.0'
	LIGHT GREY SANDY CLAYEY SILT TR. GRAVEL		74.0'
450		60/8	
	COMPACT SANDY SILT		
445	TR. GRAVEL & CLAY	60/7	
			83.0'
440		21	
435	GREY SILTY	25	
430	CLAY TR. SAND	24	
425	& GRAVEL	20	
	(TR. WOOD)	23	
415		21	
			114.0'
410	BLACK SILTY SAND & WOOD	60/11	
	SHALE OR BOULDER	60/1	116.0'
405	BORING ADVANCED BY AUGER. WATER ENCOUNTERED @ 15.0'. WATER LEVEL @ 13.0' 24 HRS. AFTER COMPLETION. USED 20.0' OF BX CASING.		

	37	
	41	
		8
	37	
GREY SANDY SILTY CLAY TR. GRAVEL	34	
		9
SAND & GRAVEL		9
	36	
GREY SILTY CLAY TR. GRAVEL	30	
		106
SAND & GRAVEL		108
	29	
GREY SANDY SILTY CLAY TR. GRAVEL	26	
	24	120
BORING ADVANCED BY AUGER TO 20.0'. WATER ENCOUNTERED @ 16.0'. WATER LEVEL @ 10.0' 24 HRS. AFTER COMPLETION. USED 20.0' OF BX CASING.		

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

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.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 236.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet of

Appendix B
Supporting Materials for LOE#1

RAMBOLL

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW15

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Adam Jochimsen Cascade Drilling	1/21/2021	1/22/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW15	Feet (NAVD88)	522.06 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 821,107.90 N, 997,938.87 E Ⓔ/W
1/4 of 1/4 of Section 26, T 6 N, R 8 E
Lat 38° 55' 17.71"
Long -88° 17' 6.79"
Local Grid Location Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 / 54		1	0 - 6.3' **FILL, LEAN CLAY:** CL, brown (10YR 5/3), silt (15-25%) sand (0-5%), stiff, no dilatancy, low toughness, medium plasticity, moist.	(FILL) CL				1.75					CS= Core Sample
			2											
			3						1.75					
			4											
2 CS	60 / 40		5											
			6											
			7	6.3 - 20' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%) sand (0-5%), gravel (0-5%), organic material (0-5%), very stiff to stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL				2.25					
			8											
			9						4					
			10											
3 CS	60 / 50		11						1					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature
Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

RAMBOLL

SOIL BORING LOG INFORMATION SUPPLEMENT

Boring Number APW15 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	6.3 - 20' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%) sand (0-5%), gravel (0-5%), organic material (0-5%), very stiff to stiff, no dilatancy, medium toughness, medium plasticity, moist. *(continued)*					2.5					
			14											
4 CS	60 54		15						1.5					
			16		CL									
			17						2.25					
			18											
			19	19.2' brown (10YR 4/3), yellowish brown (10YR 5/6) mottling (10-15%), stiff.					2.5					
5 SH	24 23		20	20 - 22' **LEAN CLAY:** CL.						18.5	33	23	59.2	SH= Shelby Tube
			21		CL									
6 CS	96 96		22	22 - 23.5' **LEAN CLAY:** CL, brown (10YR 4/3), yellowish brown (10YR 5/6) mottling (10-15%), stiff, no dilatancy, medium toughness, medium plasticity, moist.					1.25					
			23		CL				1					
			24	23.5 - 26.7' **SANDY LEAN CLAY:** s(CL), brown (10YR 5/3), gray (10YR 5/1) mottling (5-10%), stiff, slow dilatancy, low toughness, medium plasticity, moist.										
			25		s(CL)				3.75					
			26											
			27	26.7 - 39.2' **LEAN CLAY:** CL, brown (10YR 5/3), yellowish brown (10YR 5/6) mottling (10-15%), gray (10YR 5/1) mottling (5-10%), sand (5-10%), gravel (0-5%), cobbles (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry to moist.					4.5					
			28											
			29		CL				4.5					
6 CS	60 49		30	30' hard, dry.										
			31						4.5					
			32											

RAMBOLL

SOIL BORING LOG INFORMATION SUPPLEMENT

Boring Number APW15 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	26.7 - 39.2' **LEAN CLAY**: CL, brown (10YR 5/3), yellowish brown (10YR 5/6) mottling (10-15%), gray (10YR 5/1) mottling (5-10%), sand (5-10%), gravel (0-5%), cobbles (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry to moist. *(continued)*					4.5					
			34											
7 CS	60 49		35		CL				4.5					
			36											
			37						4.5					
			38											
			39						4.5					
			40	39.2 - 52.5' **LEAN CLAY**: CL, dark gray (10YR 4/1), no mottling, organic material (0-5%), sand (5-10%), gravel (0-5%), cobbles (0-5%), hard, no dilatancy, medium toughness, medium plasticity, dry, silt stringers 1mm to 3mm diameter fracture planes.										
8 CS	60 60		41						4.5					
			42											
			43						4.5					
			44											
			45						4.5					
9 CS	60 60		46		CL									
			47						4.5					
			48											
			49						4.5					
			50											
10 CS	60 60		51						4.5					
			52											

RAMBOLL

SOIL BORING LOG INFORMATION SUPPLEMENT

Boring Number APW15 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			52											
			53	52.5 - 61.4' **SILT:** ML, dark gray (10YR 4/1), clay (15-25%), hard, no dilatancy, medium toughness, non-plastic, dry.					4.5					
			54											
11 CS	60 57		55						4.5					
			56											
			57		ML				4.5					
			58											
			59						4.5					
12 CS	60 52		60											
			61						4.5					
			62	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry.										
			63						2.75					
			64											
13 CS	60 60		65						2.75					
			66											
			67		CL				2.25					
			68											
			69						2					
14 CS	60 60		70											
			71						2.5					
			72											

RAMBOLL

SOIL BORING LOG INFORMATION SUPPLEMENT

Boring Number APW15 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			73	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry. *(continued)*					2.5					
			74											
15 CS	60 53		75						2					
			76											
			77						2.5					
			78											
			79						2.25					
16 CS	60 60		80											
			81						2.25					
			82		CL									
			83						4.5					
			84	83.8' - 83.9' layer of silty sand, moist.										
17 CS	60 60		85	85' - 85.4' later of silty sand, moist.					2.75					
			86											
			87						2.5					
			88											
			89						2.75					
18 CS	60 60		90											
			91						2.5					
			92											

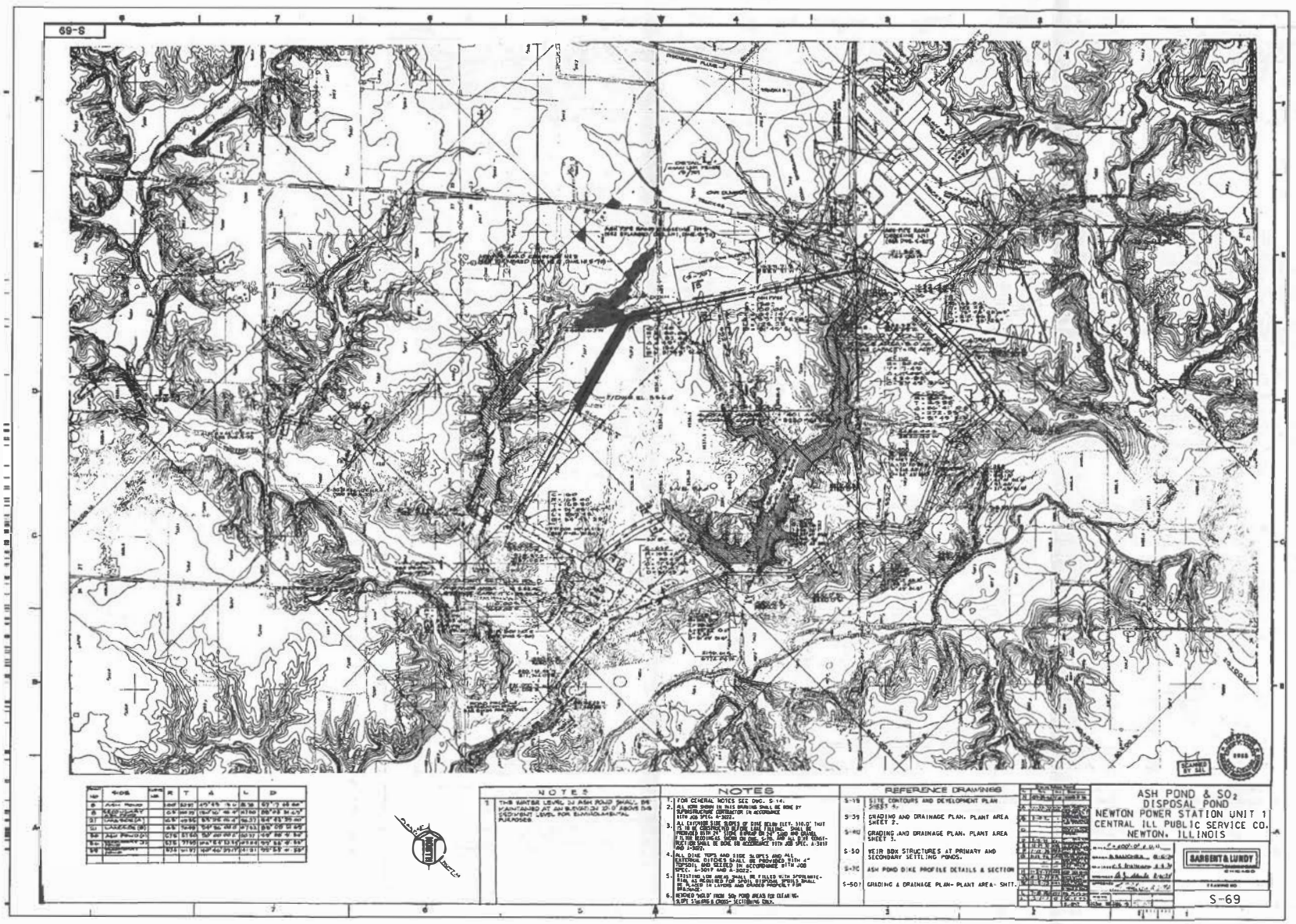
RAMBOLL

SOIL BORING LOG INFORMATION SUPPLEMENT

Boring Number APW15 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			93	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry. *(continued)*					2.75					
			94											
19 CS	60 60		95		CL									
			96											
			97											
			98	97.2 - 100' **POORLY-GRADED SAND WITH SILT:** SP-SM, dark gray (10YR 4/1), subrounded to rounded, medium to fine sand, loose, wet.	SP-SM									
			99											
20 SH	24 24		100	100 - 102' **SILTY SAND:** SM.	SM					12.1	15	3	45.8	
			101											
21 CS	36 36		102	102 - 104.3' **SANDY SILT:** s(ML), gray (10YR 5/1), firm, slow dilatancy, low toughness, non-plastic, wet.	s(ML)				1					
			103											
			104											
22 MC	24 24		105	104.3 - 105' **LEAN CLAY:** CL, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL					19.1	29	16	76.2	MC= Modified California Sample
			106	105 - 107' **LEAN CLAY:** CL.	CL									
23 CS	36 36		107	107 - 110' **LEAN CLAY:** CL, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist.					2.25					
			108		CL									
			109						2.5					
			110	110' End of Boring.										

C:\temp\A53AEC7B-4EA9-416A-AB49-1E8D12116480\ns69.dgn



NOTES
THE WATER LEVEL IN ASH POND SHALL BE MAINTAINED AT ANY ELEVATION 10.0' ABOVE THE SECONDARY LEVEL FOR ENVIRONMENTAL PURPOSES

NOTES

1. FOR GENERAL NOTES SEE DWG. S-14.
2. ALL WORK SHOWN IN THIS DRAWING SHALL BE DONE BY SUPERSTRUCTURE CONTRACTOR IN ACCORDANCE WITH JOB SPEC. A-3022.
3. ALL EXPOSED SIDE SLOPES OF DIKE BELOW ELEV. 380.0' THAT IS TO BE CONSTRUCTED OF PULVERIZED FILL MAT'L SHALL BE PROTECTED WITH 24" STONE RIPRAP ON THE LAND AND CHANNEL SIDES AS SHOWN ON DWG. S-76, AND ALL SUCH CONSTRUCTION SHALL BE DONE IN ACCORDANCE WITH JOB SPEC. A-3017 AND A-3025.
4. ALL DIKE TOPS AND SIDE SLOPES AND ALL EXTERNAL DITCHES SHALL BE PROVIDED WITH 4" TOPSOIL AND SEEDED IN ACCORDANCE WITH JOB SPEC. A-3019 AND A-3022.
5. EXCAVATION ALSO AREAS SHALL BE FILLED WITH SUITABLE MAT'L AND COMPACTED AS SPECIFIED. ALL AREAS SHALL BE BLADED TO LAYOUT AND GRADED PROPERLY. SEE DRAWING.
6. REMOVE "MUCK" FROM ASH POND AREAS TO CLEAN SUPT STRATA & CROSS-SECTIONS ONLY.

REFERENCE DRAWINGS

S-1S	SITE CONTOURS AND DEVELOPMENT PLAN SHEET 1.
S-3S	GRADING AND DRAINAGE PLAN. PLANT AREA SHEET 2.
S-4S	GRADING AND DRAINAGE PLAN. PLANT AREA SHEET 3.
S-5O	WEIR BOX STRUCTURES AT PRIMARY AND SECONDARY SETTLING PONDS.
S-7C	ASH POND DIKE PROFILE DETAILS & SECTION
S-50?	GRADING & DRAINAGE PLAN- PLANT AREA- SHT.

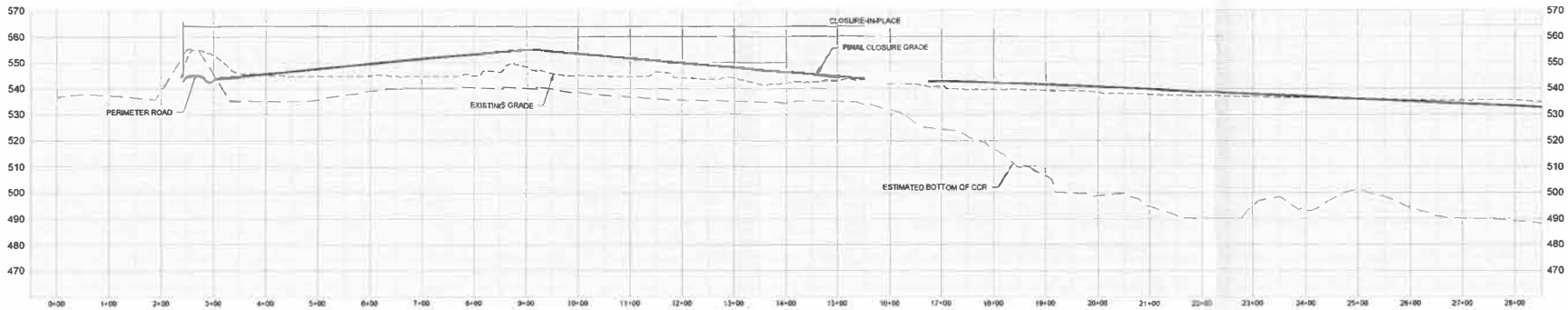
ASH POND & SO_2 DISPOSAL POND
NEWTON POWER STATION UNIT 1
CENTRAL ILL PUBLIC SERVICE CO.
NEWTON, ILLINOIS

SARGENT & LUNDY

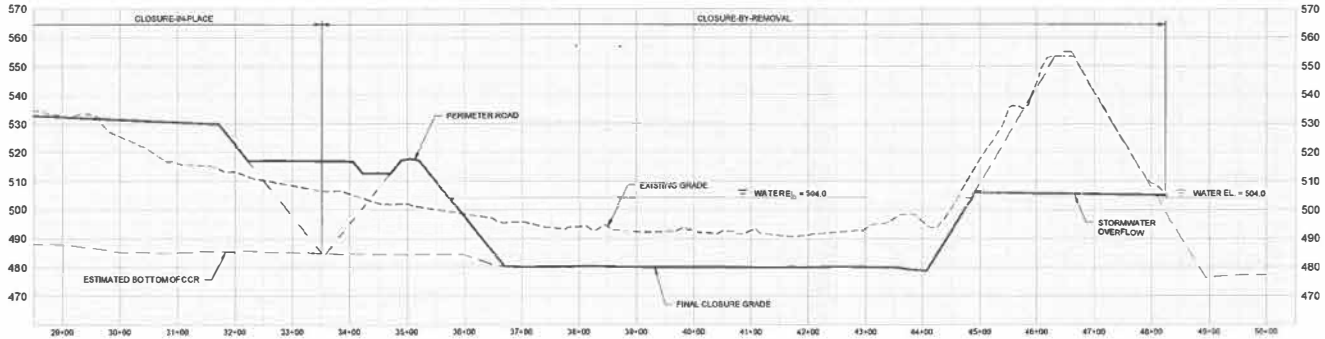
S-69

1 of 1

R001530



B-B / 00C108 SECTION B-B
HORIZ. 1" = 100' | VERT. 1" = 20'



B-B / 00C108 SECTION B-B (cont.)
HORIZ. 1" = 100' | VERT. 1" = 20'

ISSUE	DATE	DESCRIPTION
0	07/29/2022	ISSUED TO IEPA

PROJECT MANAGER M.ROBERTS
CIVIL G. WILLIAMS
CIVIL K. KIMLEY
DRAWN BY M.BICKFORD
PROJECT NUMBER 10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

CROSS SECTIONS

FILENAME 00C302.DWG
SCALE AS NOTED

SHEET
00C302

R001531

Appendix C
Supplemental Analytical Data

APPENDIX C.
SUPPORTING GROUNDWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Date	Parameter	Result	Unit
APW15	Compliance	02/23/2021	Boron, total	0.140	mg/L
APW15	Compliance	03/10/2021	Boron, total	0.130	mg/L
APW15	Compliance	03/31/2021	Boron, total	0.160	mg/L
APW15	Compliance	04/28/2021	Boron, total	0.130	mg/L
APW15	Compliance	05/24/2021	Boron, total	0.150	mg/L
APW15	Compliance	06/17/2021	Boron, total	0.130	mg/L
APW15	Compliance	06/30/2021	Boron, total	0.130	mg/L
APW15	Compliance	07/14/2021	Boron, total	0.160	mg/L
APW15	Compliance	03/14/2023	Boron, total	0.180	mg/L
APW15	Compliance	04/26/2023	Boron, total	0.130	mg/L
APW15	Compliance	02/23/2021	Chloride, total	260	mg/L
APW15	Compliance	03/10/2021	Chloride, total	250	mg/L
APW15	Compliance	03/31/2021	Chloride, total	240	mg/L
APW15	Compliance	04/28/2021	Chloride, total	230	mg/L
APW15	Compliance	05/24/2021	Chloride, total	230	mg/L
APW15	Compliance	06/17/2021	Chloride, total	240	mg/L
APW15	Compliance	06/30/2021	Chloride, total	230	mg/L
APW15	Compliance	07/14/2021	Chloride, total	130	mg/L
APW15	Compliance	03/14/2023	Chloride, total	230	mg/L
APW15	Compliance	04/26/2023	Chloride, total	270	mg/L
APW15	Compliance	02/23/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	03/10/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	03/31/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	04/28/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	05/24/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	06/17/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	06/30/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	07/14/2021	Sulfate, total	1 U	mg/L
APW15	Compliance	03/14/2023	Sulfate, total	0.6 J	mg/L
APW15	Compliance	04/26/2023	Sulfate, total	0.4 J	mg/L
XPW01	Porewater	02/17/2021	Boron, total	9.50	mg/L
XPW01	Porewater	03/09/2021	Boron, total	11.0	mg/L
XPW01	Porewater	03/30/2021	Boron, total	9.90	mg/L
XPW01	Porewater	04/28/2021	Boron, total	10.0	mg/L
XPW01	Porewater	07/14/2021	Boron, total	12.0	mg/L
XPW01	Porewater	02/23/2022	Boron, total	12.0	mg/L
XPW01	Porewater	08/15/2022	Boron, total	13.0	mg/L
XPW01	Porewater	02/01/2023	Boron, total	15.0	mg/L
XPW01	Porewater	04/27/2023	Boron, total	14.0	mg/L
XPW01	Porewater	02/17/2021	Chloride, total	49.0	mg/L
XPW01	Porewater	03/09/2021	Chloride, total	38.0	mg/L
XPW01	Porewater	03/30/2021	Chloride, total	32.0	mg/L
XPW01	Porewater	04/28/2021	Chloride, total	33.0	mg/L
XPW01	Porewater	07/14/2021	Chloride, total	27.0	mg/L
XPW01	Porewater	02/23/2022	Chloride, total	25.0	mg/L
XPW01	Porewater	06/14/2022	Chloride, total	14.0	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Date	Parameter	Result	Unit
XPW01	Porewater	08/15/2022	Chloride, total	11.0	mg/L
XPW01	Porewater	02/01/2023	Chloride, total	9.70	mg/L
XPW01	Porewater	04/27/2023	Chloride, total	8.10	mg/L
XPW01	Porewater	02/17/2021	Sulfate, total	19,000	mg/L
XPW01	Porewater	03/09/2021	Sulfate, total	14,000	mg/L
XPW01	Porewater	03/30/2021	Sulfate, total	19,000	mg/L
XPW01	Porewater	04/28/2021	Sulfate, total	12,000	mg/L
XPW01	Porewater	07/14/2021	Sulfate, total	11,000	mg/L
XPW01	Porewater	02/23/2022	Sulfate, total	9,300	mg/L
XPW01	Porewater	06/14/2022	Sulfate, total	6,100	mg/L
XPW01	Porewater	08/15/2022	Sulfate, total	5,900	mg/L
XPW01	Porewater	02/01/2023	Sulfate, total	4,200	mg/L
XPW01	Porewater	04/27/2023	Sulfate, total	2,900	mg/L
XPW02	Porewater	02/17/2021	Boron, total	2.30	mg/L
XPW02	Porewater	03/09/2021	Boron, total	2.50	mg/L
XPW02	Porewater	03/30/2021	Boron, total	2.40	mg/L
XPW02	Porewater	04/28/2021	Boron, total	2.60	mg/L
XPW02	Porewater	07/14/2021	Boron, total	2.50	mg/L
XPW02	Porewater	02/23/2022	Boron, total	2.40	mg/L
XPW02	Porewater	08/15/2022	Boron, total	2.40	mg/L
XPW02	Porewater	02/01/2023	Boron, total	2.30	mg/L
XPW02	Porewater	04/27/2023	Boron, total	2.30	mg/L
XPW02	Porewater	02/17/2021	Chloride, total	10.0	mg/L
XPW02	Porewater	03/09/2021	Chloride, total	9.60	mg/L
XPW02	Porewater	03/30/2021	Chloride, total	9.90	mg/L
XPW02	Porewater	04/28/2021	Chloride, total	9.70	mg/L
XPW02	Porewater	07/14/2021	Chloride, total	10.0	mg/L
XPW02	Porewater	02/23/2022	Chloride, total	12.0	mg/L
XPW02	Porewater	06/14/2022	Chloride, total	8.60	mg/L
XPW02	Porewater	08/15/2022	Chloride, total	8.90	mg/L
XPW02	Porewater	02/01/2023	Chloride, total	8.40 B	mg/L
XPW02	Porewater	04/27/2023	Chloride, total	8.80	mg/L
XPW02	Porewater	02/17/2021	Sulfate, total	160	mg/L
XPW02	Porewater	03/09/2021	Sulfate, total	150	mg/L
XPW02	Porewater	03/30/2021	Sulfate, total	160	mg/L
XPW02	Porewater	04/28/2021	Sulfate, total	190	mg/L
XPW02	Porewater	07/14/2021	Sulfate, total	160	mg/L
XPW02	Porewater	02/23/2022	Sulfate, total	210	mg/L
XPW02	Porewater	06/14/2022	Sulfate, total	170	mg/L
XPW02	Porewater	08/15/2022	Sulfate, total	160	mg/L
XPW02	Porewater	02/01/2023	Sulfate, total	150	mg/L
XPW02	Porewater	04/27/2023	Sulfate, total	150	mg/L
XPW03	Porewater	02/17/2021	Boron, total	1.30	mg/L
XPW03	Porewater	03/09/2021	Boron, total	1.20	mg/L
XPW03	Porewater	03/30/2021	Boron, total	0.840	mg/L
XPW03	Porewater	04/28/2021	Boron, total	1.20	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Date	Parameter	Result	Unit
XPW03	Porewater	07/14/2021	Boron, total	1.30	mg/L
XPW03	Porewater	02/23/2022	Boron, total	1.70	mg/L
XPW03	Porewater	08/16/2022	Boron, total	1.40	mg/L
XPW03	Porewater	02/02/2023	Boron, total	1.70	mg/L
XPW03	Porewater	04/27/2023	Boron, total	1.80	mg/L
XPW03	Porewater	02/17/2021	Chloride, total	14.0	mg/L
XPW03	Porewater	03/09/2021	Chloride, total	9.20	mg/L
XPW03	Porewater	03/30/2021	Chloride, total	13.0	mg/L
XPW03	Porewater	04/28/2021	Chloride, total	11.0	mg/L
XPW03	Porewater	07/14/2021	Chloride, total	11.0	mg/L
XPW03	Porewater	02/23/2022	Chloride, total	13.0	mg/L
XPW03	Porewater	06/15/2022	Chloride, total	11.0	mg/L
XPW03	Porewater	08/16/2022	Chloride, total	11.0	mg/L
XPW03	Porewater	02/02/2023	Chloride, total	9.60	mg/L
XPW03	Porewater	04/27/2023	Chloride, total	9.70	mg/L
XPW03	Porewater	02/17/2021	Sulfate, total	92.0	mg/L
XPW03	Porewater	03/09/2021	Sulfate, total	93.0	mg/L
XPW03	Porewater	03/30/2021	Sulfate, total	94.0	mg/L
XPW03	Porewater	04/28/2021	Sulfate, total	96.0	mg/L
XPW03	Porewater	07/14/2021	Sulfate, total	120	mg/L
XPW03	Porewater	02/23/2022	Sulfate, total	130	mg/L
XPW03	Porewater	06/15/2022	Sulfate, total	150	mg/L
XPW03	Porewater	08/16/2022	Sulfate, total	180	mg/L
XPW03	Porewater	02/02/2023	Sulfate, total	98.0	mg/L
XPW03	Porewater	04/27/2023	Sulfate, total	120	mg/L
XPW04	Porewater	02/17/2021	Boron, total	2.50	mg/L
XPW04	Porewater	03/09/2021	Boron, total	2.40	mg/L
XPW04	Porewater	03/29/2021	Boron, total	2.10	mg/L
XPW04	Porewater	04/28/2021	Boron, total	2.80	mg/L
XPW04	Porewater	07/14/2021	Boron, total	2.30	mg/L
XPW04	Porewater	02/23/2022	Boron, total	2.20	mg/L
XPW04	Porewater	08/16/2022	Boron, total	3.70	mg/L
XPW04	Porewater	02/01/2023	Boron, total	3.50	mg/L
XPW04	Porewater	04/28/2023	Boron, total	4.00	mg/L
XPW04	Porewater	02/17/2021	Chloride, total	62.0	mg/L
XPW04	Porewater	03/09/2021	Chloride, total	34.0	mg/L
XPW04	Porewater	03/29/2021	Chloride, total	31.0	mg/L
XPW04	Porewater	04/28/2021	Chloride, total	37.0	mg/L
XPW04	Porewater	07/14/2021	Chloride, total	34.0	mg/L
XPW04	Porewater	02/23/2022	Chloride, total	30.0	mg/L
XPW04	Porewater	06/15/2022	Chloride, total	50.0	mg/L
XPW04	Porewater	08/16/2022	Chloride, total	54.0	mg/L
XPW04	Porewater	02/01/2023	Chloride, total	46.0	mg/L
XPW04	Porewater	04/28/2023	Chloride, total	59.0	mg/L
XPW04	Porewater	02/17/2021	Sulfate, total	2,200	mg/L
XPW04	Porewater	03/09/2021	Sulfate, total	1,400	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Date	Parameter	Result	Unit
XPW04	Porewater	03/29/2021	Sulfate, total	600	mg/L
XPW04	Porewater	04/28/2021	Sulfate, total	3,800	mg/L
XPW04	Porewater	07/14/2021	Sulfate, total	1,600	mg/L
XPW04	Porewater	02/23/2022	Sulfate, total	1,800	mg/L
XPW04	Porewater	06/15/2022	Sulfate, total	7,500	mg/L
XPW04	Porewater	08/16/2022	Sulfate, total	4,000	mg/L
XPW04	Porewater	02/01/2023	Sulfate, total	6,200	mg/L
XPW04	Porewater	04/28/2023	Sulfate, total	9,500	mg/L

Notes:
mg/L = milligrams per liter
B = The analyte was found in sample and in associated method blank.
J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.
U = The analyte was analyzed for, but was not detected above the level of the adjusted detection limit or quantitation limit, as appropriate.

217-782-1020

April 29, 2024

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Joppa Power Plant East Ash Pond; W1270100004-02
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 Joppa East Ash Pond Alternative Source Demonstration (ASD) dated October 21, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Source characterization of the CCR at the East Ash Pond must include total solids sampling in accordance with SW846.
2. Hydraulic conductivities from laboratory or insitu testing must be collected and presented with hydrogeologic characterization of all units including aquifers and confining units.
3. Characterization to include sample and analysis in accordance with 35 IAC 845.640 of alternative source must be provided with the ASD.

If you have any questions, please contact: **Lauren Hunt** Illinois EPA, Bureau of Water, PWS #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: Lauren Hunt
Keegan Macdonna
WPC Files 06M

Luminant

Electric Energy, Inc.
1500 Eastport Plaza Drive
Collinsville, IL 62234

October 21, 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

RECEIVED
OCT 20 2023
IEPA
BOW/WPC/PERMIT SECTION

Re: Joppa Power Plant East Ash Pond; IEPA ID # W1270100004-02

Dear Mr. LeCrone:

In accordance with Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.650(e), Electric Energy, Inc. (EEI) is submitting this Alternative Source Demonstration (ASD) for exceedances observed from the Quarter 2 2023 sampling event at the Joppa Power Plant East Ash Pond, identified by Illinois Environmental Protection Agency (IEPA) ID No. W1270100004-02.

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, East Ash Pond Joppa Power Plant, Joppa Illinois

Intended for
Electric Energy, Inc.

Date
October 21, 2023

Project No.
1940103649-011

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION

EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS
IEPA ID: W1270100004-02

RAMBOLL Bright ideas. Sustainable change.

CERTIFICATIONS

I, Anne Frances Ackerman, a qualified professional engineer in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Anne Frances Ackerman
Qualified Professional Engineer
062-060586
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 21, 2023

I, Brian G. Hennings, a professional geologist in good standing in the State of Illinois, certify that the information in this report is accurate as of the date of my signature below. The content of this report is not to be used other than for its intended purpose and meaning, or for extrapolations beyond the interpretations contained herein.

Brian G. Hennings
Professional Geologist
196-001482
Illinois
Ramboll Americas Engineering Solutions, Inc.
Date: October 21, 2023

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA
T 414-837-3607
F 414-837-3608
https://ramboll.com

CONTENTS

1.	**Introduction**	**3**
2.	**Background**	**4**
2.1	Site Location and Description	4
2.2	Description of East Ash Pond CCR Unit	4
2.3	Geology and Hydrogeology	4
2.4	Groundwater and EAP Monitoring	6
3.	**Alternative Source Demonstration: Lines of Evidence for Cobalt**	**7**
3.1	LOE #1: Cobalt Concentrations at G05 are Consistent with Cobalt Mobilization from Native Soils Due to Reductive Dissolution of Manganese Oxides	7
3.2	LOE #2: Cobalt Concentrations at G05 are Greater Than Source Concentrations	9
3.3	LOE #3: Cobalt Concentrations at G05 Are Not Correlated with Concentrations of CCR Indicator Parameters	10
4.	**Alternative Source Demonstration: Lines of Evidence for pH**	**12**
4.1	LOE #1: G11 and G51D are Upgradient of the EAP	12
4.2	LOE #2: Groundwater Chemistry at G11 and G51D is Aligned with the Groundwater Signature Observed West of the Monitoring Wells	12
4.3	LOE #3: pH Exceedances at G11 and G51D are Consistent with Iron Oxidation	12
5.	**Conclusions**	**14**
6.	**References**	**15**

TABLES (IN TEXT)

Table A	Cobalt Concentration Ranges in G05 and EAP Porewater (March 2021 to May 2023)

FIGURES (IN TEXT)

Figure A	Scatter Plot and Linear Regression Results of Cobalt and Manganese in UA Solids
Figure B	Scatter Plot and Linear Regression Results of Total Cobalt and Total Manganese in Groundwater
Figure C	Scatter Plot of Cobalt Versus Boron and Sulfate Concentrations at Monitoring Well G05

FIGURES (ATTACHED)

Figure 1	Top of Uppermost Aquifer
Figure 2	Sampling Locations and Potentiometric Surface Map – May 1, 2023

APPENDICES (ATTACHED)

Appendix A	Supporting Solid Phase Analytical Data
Appendix B	Supporting Analysis for Reductive Dissolution of Manganese Oxides as a Likely Source of Cobalt Concentrations at G05
Appendix C	Supporting Groundwater and Porewater Analytical Data
Appendix D	Geochemical Analysis of Joppa East Ash Pond Groundwater in Support of An Alternative Source Demonstration (Life Cycle Geo, LLC, 2023)

ACRONYMS AND ABBREVIATIONS

35 I.A.C.	Title 35 of the Illinois Administrative Code
ASD	Alternative Source Demonstration
CCR	coal combustion residuals
E001	Event 1
EAP	East Ash Pond
Geosyntec	Geosyntec Consultants
GWPS	groundwater protection standard
JPP	Joppa Power Plant
LAU	Lower aquifer unit
LCU	lower confining unit
LOE(s)	Line(s) of evidence
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
NAVD88	North American Vertical Datum of 1988
NRT/OBG	Natural Resource Technology, an OBG Company
NTU	nephelometric turbidity units
OBG	O'Brien and Gere Engineers, Inc.
ORP	oxidation reduction potential
PCA	principal component analysis
PMP	potential migration pathway
Ramboll	Ramboll Americas Engineering Solutions, Inc.
SI	surface impoundment
UA	uppermost aquifer
UCU	upper confining unit
WAP	West Ash Pond

1. INTRODUCTION

Under Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e), 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, an owner or operator of a coal combustion residuals (CCR) surface impoundment (SI) may complete a written demonstration that a source other than the CCR SI caused the contamination and the CCR SI 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 (Alternative Source Demonstration [ASD]).

This ASD has been prepared on behalf of Electric Energy Inc. by Ramboll Americas Engineering Solutions, Inc (Ramboll), to provide pertinent information pursuant to 35 I.A.C. § 845.650(e) for the Joppa Power Plant (JPP) East Ash Pond (EAP) (*i.e.,* Site) located near Joppa, Illinois.

The most recent quarterly sampling event (Event 1 [E001]) was completed on May 3, 2023, and analytical data were received on June 23, 2023. In accordance with 35 I.A.C. § 845.610(b)(3)(C), comparison of statistically derived values with the GWPSs described in 35 I.A.C. § 845.600 to determine exceedances of the GWPS was completed by August 22, 2023, within 60 days of receipt of the analytical data (Ramboll, 2023). The statistical comparison identified the following GWPS exceedances at compliance groundwater monitoring wells:

- Boron at wells G06, G07, G08, G09, G10
- Cobalt at well G05
- pH at wells G11 and G51D

Pursuant to 35 I.A.C. § 845.650(e), the lines of evidence (LOE) presented in **Section 3** and **Section 4** demonstrate that sources other than the EAP are the cause of the cobalt and pH GWPS exceedances (respectively) listed above. Cobalt is believed to be naturally occurring and pH is associated with iron oxidation. This ASD was completed by October 21, 2023, within 60 days of determination of the exceedances (August 22, 2023), as required by 35 I.A.C. § 845.650(e).

Boron GWPS exceedances at the EAP will be addressed in accordance with 35 I.A.C. § 845.660.

2. BACKGROUND

2.1 Site Location and Description

The JPP is west of the Village of Joppa in Massac County, Illinois, northeast of the Ohio River in Section 14, Township 15 South, Range 3 East. The JPP property is bordered by LaFarge North America cement plant to the west, Trunkline Gas Company-Joppa Compressor Station to the north and west, the Village of Joppa to the east, and the Ohio River to the south. The EAP is located in the west half of Section 14 directly north of the JPP and is bounded immediately to the east by the railway right-of-way, which is adjacent to forested portions of residential property in the Village of Joppa.

2.2 Description of East Ash Pond CCR Unit

The JPP operated the EAP for management of CCR waste streams between 1973 and 2022. Another inactive SI, referred to as the West Ash Pond (WAP), is present in the western portion of the JPP property, and a permit exempt landfill is present in the northwestern portion of the JPP property. The landfill and the WAP are not the subject of this ASD but are relevant to the discussion of the LOEs presented below.

The EAP is an unlined CCR SI which was used to manage both fly ash and bottom ash. The EAP perimeter embankment height varies from approximately 15 to 45 feet above the outboard toe of slope and the crest is at an approximate elevation of 380 feet North American Vertical Datum of 1988 (NAVD88) (O'Brien and Gere Engineers, Inc. [OBG], 2010).

2.3 Geology and Hydrogeology

The information used to describe the hydrogeology is based on the local geology obtained from published sources, hydrogeologic investigation data, and boring data collected during site investigations conducted from 1997 to 2022 (Natural Resource Technology, an OBG Company [NRT/OBG], 2017; Ramboll, 2021a; Geosyntec, 2023).

Quaternary deposits in the Joppa area consist mainly of diamictons and lacustrine/alluvial deposits that were deposited during Illinoian and Pre-Illinoian glaciations (Lineback, 1979; Willman et al., 1975). The unconsolidated deposits include the following units (beginning at the ground surface):

- **Upper Confining Unit (UCU):** The uppermost hydrostratigraphic unit is comprised of the Equality Formation, the Silt Unit, and Metropolis Formation deposits. The average thickness of this unit is approximately 40 feet with a range of 8 to 58 feet. The UCU underlies the CCR fill in all locations and is thinnest in the southeast portion of the unit. These deposits are predominantly fine-grained, comprised of clay, silt, and silty clay with limited intervals of sandy material. This hydrostratigraphic unit was encountered at all locations and extends down to the McNairy Formation.
- **Uppermost Aquifer (UA):** The UA consists of the McNairy Formation and Mounds Gravel which are composed of highly permeable sands and gravels with isolated lenses of finer grained material. The Mounds Gravel has been interpreted as a braided river deposit, located within eroded portions of the McNairy Formation (Nelson and Masters, 2008). The McNairy formation, underlying the Mounds Gravel, at the site is mostly composed of medium to fine grained sand with mica and lenses of silt and clay. At the EAP, this unit has been further divided into the Upper McNairy Formation consisting of relatively thick fine to medium grained

sand with some gravel while the Lower McNairy exhibits more variability including lenses and zones with higher silt and clay content.

A northwest to southeast trending stratigraphic high in the UA is present through the center of the EAP and bifurcates near the eastern extent of the unit. This stratigraphic high (elevations higher than 305 ft) is illustrated on **Figure 1** where the UA is bounded by the UCU which is shaded purple where elevations extend below 305 feet. Wells screened within the UA along the southern fork of the stratigraphic high (G07, G08, G12S/D, G13S/D) generally encountered thicker gravel layers at higher elevations and reported higher hydraulic conductivities (Ramboll, 2021a; Geosyntec, 2023). The thicker gravels at higher elevations also extend east and southeast of the EAP (G12S/D, G13S/D, G16S/D) and connect to the Ohio River as illustrated in **Figure 1.** The UA was encountered at a thickness of up to 58 feet thick, with elevations ranging from 215 to 316.6 feet, and is underlain by the lower confining unit (LCU).

- **Lower Confining Unit (LCU):** Clay, silt, or chert gravel residuum in on-Site wells (Nelson, 1997) has been interpreted and characterized as part of the Lower McNairy Formation, Post Creek (Tuscaloosa) Formation, or weathered limestone residuum. This material has been encountered in all borings advanced to bedrock. Based on material descriptions (high clay and/or silt content, and partial cementation), continuous lateral extent, and vertical gradients observed between the UA and the lower aquifer unit (LAU), this unit is identified as the LCU.
- **Lower Aquifer Unit (LAU):** The LAU, composed of the Salem Limestone bedrock, is the lowermost hydrostratigraphic unit identified and is considered a potential migration pathway (PMP). The limestone bedrock is encountered at an elevation of approximately 200 feet NAVD88 below the EAP, slopes towards a syncline to the east (Nelson and Masters, 2008), and has a reported thickness of 200 to 500 feet. The Salem Limestone is used to supply water for various uses in the region and provides non-potable water for the JPP and potable water for the Village of Joppa.

Groundwater elevations in the UA (referenced to NAVD88) across the EAP ranged from approximately 312 to 322 feet during E001 (**Figure 2**). Historically they have ranged from approximately 305 feet near the Ohio River to 330 feet near the northern property boundary. Depth to groundwater measurements used to generate the groundwater elevation contours shown on **Figure 2** were collected on May 1, 2023. Groundwater elevations vary seasonally and may fluctuate by about 10 feet within a well.

Groundwater flow directions are largely a result of the aquifer geology described above. The shallow highly permeable gravels present a path of least resistance (preferential flow pathway) for groundwater migrating toward the Ohio River which is the receiving body of water in the region (**Figure 1**). Wells located to the north of the UA stratigraphic high, such as G05, were terminated shortly after penetrating the UA and did not encounter significant gravel layers indicating gravel may be at a lower elevation or not present, and flow through this area may not be as significant. Interpreted groundwater flow directions are illustrated on **Figure 1** with flow to the southeast, generally parallel to the UA stratigraphic high across the EAP, and then south toward the Ohio River.

2.4 Groundwater and EAP Monitoring

The monitoring system for the EAP is shown on **Figure 2** and consists of two background monitoring wells (G01D and G02D) and 12 compliance monitoring wells (G03, G05, G06, G07, G08, G09, G10 G11, G51D, G52D, G53D, and G54D) screened within the UA. The monitoring system also includes two temporary water level only surface water staff gage (XSG01 and SG02) to monitor potential impacts from the EAP (Ramboll, 2021b). Porewater samples are collected from locations XPW01 and XPW02 on the northern side of the EAP, and from XPW03 on the southern side of the EAP (**Figure 2**). To further delineate potential boron exceedances, 10 monitoring wells were installed in September 2021 (nests G12 through G16) and 21 wells (10 off-Site) were installed between May 2022 and September 2023 (nests G17 through G24, and G13; Geosyntec Consultants [Geosyntec], 2023).

3. ALTERNATIVE SOURCE DEMONSTRATION: LINES OF EVIDENCE FOR COBALT

As allowed by 35 I.A.C. § 845.650(e), this ASD demonstrates that sources other than the EAP (the CCR unit) caused the cobalt exceedance at G05. LOEs supporting the ASD for the pH exceedances at G11 and G51D are presented in **Section 4**. This section presents the LOEs supporting the ASD for cobalt at G05, which include the following:

1. Cobalt concentrations at G05 are consistent with cobalt mobilization from native soils due to reductive dissolution of manganese oxides.
2. Cobalt concentrations at G05 are greater than source concentrations.
3. Cobalt concentrations at G05 are not correlated with concentrations of CCR indicator parameters.

3.1 LOE #1: Cobalt Concentrations at G05 are Consistent with Cobalt Mobilization from Native Soils Due to Reductive Dissolution of Manganese Oxides

Cobalt and manganese are often closely associated with each other in soils due to their similar chemical properties (Uren, 2013). Under oxidizing conditions, manganese is present in the solid phase as manganese oxides. Cobalt sorbs strongly to manganese oxides and is thus often associated with manganese in the solid phase. When solid-phase manganese oxides in soils are dissolved by reduction of manganese to a more soluble species (a process called reductive dissolution), the cobalt previously sorbed to the manganese oxide surface is also released. If cobalt concentrations in groundwater are primarily controlled by the reductive dissolution of manganese oxides, cobalt and manganese concentrations in both soils and groundwater will be correlated with one another. This LOE demonstrates that cobalt concentrations at G05 are consistent with reductive dissolution of manganese, and the cobalt exceedance at G05 is therefore likely due to natural variation in groundwater quality. Solid phase data were used to determine if cobalt and manganese are associated in the solid phase. Groundwater redox potential and pH were assessed to determine if reductive dissolution of manganese oxides is thermodynamically favorable under observed groundwater conditions. To inform further analysis of groundwater data, wells with a geochemical signature similar to G05 were identified using principal component analysis (PCA). The relationship between cobalt and manganese in similar groundwater was then evaluated using regression analysis.

Figure A on the following page shows the relationship between total cobalt and total manganese in soil samples from the UA at five soil boring locations (data tabulated in **Appendix A**). The strong correlation between cobalt and manganese in these data (R^2 of 0.99) indicates that they are likely physically associated in soils, consistent with literature data (Uren, 2013). It is possible that cobalt released from CCR porewater could become associated with naturally occurring manganese oxides in the downgradient environment and accumulate in the soils; however, this is not likely at the site based on the following observations: 1) Cobalt is not present in CCR porewater (described further in **Section 3.2**), indicating that the EAP could not be a source of cobalt to the downgradient solid phase; 2) The ratio of cobalt to manganese is consistent across five different samples, some of which are from areas of the site with no known influence from

CCR porewater (*i.e.*, have had no reported exceedances). Therefore, the cobalt present in the UA soil is likely naturally occurring.

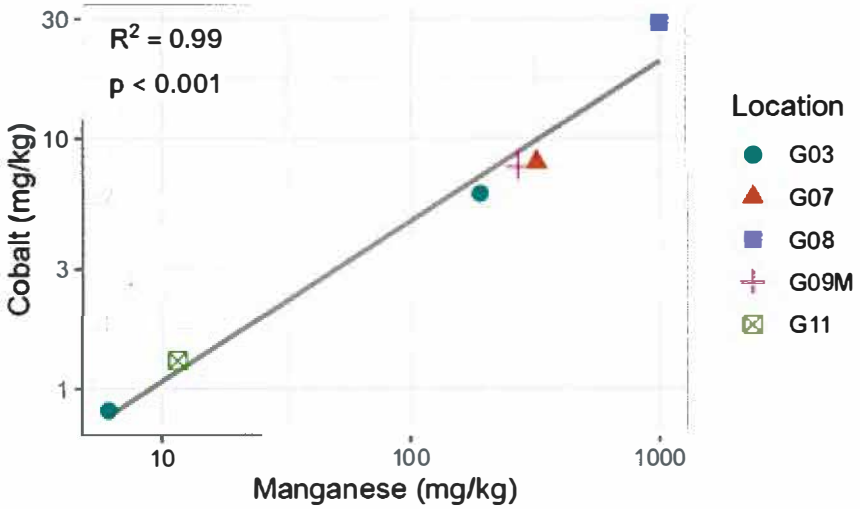


Figure A. Scatter Plot and Linear Regression Results of Cobalt and Manganese in UA Solids
mg/kg = milligrams per kilogram

The thermodynamic favorability of manganese oxide reductive dissolution depends on the oxidation reduction potential (ORP) and pH of the groundwater. The pH and ORP of the groundwater samples collected from the EAP monitoring network all indicate that manganese is expected to exist in the reduced Mn^{2+} form in groundwater (**see Appendix B**), supporting the conclusion that reductive dissolution of manganese oxides can occur in the groundwater.

To determine if cobalt and manganese are correlated in groundwater, locations with a similar groundwater signature to G05 were identified for appropriate inclusion in the correlation analysis. PCA, a multivariate statistical approach, was used to evaluate how the groundwater composition at G05 related to the groundwater composition of EAP porewater, background groundwater, and downgradient groundwater north versus south of the UA stratigraphic high (**Section 2.3**). Details about the PCA analysis are included in **Appendix B**. The PCA results indicate that the geochemical signatures of the UA wells located on either side of the northwest to southeast trending stratigraphic high in the UA that extends through the EAP are largely distinct from one another, with wells to the north of the stratigraphic high being more similar to background. This difference may be related to the differences in stratigraphic conditions, with wells to the north of the stratigraphic high having less gravel beds, while the wells to the south of the stratigraphic high have shallow highly permeable gravels which create a preferential flow pathway to the south. Groundwater from well G05 is most like other northeast wells, suggesting similar geochemical influences.

Figure B on the following page shows the relationship between total cobalt and total manganese in wells to the north of the stratigraphic high (data tabulated in **Appendix C**). To avoid potential confounding effects due to the presence of suspended solids in the groundwater sample, only samples with a turbidity less than 50 nephelometric turbidity units (NTU) were used in the

correlation analysis. The strong (R^2 of 0.77) statistically significant ($p < 0.001$) correlation between total cobalt and total manganese in the groundwater suggests similar controls on concentrations.

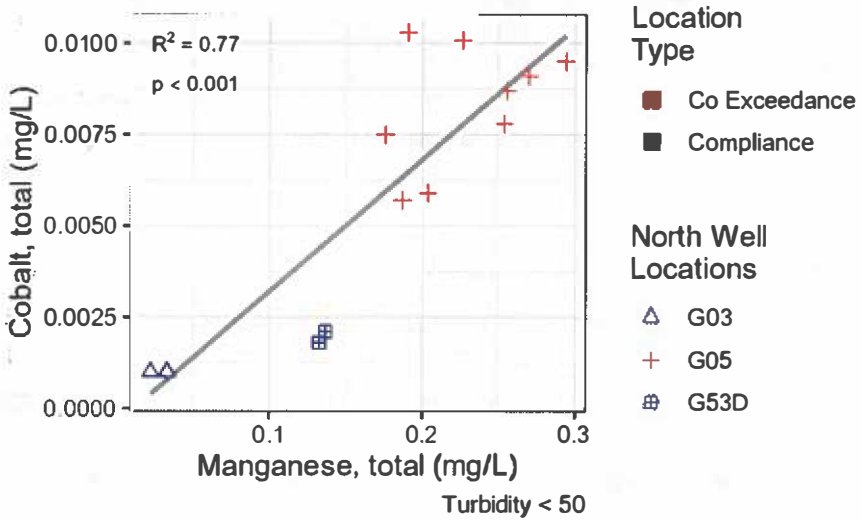


Figure B. Scatter Plot and Linear Regression Results of Total Cobalt and Total Manganese in Groundwater

The strong association between cobalt and manganese in both the soil and groundwater, in addition to groundwater conditions in the area of G05 favoring manganese reduction, supports the conclusion that reductive dissolution of manganese oxides in native soil is occurring and is strongly influencing the cobalt concentrations in the groundwater rather than the EAP.

3.2 LOE #2: Cobalt Concentrations at G05 are Greater Than Source Concentrations

Table A on the following page provides the range of cobalt concentrations detection in G05 between March 2021 and May 2023. Porewater samples collected from XPW01, XPW02 and XPW03 between March 2021 and May 2023 did not have cobalt concentrations above the reporting limit. A summary of the laboratory data is included in **Appendix C**.

Table A. Cobalt Concentration Ranges in G0S and EAP Porewater (March 2021 to May 2023).

Sample Location	Cobalt (mg/L)			
	Samples	Non-Detects	Minimum	Maximum
Composite Porewater[1]	24	24	<0.0001	<0.001
G05	11	0	0.0057	0.0103

[1] Composite Porewater includes summary statistics of data collected at EAP porewater locations XPW01, XPW02, and XPW03

mg/L = milligrams per liter

The following observations can be made from **Table A**:

- The concentration of cobalt in compliance monitoring well G05 ranged from 0.0057 mg/L to 0.0103 mg/L.
- Cobalt was not detected in EAP porewater, with reporting limits ranging from 0.0001 mg/L to 0.001 mg/L.
- The minimum cobalt concentration observed at G05 is five times the highest reporting limit for cobalt in porewater.

If the EAP were the source of cobalt in downgradient groundwater, EAP porewater concentrations of cobalt would be expected to be higher than the groundwater concentrations. Cobalt was not detected above the reporting limit in any porewater samples, indicating that cobalt concentrations are not related to the EAP.

3.3 LOE #3: Cobalt Concentrations at G05 Are Not Correlated with Concentrations of CCR Indicator Parameters

Boron is commonly used as an indicator parameter for contaminant transport of CCR because: (i) it is commonly present at elevated concentrations in coal ash leachate; (ii) it is mobile and typically not very reactive but conservative (*i.e.*, low rates of sorption or degradation) in groundwater; and (iii) it is less likely than other constituents to be present at elevated concentrations in background groundwater from natural or other anthropogenic sources. Porewater in the EAP is elevated in both boron and sulfate (**Appendix C**), indicating that these parameters are Site-specific key indicators for CCR. If an exceedance is identified for a monitored CCR parameter but concentrations of boron and sulfate are not correlated with that parameter, it is unlikely that the CCR unit is the source of the GWPS exceedance.

A scatter plot of cobalt versus boron and sulfate concentrations for G05 between March 2021 and May 2023 is presented in **Figure C** on the following page and laboratory data is included in **Appendix C.** The p-value of a Kendall correlation test for non-parametric data are also included on **Figure C**. Typically, a p-value greater than 0.05 is considered to be a statistically insignificant relationship.

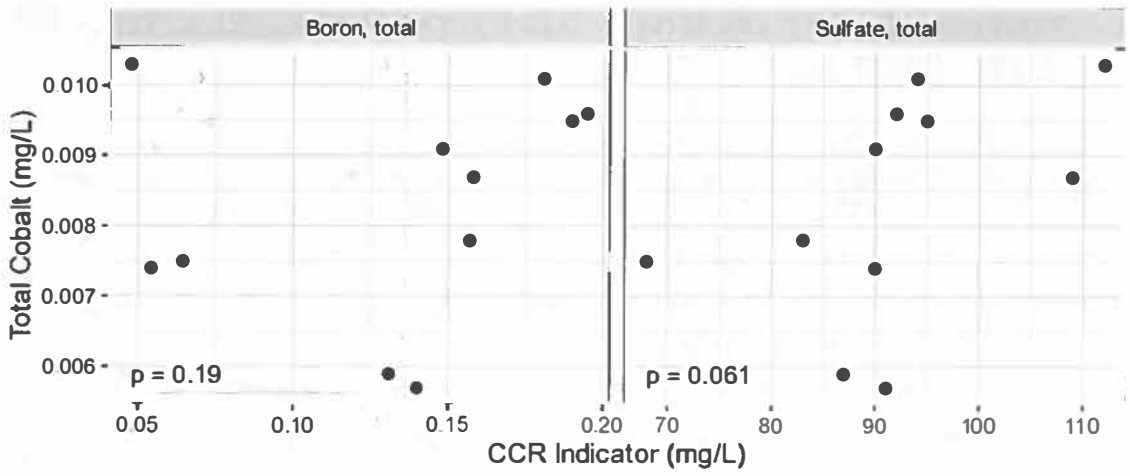


Figure C. Scatter Plot of Cobalt Versus Boron and Sulfate Concentrations at Monitoring Well G0S

Calculated p-values greater than 0.05 indicate that cobalt is not correlated with boron and sulfate at monitoring well G05. A lack of correlation between cobalt and CCR indicators in the compliance monitoring well indicates the EAP is not the source of the cobalt exceedance.

4. ALTERNATIVE SOURCE DEMONSTRATION: LINES OF EVIDENCE FOR pH

As allowed by 35 I.A.C. § 845.650(e), this ASD demonstrates that sources other than the EAP (the CCR unit) caused the pH exceedances at G11 and G51D. This section presents the LOEs supporting the ASD for pH at G11 and G51D, which include the following:

1. G11 and G51D are upgradient of the EAP.
2. Groundwater chemistry at G11 and G51D is aligned with the groundwater signature observed west of the monitoring wells.
3. pH exceedances at G11 and G51D are consistent with iron oxidation.

These LOEs are summarized below and described in greater detail in **Appendix D**.

4.1 LOE #1: G11 and G51D are Upgradient of the EAP

As described in **Section 2.3** dominant UA groundwater flow direction at the EAP is to the southeast, generally parallel to the UA stratigraphic high across the EAP, and then south toward the Ohio River (**Figure 1**). Wells G11 and G51D are located on the western edge of the EAP and are upgradient of the EAP. Therefore, it is unlikely that porewater from the EAP would flow in the direction of G11 and G51D. Because the wells with pH exceedances are upgradient of the unit, it is unlikely that the EAP is the source of the exceedances.

4.2 LOE #2: Groundwater Chemistry at G11 and G51D is Aligned with the Groundwater Signature Observed West of the Monitoring Wells

Groundwater from exceedance wells G11 and G51D exhibit a high degree of similarity with groundwater from upgradient UA wells west of G11 and G51D (western groundwater) as opposed to eastern groundwater or CCR porewaters from other compliance wells in the EAP monitoring network (eastern groundwater). PCA (**Appendix D**) was used to compare the geochemical compositions of the western groundwater, CCR porewaters, and pH exceedance wells G11 and G51D. The PCA found that:

- Exceedance wells G51D and G11 exhibit a high degree of similarity with the western (*i.e.*, upgradient) wells screened in the UA.
- The CCR porewaters are distinctly separate from the groundwater samples.

The similarity of the groundwater composition at G11 and G51D to upgradient western groundwater, as opposed to eastern groundwater or CCR porewater, suggests that the EAP does not influence the groundwater at G11 and G51D and therefore is not the source of the pH exceedances.

4.3 LOE #3: pH Exceedances at G11 and G51D are Consistent with Iron Oxidation

The PCA analysis (**Appendix D**) suggests chemical evolution and/or communication within the western groundwater. The western UCU groundwater composition is dominated by the redox-sensitive parameters manganese, iron, and sulfate. The UA groundwater composition is spread between a composition similar to the UCU and a composition similar to background. Groundwater

composition at wells G11 and G51D is very similar to (*i.e.*, plots close to on the PCA diagram) the background wells, all of which are dominated by alkalinity, chloride, fluoride and sodium.

Redox conditions were evaluated along the flow path from upgradient (further northwest) to downgradient (further southeast) groundwater wells. A distinct redox transition was identified, shifting from more reducing conditions in upgradient waters to more oxidizing conditions in downgradient wells, including the exceedance wells. The reducing upgradient waters are characterized by lower ORP and higher iron concentrations, while downgradient waters are largely the opposite with higher ORP and lower iron concentrations.

This change in redox condition is the likely source of acidity in G11 and G51D. It is likely that dissolved iron present in reducing environments moves downgradient with groundwater and subsequently oxidizes. The oxidation of dissolved iron to iron oxides is known to produce acidity. In this way, reduced upgradient waters from the northwest provides the constituent (*i.e.*, reduced iron) necessary to cause a drop in pH (*i.e.*, through iron oxidation) in G11 and G51D, once transported into an area with sufficient dissolved oxygen to drive the precipitation reaction. The oxidized environment in wells G11 and G51D likely results from mixing with the upgradient oxidized background groundwater. Therefore, mixing of groundwater resulting in natural variability in the groundwater conditions is the likely driver of the pH exceedances at G11 and G51D.

5. CONCLUSIONS

Based on the LOEs presented below and described in **Section 3**, it has been demonstrated that sources other than the EAP (the CCR unit) caused the cobalt exceedance at G05.

1. Cobalt concentrations at G05 are consistent with cobalt mobilization from native soils due to reductive dissolution of manganese oxides.
2. Cobalt concentrations at G05 are greater than source concentrations.
3. Cobalt concentrations at G05 are not correlated with concentrations of CCR indicator parameters.

Furthermore, based on the LOEs presented below and described in **Section 4**, it has been demonstrated that sources other than the EAP caused the pH exceedances at G11 and G51D.

1. G11 and G51D are upgradient of the EAP.
2. Groundwater chemistry at G11 and G51D is aligned with the groundwater signature observed west of the monitoring wells.
3. pH exceedances at G11 and G51D are consistent with iron oxidation.

Pursuant to 35 I.A.C. § 845.650(e), the LOEs presented in **Section 3** and **Section 4** demonstrate that sources other than the EAP were the cause of the cobalt and pH GWPS exceedances (respectively) listed above. Boron GWPS exceedances at the EAP will be addressed in accordance with 35 I.A.C. § 845.660.

6. REFERENCES

Geosyntec Consultants, Inc. (Geosyntec), 2023. *Supplemental Site Investigation Report. Joppa Power Station, East Ash Pond (CCR Unit #401), Electric Energy, Inc.*

Life Cycle Geo, LLC., 2023, *Geochemical Analysis of Joppa East Ash Pond Groundwater in Support of an Alternative Source Demonstration.*

Lineback, J., 1979, *Quaternary Deposits of Illinois: Illinois State Geological Survey map, scale 1:500,000.*

Natural Resource Technology, an OBG Company (NRT/OBG), 2017. *Hydrogeologic Monitoring Plan, Joppa East Ash Pond – CCR Unit ID 401, Joppa Power Station, Joppa, Illinois, Electric Energy, Inc.* October 17, 2017.

Nelson, W.J. and Masters, J.M., 2008. Geology of Joppa Quadrangle, Massac County, Illinois. Illinois Department of Natural Resources. Illinois State Geological Survey. Champaign, Illinois.

O'Brien & Gere Engineers, Inc. (OBG), 2010. *Dam Safety Assessment of CCW Impoundments. Joppa Plant, Prepared for: US Environmental Protection Agency, Washington, DC.* September 24, 2010.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021a. *Hydrogeologic Site Characterization Report. Joppa Power Plant, East Ash Pond, Joppa, Illinois. Electric Energy, Inc.* October 25, 2021.

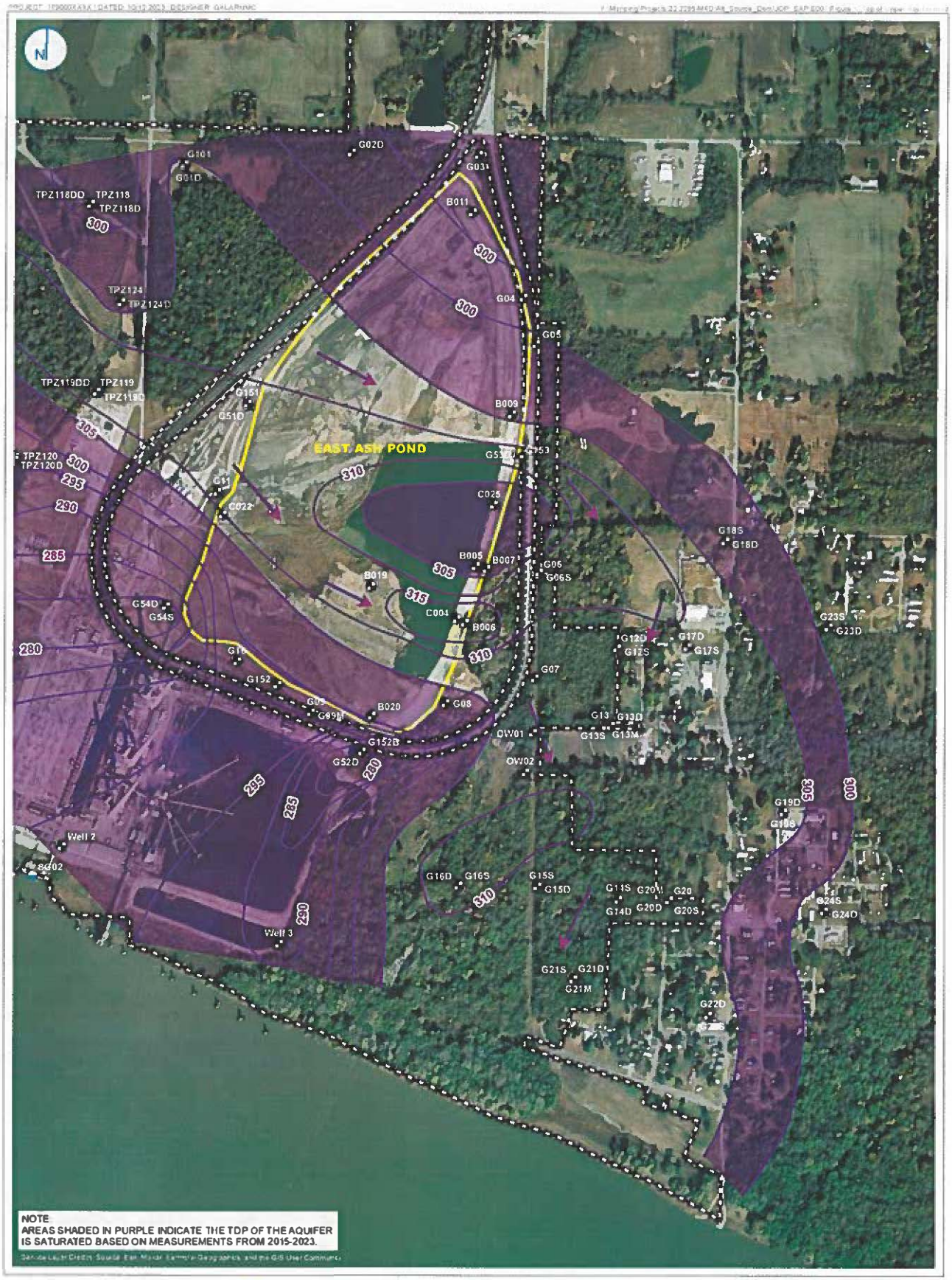
Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021b. *Groundwater Monitoring Plan, Joppa Power Plant, East Ash Pond, Joppa, Illinois, Electric Energy, Inc.* October 25, 2021.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2023. *35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances, 2023 Quarter 2, East Ash Pond, Joppa Power Plant, Joppa, Illinois*. August 22, 2023.

Uren, N.C. 2013. *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Ed. B.J. Alloway. Springer Science+Business Media. Chapter 12: Cobalt and Manganese. p 335-366.

Willman, H.B., E. Atherton, T.C. Buschbach, C. Collinson, J.C. Frye, M.E. Hopkins, J.A. Lineback, and J.A. Simon, 1975. *Handbook of Illinois Stratigraphy: Illinois State Geological Survey, Bulletin 95, 261 p.*

FIGURES



MONITORING WELL
STAFF GAGE, RIVER
TOP OF MCNAIRY FORMATION ELEVATION (5-FT CONTOUR INTERVAL)
FLOW DIRECTION
AREA WHERE TOP OF AQUIFER IS SATURATED BASED ON MEASUREMENTS FROM 2015-2023
REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

0 300 600 Feet

TOP OF UPPERMOST AQUIFER

FIGURE 1

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION
EAST ASH POND
JOPPA POWER PLANT JOPPA, ILLINOIS

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

COMPLIANCE MONITORING WELL
BACKGROUND MONITORING WELL
PORE WATER WELL
STAFF GAGE, RIVER
MONITORING WELL
STAFF GAGE, CCR UNIT

GROUNDWATER ELEVATION CONTOUR (2-FT CONTOUR INTERVAL, NAVD88)
INFERRED GROUNDWATER ELEVATION CONTOUR
GROUNDWATER FLOW DIRECTION
REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

0 300 600 Feet

NOTES:
1. ELEVATIONS IN PARENTHESES ARE NOT USED FOR CONTOURING.
2. ELEVATIONS SHOWN IN FEET NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).
3. BASEMAP DATA FROM USGS 335712600 OHIO RIVER AT OLIVEHILL (LOCATED APPROX. NAMED) 11 MILES DOWNSTREAM OF JOPPA POWER PLANT.

SAMPLING LOCATIONS AND POTENTIOMETRIC SURFACE MAP - MAY 1, 2023

FIGURE 2

35 I.A.C. § 845.650(e): ALTERNATIVE SOURCE DEMONSTRATION
EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC

RAMBOLL

APPENDICES

APPENDIX A
SUPPORTING SOLID PHASE ANALYTICAL DATA

APPENDIX A.
SUPPORTING SOLIDS PHASE ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Boring ID	Sample Elevation (feet NAVD88)	Cobalt (mg/kg)	Manganese (mg/kg)
G03	284.84 - 297.34	6.0	190
G03	294.84 - 296.84	0.82	6.1
G07	294.34 - 300.34	8.0	320
G08	261.72 - 266.72	29	1000
G09M	264.60 - 266.60	7.7	270
G11	303.38 - 305.38	1.3	11.6

Notes:
NAVD88 = North American Vertical Datum of 1988
mg/kg = milligrams per kilogram

APPENDIX B
SUPPORTING ANALYSIS OF REDUCTIVE DISSOLUTION OF MANGANESE OXIDES AS A LIKELY SOURCE OF COBALT CONCENTRATIONS AT G05

RAMBOLL

ENVIRONMENT
& HEALTH

TECHNICAL MEMORANDUM

Project no. 1940103649-011
Client Electric Energy, Inc.
Prepared by Alison O'Connor, Ph.D.

Supporting Analysis for Reductive Dissolution of Manganese Oxides as a Likely Source of Cobalt Concentrations at G0S

Joppa Power Plant, East Ash Pond

October 12, 2023

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608

1 INTRODUCTION

This document serves as an appendix for the October 21, 2023, Alternative Source Demonstration (ASD) for Joppa Power Plant (JPP) East Ash Pond (EAP) for monitoring Event 1 (E001), completed to fulfil the requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e).

Cobalt and manganese are often closely associated in soils due to their similar chemical properties (Uren, 2013). In igneous rocks, cobalt and manganese occur together in minerals due to carrying +2 charge and having similar atomic radii (Uren, 2013). Cobalt and manganese are released together during weathering processes and are often transported together through the environment. In highly oxidizing environments, manganese 2+ can be oxidized to manganese 4+ which exists as solid phase manganese oxide minerals. Cobalt sorbs strongly to manganese oxides compared to other divalent cations (McKenzie, 1967; Backes et al., 1995). Therefore, manganese-associated cobalt is released when solid-phase manganese oxides in soils are dissolved by reduction to a more soluble species.

This line of evidence (LOE) demonstrates that cobalt concentrations at G05 are consistent with reductive dissolution of manganese, and the cobalt exceedance at G05 is therefore likely due to natural variation in groundwater quality. Solid phase data were used to determine if cobalt and manganese are associated in the solid phase. To inform further analysis of groundwater data, wells with a geochemical signature like G05 were identified using principal component analysis (PCA). The relationship between cobalt and manganese in similar groundwater was then evaluated using regression analysis.

2 METHODS

2.1 Solid Phase Measurements

Total cobalt and total manganese data were available for samples collected from the uppermost aquifer (UA) at five boring locations. Six total samples were available (two samples were collected from G03). These soil data represent the acid-digestible portion of the solids phase, which may be mobilized under environmental relevant geochemical conditions. Any metals entrained within the highly refractory aluminosilicate matrix are not extracted.

2.2 Regression Analysis

Least squares linear regression (abbreviated here as regression analysis) was used in this work to understand correlations between data. Regression analysis determines the equation for the line that minimizes the sum of the squared differences between the data and the regression estimate. Regression analysis assumes that the errors in the regression (called residuals) have a mean of zero and are randomly distributed around the mean following a normal distribution. The distribution of regression residuals can be visualized by plotting the residuals against the fitted values.

The relationship between the variables is assessed using the p value and the R^2 of the regression. The p value represents the chance the relationship between the data is due to random variability. A cut off p value of 0.05 often is used to determine if a regression is statistically significant (*i.e.*, it has less than a 5 percent (%) chance of being due to random variability). The R^2 value represents the proportion of the variance in the dependent variable that is explained by the independent variable. A higher R^2 value indicates a close relationship between the two variables (with an R^2 of 1 representing a perfectly straight line).

2.3 Principal Component Analysis

Groundwater data is frequently defined by many chemical parameters and may therefore be described statistically as "multivariate". PCA is a common multivariate statistical approach that simplifies multivariate data by combining those variables into a smaller number of new variables called principal components. This is possible because in multivariate data sets, there is often some correlation between variables. These correlations represent "redundant" information that may be mathematically removed by PCA. The principal components represent linear combinations of the original data which maximize the variance between the samples, and which are uncorrelated with one another. PCA thereby allows patterns in the data to be more easily recognized and correlations between input variables to be assessed.

The goal of this PCA was to identify wells similar to G05 and which are therefore likely affected by similar geochemical processes. The groundwater potentiometric map (E001 ASD Figure 2) and stratigraphic conditions in the UA (E001 ASD Section 2.3) suggest that wells in different areas downgradient of the EAP may be influenced by different areas of upgradient water. Additionally, as discussed in Appendix D, compliance wells G11 and G51D are strongly influenced by groundwater west of the EAP. To focus this analysis on identifying distinct populations of downgradient groundwater, the dataset for this PCA included only background wells, EAP porewater, and compliance wells east and south of the EAP (*i.e.*, downgradient from the unit; see E001 ASD Figure 2) screened in the UA.

Samples with a turbidity greater than 50 nephelometric turbidity units (NTU) were excluded from the analysis to mitigate the confounding influence of suspended solids. Geochemical parameters excluded from the PCA were to have measurements in over half the samples or to have an overall proportion of detected measurements exceeding 50 %. Individual samples missing data for more than half of the parameters (7 of 14 included in the PCA) were excluded from the analysis. Any measurements that were below the reporting limit were assumed to be half the reporting limit. Results for pH were converted to milligrams per liter (mg/L) H^+ ion for consistency with other analytes. Any missing values were imputed (*i.e.*, interpolated based on the available data) using the nearest neighbor method. The final data set (**Attachment A**) contained 1,232 parameter measurements (67 of which were imputed) from 88 individual groundwater samples at 15 wells in the vicinity of the EAP (three porewater wells, two background wells, and 10 compliance wells). All data were log transformed, scaled, and centered so that parameters with larger concentrations did not have disproportionate influence on the results.

Results of the PCA analysis are presented in a biplot. In a PCA biplot, the axes represent the new "variables," or principal components (PCs). The length of the arrows represents how strongly each individual variable contributes to the PCs, and the direction of the arrow along the respective axis represents the direction of the contribution (positive or negative). Each data point represents a sample plotted according to the PCs.

2.4 Pourbaix Diagrams

Pourbaix diagrams, also called Eh-pH diagrams, are visual representations of redox speciation under equilibrium conditions at a given pH (x axis) an Eh (y axis). Eh is the measure of redox potential based on the standard hydrogen electrode and is calculated by converting an oxidation reduction potential (ORP) measurement using an equation appropriate to the type of electrode used in the ORP sensor (typically silver/silver chloride or calomel). An Aqua TROLL field meter was used to measure ORP in the field. The equation to convert ORP to Eh for this meter is[1]:

Eh = ORP (mV) + 221.4 – 0.9*Temperature (°C)

3 RESULTS AND DISCUSSION

3.1 Regression quality

The results of the regressions of aquifer solids and groundwater data are presented in the main text of the ASD. This section discusses how the regressions meet the standard assumptions.

For the regression of aquifer solids data, the residuals are most extreme in the negative direction, but the mean of the residuals is zero and there is considerable scatter (**Figure B-1**). Therefore, the regression meets the assumptions relatively well.

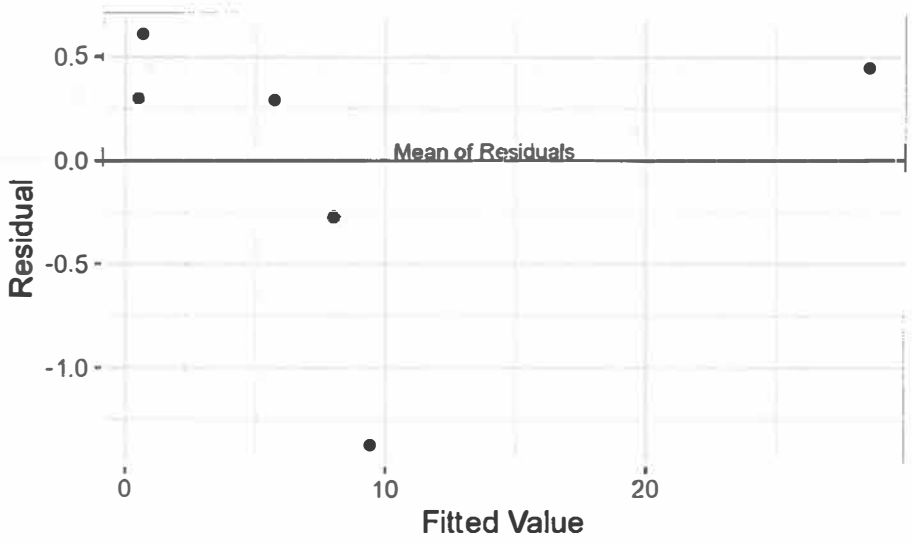


Figure B-1. Plot of residuals against fitted values for the UA solids cobalt versus manganese regression model.

[1] As reported at https://in-situ.com/us/news/orp-field-measurements-reporting-redox-potential-eh-correctly

For the regression of groundwater data, the residuals are most extreme toward the middle of the fitted values, but the mean of the residuals is zero and there is considerable scatter (**Figure B-2**). Therefore, the regression meets the assumptions relatively well.

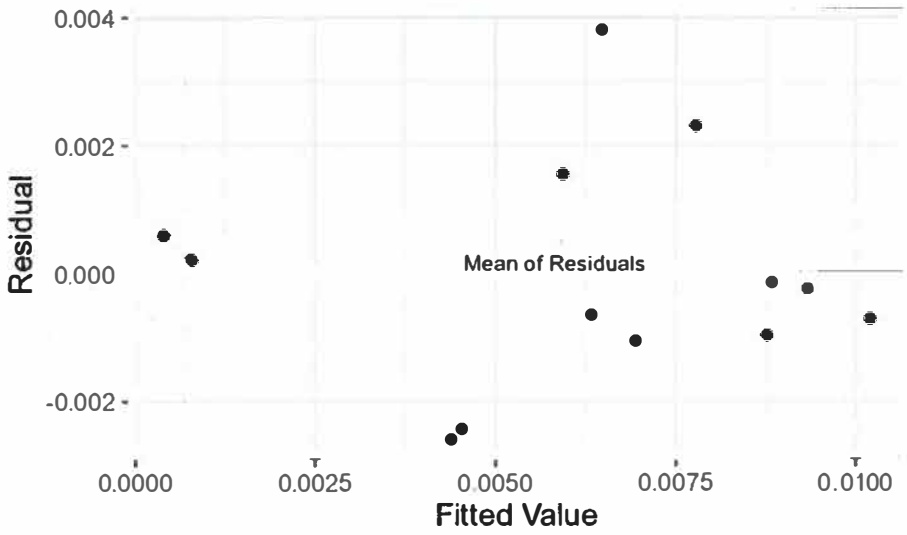


Figure B-2. Plot of residuals against fitted values for the groundwater cobalt versus manganese regression model.

3.2 Pourbaix Diagram

Figure B-3 shows the Pourbaix diagram for manganese with 2023 groundwater data plotted. Manganese is expected to exist in the reduced Mn^{2+} form at all groundwater locations (including G05), as opposed to insoluble manganese oxide mineral forms (*i.e.*, birnessite and todorokite). This indicates that reductive dissolution of manganese oxide minerals is thermodynamically favorable at G05, which supports this mechanism as a source of cobalt in the groundwater.

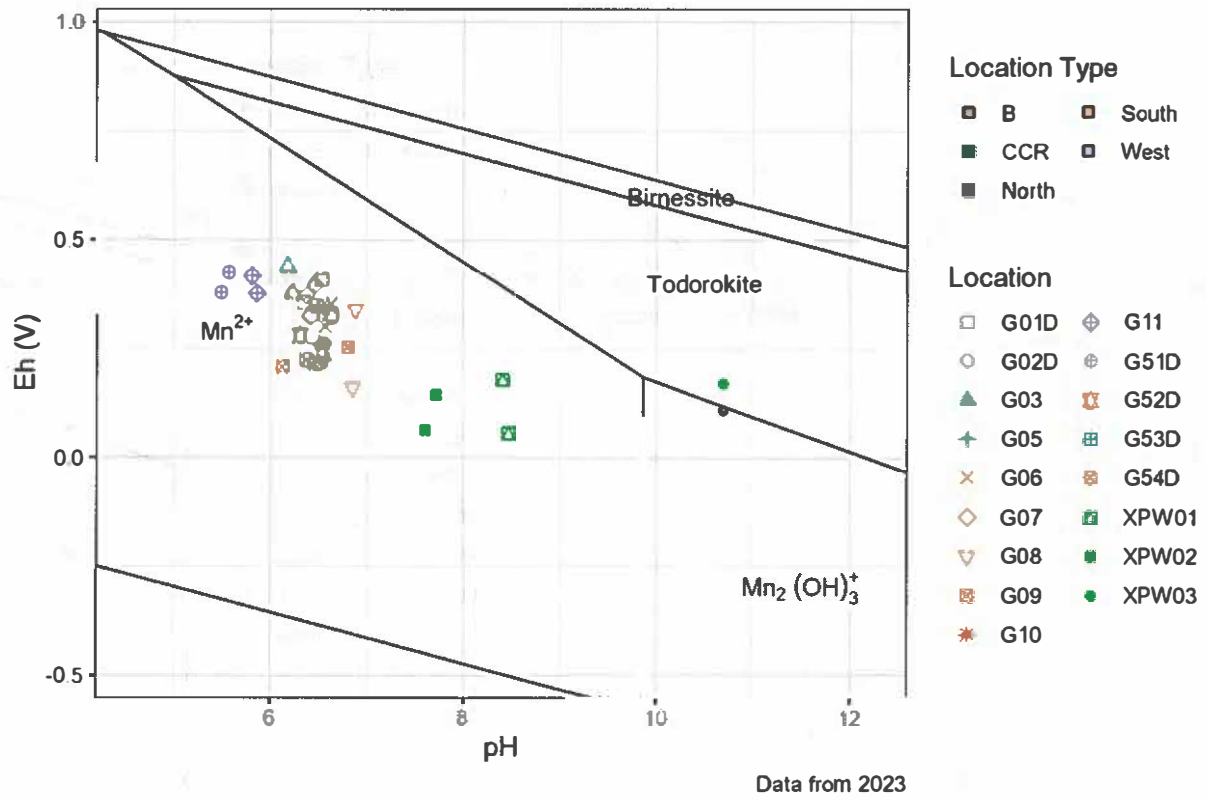


Figure B-3. Manganese Pourbaix diagram with 2023 Eh and pH data from groundwater and porewater.

3.3 PCA

The PCA biplot (**Figure B-4**) shows the results of the PCA analysis with wells colored by location type: background, CCR porewater, north of the UA stratigraphic high ("north"), south of the UA stratigraphic high ("south"), and G05 as the cobalt exceedance location. Approximately 58% of the variability in the data is encompassed in the first two principal component (PC1 explains approximately 40% of the variability in the data, and PC2 explains approximately 18%). Ninety-five % confidence ellipses for the north wells and south wells are shown in their respective location type colors. The minimal overlap of the 95% confidence ellipses shows that the groundwater compositions from the north wells and the south wells are largely distinct from one another. Well G05 plots within the 95% confidence ellipse for the north wells, indicating similarity of groundwater composition. The similarity between the north wells and dissimilarity from the south wells indicates that groundwater from these two groups of wells should be considered as distinct populations of data.

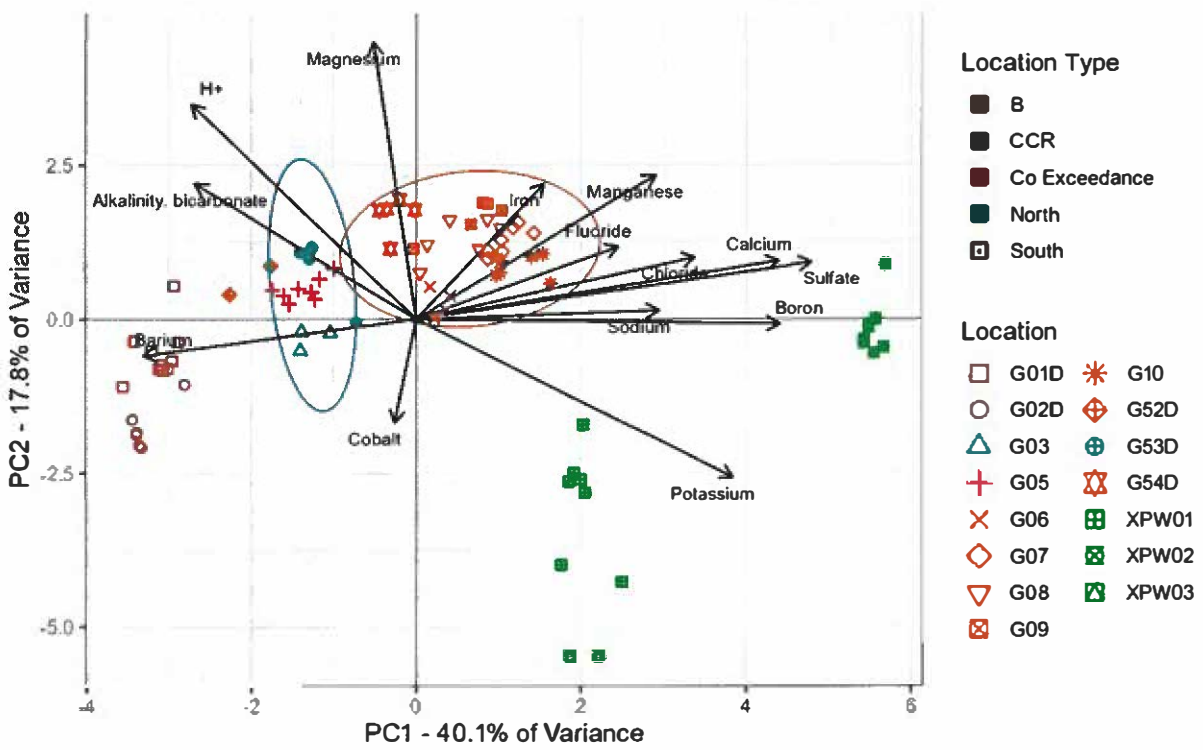


Figure B-4. Biplot of PCA results.

3.4 Redox Environment at JPP EAP

Appendix D of the associated E001 ASD, which addresses pH exceedances on the west side of the EAP, identifies a redox front west of the pond as driving iron oxidation and an associated drop in pH. The redox potential at which iron reduction/oxidation occurs is more reducing than the manganese reduction/oxidation potential. The redox potential and pH at wells G51D and G11 are consistent with an iron redox transition (Appendix D, Attachment 6-B) but all recent EAP groundwater samples fall within manganese-reducing conditions (Figure B-3). G05 is not substantially more reducing than other nearby wells without elevated cobalt. Appendix A of the E001 ASD shows that cobalt and manganese concentrations in the soil encompass 1.5 and 2.5 orders of magnitude difference, respectively, across the UA. In contrast to a redox front driving an iron speciation transition west of the EAP, local variations in solid phase cobalt and manganese concentrations appear to drive the differences in cobalt concentrations in groundwater.

4 CONCLUSIONS

The methods and results reported in this appendix support the conclusion that cobalt concentrations at G05 are consistent with mobilization due to reductive dissolution of manganese oxides. The regression analyses for cobalt and manganese correlation in solid phase material and groundwater are validated by illustrating the quality of the regressions. The Pourbaix diagram shows the manganese speciation in greater detail and concludes that reductive dissolution of manganese is thermodynamically favorable. The detailed PCA results show that the wells north and south of the UA stratigraphic high have distinct groundwater quality signatures and should be analyzed as distinct populations. Along with the strong association between cobalt and manganese in both the soil and groundwater, these results support the

conclusion that the reductive dissolution of manganese oxides is a primary control on cobalt concentrations in the groundwater.

5 REFERENCES

Backes, C.A., McLaren, R.G., Rate, A.W. and Swift, R.S., 1995. Kinetics of Cadmium and Cobalt Desorption from Iron and Manganese Oxides. *Soil Sci. Soc. Am. J.*, **59**: 778-785.

McKenzie, R.M., 1967. The sorption of cobalt by manganese minerals in soils. *Aust. J. Soil Res.* **5**: 235-246.

Uren, N.C., 2013. *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. Ed. B.J. Alloway. Springer Science+Business Media. Chapter 12: Cobalt and Manganese. p 335-366.

ATTACHMENTS

Attachment A Electronic PCA Data

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	3/3/2021	Alkalinity, bicarbonate	209	FALSE	FALSE
G01D	3/3/2021	Calcium	25.8	FALSE	FALSE
G01D	3/3/2021	Magnesium	7.79	FALSE	FALSE
G01D	3/3/2021	Sodium	79	FALSE	FALSE
G01D	3/3/2021	Potassium	1.24	FALSE	FALSE
G01D	3/3/2021	Chloride	10	FALSE	FALSE
G01D	3/3/2021	Sulfate	18	FALSE	FALSE
G01D	3/3/2021	Fluoride	0.2	FALSE	FALSE
G01D	3/3/2021	Barium	0.137	FALSE	FALSE
G01D	3/3/2021	Boron	0.158	FALSE	TRUE
G01D	3/3/2021	Cobalt	0.0015	FALSE	FALSE
G01D	3/3/2021	Iron	1.09	FALSE	FALSE
G01D	3/3/2021	Manganese	0.0232	FALSE	FALSE
G01D	3/3/2021	H+	0.000000251	FALSE	FALSE
G01D	3/24/2021	Alkalinity, bicarbonate	219	FALSE	FALSE
G01D	3/24/2021	Calcium	24.8	FALSE	FALSE
G01D	3/24/2021	Magnesium	7.06	FALSE	FALSE
G01D	3/24/2021	Sodium	73.9	FALSE	FALSE
G01D	3/24/2021	Potassium	1.05	FALSE	FALSE
G01D	3/24/2021	Chloride	9	FALSE	FALSE
G01D	3/24/2021	Sulfate	21	FALSE	FALSE
G01D	3/24/2021	Fluoride	0.21	FALSE	FALSE
G01D	3/24/2021	Barium	0.136	FALSE	FALSE
G01D	3/24/2021	Boron	0.158	FALSE	TRUE
G01D	3/24/2021	Cobalt	0.0316	FALSE	TRUE
G01D	3/24/2021	Iron	1.15	FALSE	FALSE
G01D	3/24/2021	Manganese	0.0181	FALSE	FALSE
G01D	3/24/2021	H+	0.000000324	FALSE	FALSE
G01D	4/14/2021	Alkalinity, bicarbonate	240	FALSE	FALSE
G01D	4/14/2021	Calcium	23.3	FALSE	FALSE
G01D	4/14/2021	Magnesium	7.56	FALSE	FALSE
G01D	4/14/2021	Sodium	94.5	FALSE	FALSE
G01D	4/14/2021	Potassium	0.979	FALSE	FALSE
G01D	4/14/2021	Chloride	6	FALSE	FALSE
G01D	4/14/2021	Sulfate	39	FALSE	FALSE
G01D	4/14/2021	Fluoride	0.23	FALSE	FALSE
G01D	4/14/2021	Barium	0.112	FALSE	FALSE
G01D	4/14/2021	Boron	0.158	FALSE	TRUE
G01D	4/14/2021	Cobalt	0.0316	FALSE	TRUE
G01D	4/14/2021	Iron	0.698	FALSE	FALSE
G01D	4/14/2021	Manganese	0.0117	FALSE	FALSE
G01D	4/14/2021	H+	0.0000002	FALSE	FALSE
G01D	5/12/2021	Alkalinity, bicarbonate	200	FALSE	FALSE
G01D	5/12/2021	Calcium	24.9	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	5/12/2021	Magnesium	7.55	FALSE	FALSE
G01D	5/12/2021	Sodium	82.5	FALSE	FALSE
G01D	5/12/2021	Potassium	1.13	FALSE	FALSE
G01D	5/12/2021	Chloride	7	FALSE	FALSE
G01D	5/12/2021	Sulfate	20	FALSE	FALSE
G01D	5/12/2021	Fluoride	0.21	FALSE	FALSE
G01D	5/12/2021	Barium	0.133	FALSE	FALSE
G01D	5/12/2021	Boron	0.0167	FALSE	FALSE
G01D	5/12/2021	Cobalt	0.0316	FALSE	TRUE
G01D	5/12/2021	Iron	0.65	FALSE	FALSE
G01D	5/12/2021	Manganese	0.012	FALSE	FALSE
G01D	5/12/2021	H+	0.000000324	FALSE	FALSE
G01D	6/1/2021	Alkalinity, bicarbonate	198	FALSE	FALSE
G01D	6/1/2021	Calcium	24.4	FALSE	FALSE
G01D	6/1/2021	Magnesium	7.36	FALSE	FALSE
G01D	6/1/2021	Sodium	75.3	FALSE	FALSE
G01D	6/1/2021	Potassium	1.26	FALSE	FALSE
G01D	6/1/2021	Chloride	7	FALSE	FALSE
G01D	6/1/2021	Sulfate	18	FALSE	FALSE
G01D	6/1/2021	Fluoride	0.23	FALSE	FALSE
G01D	6/1/2021	Barium	0.134	FALSE	FALSE
G01D	6/1/2021	Boron	0.158	FALSE	TRUE
G01D	6/1/2021	Cobalt	0.0316	FALSE	TRUE
G01D	6/1/2021	Iron	1.92	FALSE	FALSE
G01D	6/1/2021	Manganese	0.0249	FALSE	FALSE
G01D	6/1/2021	H+	0.000000457	FALSE	FALSE
G01D	6/14/2021	Alkalinity, bicarbonate	219	FALSE	FALSE
G01D	6/14/2021	Calcium	24.4	FALSE	FALSE
G01D	6/14/2021	Magnesium	7.41	FALSE	FALSE
G01D	6/14/2021	Sodium	78.8	FALSE	FALSE
G01D	6/14/2021	Potassium	1.26	FALSE	FALSE
G01D	6/14/2021	Chloride	9	FALSE	FALSE
G01D	6/14/2021	Sulfate	20	FALSE	FALSE
G01D	6/14/2021	Fluoride	0.23	FALSE	FALSE
G01D	6/14/2021	Barium	0.136	FALSE	FALSE
G01D	6/14/2021	Boron	0.158	FALSE	TRUE
G01D	6/14/2021	Cobalt	0.0316	FALSE	TRUE
G01D	6/14/2021	Iron	0.831	FALSE	FALSE
G01D	6/14/2021	Manganese	0.0147	FALSE	FALSE
G01D	6/14/2021	H+	0.000000347	FALSE	FALSE
G01D	7/21/2021	Alkalinity, bicarbonate	204	FALSE	FALSE
G01D	7/21/2021	Calcium	26	FALSE	FALSE
G01D	7/21/2021	Magnesium	7.54	FALSE	FALSE
G01D	7/21/2021	Sodium	75.1	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	7/21/2021	Potassium	1.24	FALSE	FALSE
G01D	7/21/2021	Chloride	9	FALSE	FALSE
G01D	7/21/2021	Sulfate	18	FALSE	FALSE
G01D	7/21/2021	Fluoride	0.21	FALSE	FALSE
G01D	7/21/2021	Barium	0.125	FALSE	FALSE
G01D	7/21/2021	Boron	0.158	FALSE	TRUE
G01D	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G01D	7/21/2021	Iron	1.35	FALSE	FALSE
G01D	7/21/2021	Manganese	0.0121	FALSE	FALSE
G01D	7/21/2021	H+	0.000000427	FALSE	FALSE
G01D	9/20/2021	Alkalinity, bicarbonate	215	FALSE	FALSE
G01D	9/20/2021	Calcium	26	FALSE	FALSE
G01D	9/20/2021	Magnesium	7.54	TRUE	NA
G01D	9/20/2021	Sodium	75.1	TRUE	NA
G01D	9/20/2021	Potassium	1.12	TRUE	NA
G01D	9/20/2021	Chloride	9	FALSE	FALSE
G01D	9/20/2021	Sulfate	18	FALSE	FALSE
G01D	9/20/2021	Fluoride	0.21	FALSE	FALSE
G01D	9/20/2021	Barium	0.145	FALSE	FALSE
G01D	9/20/2021	Boron	0.158	FALSE	TRUE
G01D	9/20/2021	Cobalt	0.0316	FALSE	TRUE
G01D	9/20/2021	Iron	1.15	TRUE	NA
G01D	9/20/2021	Manganese	0.0147	TRUE	NA
G01D	9/20/2021	H+	0.000000309	FALSE	FALSE
G01D	9/20/2022	Alkalinity, bicarbonate	171	TRUE	NA
G01D	9/20/2022	Calcium	25.5	FALSE	FALSE
G01D	9/20/2022	Magnesium	7.79	TRUE	NA
G01D	9/20/2022	Sodium	82.5	TRUE	NA
G01D	9/20/2022	Potassium	1.13	TRUE	NA
G01D	9/20/2022	Chloride	8	FALSE	FALSE
G01D	9/20/2022	Sulfate	23	FALSE	FALSE
G01D	9/20/2022	Fluoride	0.19	FALSE	FALSE
G01D	9/20/2022	Barium	0.142	FALSE	FALSE
G01D	9/20/2022	Boron	0.014	FALSE	FALSE
G01D	9/20/2022	Cobalt	0.0007	FALSE	FALSE
G01D	9/20/2022	Iron	1.15	TRUE	NA
G01D	9/20/2022	Manganese	0.0181	TRUE	NA
G01D	9/20/2022	H+	0.000000316	FALSE	FALSE
G01D	3/7/2023	Alkalinity, bicarbonate	223	FALSE	FALSE
G01D	3/7/2023	Calcium	23	FALSE	FALSE
G01D	3/7/2023	Magnesium	7.66	FALSE	FALSE
G01D	3/7/2023	Sodium	85.8	FALSE	FALSE
G01D	3/7/2023	Potassium	1.06	FALSE	FALSE
G01D	3/7/2023	Chloride	5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G01D	3/7/2023	Sulfate	36	FALSE	FALSE
G01D	3/7/2023	Fluoride	0.21	FALSE	FALSE
G01D	3/7/2023	Barium	0.134	FALSE	FALSE
G01D	3/7/2023	Boron	0.029	FALSE	FALSE
G01D	3/7/2023	Cobalt	0.0022	FALSE	FALSE
G01D	3/7/2023	Iron	1.09	TRUE	NA
G01D	3/7/2023	Manganese	0.0181	TRUE	NA
G01D	3/7/2023	H+	0.000000295	FALSE	FALSE
G01D	5/2/2023	Alkalinity, bicarbonate	240	FALSE	FALSE
G01D	5/2/2023	Calcium	28.8	FALSE	FALSE
G01D	5/2/2023	Magnesium	8.43	FALSE	FALSE
G01D	5/2/2023	Sodium	90.3	FALSE	FALSE
G01D	5/2/2023	Potassium	1.28	FALSE	FALSE
G01D	5/2/2023	Chloride	10	FALSE	FALSE
G01D	5/2/2023	Sulfate	26	FALSE	FALSE
G01D	5/2/2023	Fluoride	0.22	FALSE	FALSE
G01D	5/2/2023	Barium	0.213	FALSE	FALSE
G01D	5/2/2023	Boron	0.021	FALSE	FALSE
G01D	5/2/2023	Cobalt	0.0058	FALSE	FALSE
G01D	5/2/2023	Iron	4.09	FALSE	FALSE
G01D	5/2/2023	Manganese	0.345	FALSE	FALSE
G01D	5/2/2023	H+	0.000000457	FALSE	FALSE
G02D	5/12/2021	Alkalinity, bicarbonate	153	FALSE	FALSE
G02D	5/12/2021	Calcium	34.6	FALSE	FALSE
G02D	5/12/2021	Magnesium	10.4	FALSE	FALSE
G02D	5/12/2021	Sodium	53.6	FALSE	FALSE
G02D	5/12/2021	Potassium	1.17	FALSE	FALSE
G02D	5/12/2021	Chloride	18	FALSE	FALSE
G02D	5/12/2021	Sulfate	27	FALSE	FALSE
G02D	5/12/2021	Fluoride	0.18	FALSE	FALSE
G02D	5/12/2021	Barium	0.208	FALSE	FALSE
G02D	5/12/2021	Boron	0.0356	FALSE	FALSE
G02D	5/12/2021	Cobalt	0.0316	FALSE	TRUE
G02D	5/12/2021	Iron	0.316	FALSE	TRUE
G02D	5/12/2021	Manganese	0.0707	FALSE	TRUE
G02D	5/12/2021	H+	0.000000447	FALSE	FALSE
G02D	7/21/2021	Alkalinity, bicarbonate	148	FALSE	FALSE
G02D	7/21/2021	Calcium	36.6	FALSE	FALSE
G02D	7/21/2021	Magnesium	10.1	FALSE	FALSE
G02D	7/21/2021	Sodium	38.7	FALSE	FALSE
G02D	7/21/2021	Potassium	1.14	FALSE	FALSE
G02D	7/21/2021	Chloride	22	FALSE	FALSE
G02D	7/21/2021	Sulfate	20	FALSE	FALSE
G02D	7/21/2021	Fluoride	0.2	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G02D	7/21/2021	Barium	0.181	FALSE	FALSE
G02D	7/21/2021	Boron	0.0329	FALSE	FALSE
G02D	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G02D	7/21/2021	Iron	0.0594	FALSE	FALSE
G02D	7/21/2021	Manganese	0.0026	FALSE	FALSE
G02D	7/21/2021	H+	0.000000661	FALSE	FALSE
G02D	9/20/2021	Alkalinity, bicarbonate	156	FALSE	FALSE
G02D	9/20/2021	Calcium	34.3	FALSE	FALSE
G02D	9/20/2021	Magnesium	10.2	TRUE	NA
G02D	9/20/2021	Sodium	38.7	TRUE	NA
G02D	9/20/2021	Potassium	1.12	TRUE	NA
G02D	9/20/2021	Chloride	20	FALSE	FALSE
G02D	9/20/2021	Sulfate	19	FALSE	FALSE
G02D	9/20/2021	Fluoride	0.18	FALSE	FALSE
G02D	9/20/2021	Barium	0.189	FALSE	FALSE
G02D	9/20/2021	Boron	0.0313	FALSE	FALSE
G02D	9/20/2021	Cobalt	0.0316	FALSE	TRUE
G02D	9/20/2021	Iron	0.158	TRUE	NA
G02D	9/20/2021	Manganese	0.0032	TRUE	NA
G02D	9/20/2021	H+	0.000000479	FALSE	FALSE
G02D	1/24/2023	Alkalinity, bicarbonate	136	FALSE	FALSE
G02D	1/24/2023	Calcium	35.9	FALSE	FALSE
G02D	1/24/2023	Magnesium	10.2	FALSE	FALSE
G02D	1/24/2023	Sodium	29	FALSE	FALSE
G02D	1/24/2023	Potassium	1.11	FALSE	FALSE
G02D	1/24/2023	Chloride	23	FALSE	FALSE
G02D	1/24/2023	Sulfate	12	FALSE	FALSE
G02D	1/24/2023	Fluoride	0.21	FALSE	FALSE
G02D	1/24/2023	Barium	0.19	FALSE	FALSE
G02D	1/24/2023	Boron	0.0311	FALSE	FALSE
G02D	1/24/2023	Cobalt	0.0316	FALSE	TRUE
G02D	1/24/2023	Iron	0.158	FALSE	TRUE
G02D	1/24/2023	Manganese	0.0014	FALSE	FALSE
G02D	1/24/2023	H+	0.000000229	FALSE	FALSE
G02D	3/8/2023	Alkalinity, bicarbonate	141	FALSE	FALSE
G02D	3/8/2023	Calcium	37.3	FALSE	FALSE
G02D	3/8/2023	Magnesium	10.3	FALSE	FALSE
G02D	3/8/2023	Sodium	28.3	FALSE	FALSE
G02D	3/8/2023	Potassium	1.12	FALSE	FALSE
G02D	3/8/2023	Chloride	21	FALSE	FALSE
G02D	3/8/2023	Sulfate	11	FALSE	FALSE
G02D	3/8/2023	Fluoride	0.2	FALSE	FALSE
G02D	3/8/2023	Barium	0.171	FALSE	FALSE
G02D	3/8/2023	Boron	0.027	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G02D	3/8/2023	Cobalt	0.0316	FALSE	TRUE
G02D	3/8/2023	Iron	0.158	TRUE	NA
G02D	3/8/2023	Manganese	0.0032	TRUE	NA
G02D	3/8/2023	H+	0.000000275	FALSE	FALSE
G02D	5/3/2023	Alkalinity, bicarbonate	140	FALSE	FALSE
G02D	5/3/2023	Calcium	38.7	FALSE	FALSE
G02D	5/3/2023	Magnesium	10.4	FALSE	FALSE
G02D	5/3/2023	Sodium	39.1	FALSE	FALSE
G02D	5/3/2023	Potassium	1.14	FALSE	FALSE
G02D	5/3/2023	Chloride	21	FALSE	FALSE
G02D	5/3/2023	Sulfate	13	FALSE	FALSE
G02D	5/3/2023	Fluoride	0.22	FALSE	FALSE
G02D	5/3/2023	Barium	0.21	FALSE	FALSE
G02D	5/3/2023	Boron	0.0412	FALSE	FALSE
G02D	5/3/2023	Cobalt	0.0316	FALSE	TRUE
G02D	5/3/2023	Iron	0.049	FALSE	FALSE
G02D	5/3/2023	Manganese	0.0032	FALSE	FALSE
G02D	5/3/2023	H+	0.000000347	FALSE	FALSE
G03	6/15/2021	Alkalinity, bicarbonate	148	FALSE	FALSE
G03	6/15/2021	Calcium	46.7	FALSE	FALSE
G03	6/15/2021	Magnesium	15.1	FALSE	FALSE
G03	6/15/2021	Sodium	40.4	FALSE	FALSE
G03	6/15/2021	Potassium	1.26	FALSE	FALSE
G03	6/15/2021	Chloride	22	FALSE	FALSE
G03	6/15/2021	Sulfate	79	FALSE	FALSE
G03	6/15/2021	Fluoride	0.22	FALSE	FALSE
G03	6/15/2021	Barium	0.0705	FALSE	FALSE
G03	6/15/2021	Boron	0.225	FALSE	FALSE
G03	6/15/2021	Cobalt	0.0316	FALSE	TRUE
G03	6/15/2021	Iron	1.69	FALSE	FALSE
G03	6/15/2021	Manganese	0.033	FALSE	FALSE
G03	6/15/2021	H+	0.000000575	FALSE	FALSE
G03	7/6/2021	Alkalinity, bicarbonate	140	FALSE	FALSE
G03	7/6/2021	Calcium	42.1	FALSE	FALSE
G03	7/6/2021	Magnesium	14	FALSE	FALSE
G03	7/6/2021	Sodium	38	FALSE	FALSE
G03	7/6/2021	Potassium	1.13	FALSE	FALSE
G03	7/6/2021	Chloride	22	FALSE	FALSE
G03	7/6/2021	Sulfate	77	FALSE	FALSE
G03	7/6/2021	Fluoride	0.22	FALSE	FALSE
G03	7/6/2021	Barium	0.0564	FALSE	FALSE
G03	7/6/2021	Boron	0.235	FALSE	FALSE
G03	7/6/2021	Cobalt	0.0316	FALSE	TRUE
G03	7/6/2021	Iron	1.06	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G03	7/6/2021	Manganese	0.0226	FALSE	FALSE
G03	7/6/2021	H+	0.000000457	FALSE	FALSE
G03	7/21/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
G03	7/21/2021	Calcium	50	FALSE	FALSE
G03	7/21/2021	Magnesium	15.7	FALSE	FALSE
G03	7/21/2021	Sodium	40.2	FALSE	FALSE
G03	7/21/2021	Potassium	1.39	FALSE	FALSE
G03	7/21/2021	Chloride	24	FALSE	FALSE
G03	7/21/2021	Sulfate	92	FALSE	FALSE
G03	7/21/2021	Fluoride	0.2	FALSE	FALSE
G03	7/21/2021	Barium	0.0555	FALSE	FALSE
G03	7/21/2021	Boron	0.294	FALSE	FALSE
G03	7/21/2021	Cobalt	0.0316	FALSE	TRUE
G03	7/21/2021	Iron	2.42	FALSE	FALSE
G03	7/21/2021	Manganese	0.0334	FALSE	FALSE
G03	7/21/2021	H+	0.000000437	FALSE	FALSE
G05	3/4/2021	Alkalinity, bicarbonate	180	FALSE	FALSE
G05	3/4/2021	Calcium	55.3	FALSE	FALSE
G05	3/4/2021	Magnesium	17.2	FALSE	FALSE
G05	3/4/2021	Sodium	44.1	FALSE	FALSE
G05	3/4/2021	Potassium	1.37	FALSE	FALSE
G05	3/4/2021	Chloride	13	FALSE	FALSE
G05	3/4/2021	Sulfate	94	FALSE	FALSE
G05	3/4/2021	Fluoride	0.28	FALSE	FALSE
G05	3/4/2021	Barium	0.13	FALSE	FALSE
G05	3/4/2021	Boron	0.181	FALSE	FALSE
G05	3/4/2021	Cobalt	0.0101	FALSE	FALSE
G05	3/4/2021	Iron	0.905	FALSE	FALSE
G05	3/4/2021	Manganese	0.227	FALSE	FALSE
G05	3/4/2021	H+	0.000000316	FALSE	FALSE
G05	4/13/2021	Alkalinity, bicarbonate	206	FALSE	FALSE
G05	4/13/2021	Calcium	68.5	FALSE	FALSE
G05	4/13/2021	Magnesium	19.5	FALSE	FALSE
G05	4/13/2021	Sodium	53.7	FALSE	FALSE
G05	4/13/2021	Potassium	2.14	FALSE	FALSE
G05	4/13/2021	Chloride	21	FALSE	FALSE
G05	4/13/2021	Sulfate	95	FALSE	FALSE
G05	4/13/2021	Fluoride	0.33	FALSE	FALSE
G05	4/13/2021	Barium	0.126	FALSE	FALSE
G05	4/13/2021	Boron	0.19	FALSE	FALSE
G05	4/13/2021	Cobalt	0.0095	FALSE	FALSE
G05	4/13/2021	Iron	2	FALSE	FALSE
G05	4/13/2021	Manganese	0.294	FALSE	FALSE
G05	4/13/2021	H+	0.000000316	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	5/11/2021	Alkalinity, bicarbonate	193	FALSE	FALSE
G05	5/11/2021	Calcium	60.3	FALSE	FALSE
G05	5/11/2021	Magnesium	19.4	FALSE	FALSE
G05	5/11/2021	Sodium	49.6	FALSE	FALSE
G05	5/11/2021	Potassium	1.97	FALSE	FALSE
G05	5/11/2021	Chloride	19	FALSE	FALSE
G05	5/11/2021	Sulfate	109	FALSE	FALSE
G05	5/11/2021	Fluoride	0.34	FALSE	FALSE
G05	5/11/2021	Barium	0.132	FALSE	FALSE
G05	5/11/2021	Boron	0.158	FALSE	FALSE
G05	5/11/2021	Cobalt	0.0087	FALSE	FALSE
G05	5/11/2021	Iron	1.14	FALSE	FALSE
G05	5/11/2021	Manganese	0.256	FALSE	FALSE
G05	5/11/2021	H+	0.000000417	FALSE	FALSE
G05	6/1/2021	Alkalinity, bicarbonate	190	FALSE	FALSE
G05	6/1/2021	Calcium	57.1	FALSE	FALSE
G05	6/1/2021	Magnesium	18.6	FALSE	FALSE
G05	6/1/2021	Sodium	45.5	FALSE	FALSE
G05	6/1/2021	Potassium	2.18	FALSE	FALSE
G05	6/1/2021	Chloride	21	FALSE	FALSE
G05	6/1/2021	Sulfate	83	FALSE	FALSE
G05	6/1/2021	Fluoride	0.34	FALSE	FALSE
G05	6/1/2021	Barium	0.144	FALSE	FALSE
G05	6/1/2021	Boron	0.157	FALSE	FALSE
G05	6/1/2021	Cobalt	0.0078	FALSE	FALSE
G05	6/1/2021	Iron	0.81	FALSE	FALSE
G05	6/1/2021	Manganese	0.254	FALSE	FALSE
G05	6/1/2021	H+	0.000000331	FALSE	FALSE
G05	7/6/2021	Alkalinity, bicarbonate	178	FALSE	FALSE
G05	7/6/2021	Calcium	51.8	FALSE	FALSE
G05	7/6/2021	Magnesium	17.6	FALSE	FALSE
G05	7/6/2021	Sodium	45.9	FALSE	FALSE
G05	7/6/2021	Potassium	2.04	FALSE	FALSE
G05	7/6/2021	Chloride	22	FALSE	FALSE
G05	7/6/2021	Sulfate	90	FALSE	FALSE
G05	7/6/2021	Fluoride	0.34	FALSE	FALSE
G05	7/6/2021	Barium	0.139	FALSE	FALSE
G05	7/6/2021	Boron	0.148	FALSE	FALSE
G05	7/6/2021	Cobalt	0.0091	FALSE	FALSE
G05	7/6/2021	Iron	0.729	FALSE	FALSE
G05	7/6/2021	Manganese	0.27	FALSE	FALSE
G05	7/6/2021	H+	0.00000038	FALSE	FALSE
G05	7/20/2021	Alkalinity, bicarbonate	186	FALSE	FALSE
G05	7/20/2021	Calcium	55.9	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	7/20/2021	Magnesium	18.5	FALSE	FALSE
G05	7/20/2021	Sodium	43.4	FALSE	FALSE
G05	7/20/2021	Potassium	1.75	FALSE	FALSE
G05	7/20/2021	Chloride	20	FALSE	FALSE
G05	7/20/2021	Sulfate	87	FALSE	FALSE
G05	7/20/2021	Fluoride	0.32	FALSE	FALSE
G05	7/20/2021	Barium	0.133	FALSE	FALSE
G05	7/20/2021	Boron	0.131	FALSE	FALSE
G05	7/20/2021	Cobalt	0.0059	FALSE	FALSE
G05	7/20/2021	Iron	0.747	FALSE	FALSE
G05	7/20/2021	Manganese	0.204	FALSE	FALSE
G05	7/20/2021	H+	0.000000447	FALSE	FALSE
G05	7/26/2022	Alkalinity, bicarbonate	181	FALSE	FALSE
G05	7/26/2022	Calcium	50.6	FALSE	FALSE
G05	7/26/2022	Magnesium	17.6	FALSE	FALSE
G05	7/26/2022	Sodium	35.4	FALSE	FALSE
G05	7/26/2022	Potassium	1.07	FALSE	FALSE
G05	7/26/2022	Chloride	15	FALSE	FALSE
G05	7/26/2022	Sulfate	68	FALSE	FALSE
G05	7/26/2022	Fluoride	0.37	FALSE	FALSE
G05	7/26/2022	Barium	0.141	FALSE	FALSE
G05	7/26/2022	Boron	0.0645	FALSE	FALSE
G05	7/26/2022	Cobalt	0.0075	FALSE	FALSE
G05	7/26/2022	Iron	1.38	FALSE	FALSE
G05	7/26/2022	Manganese	0.176	FALSE	FALSE
G05	7/26/2022	H+	0.000000234	FALSE	FALSE
G05	3/9/2023	Alkalinity, bicarbonate	179	FALSE	FALSE
G05	3/9/2023	Calcium	52.6	FALSE	FALSE
G05	3/9/2023	Magnesium	19.4	FALSE	FALSE
G05	3/9/2023	Sodium	41.8	FALSE	FALSE
G05	3/9/2023	Potassium	1.59	FALSE	FALSE
G05	3/9/2023	Chloride	22	FALSE	FALSE
G05	3/9/2023	Sulfate	90	FALSE	FALSE
G05	3/9/2023	Fluoride	0.32	FALSE	FALSE
G05	3/9/2023	Barium	0.175	FALSE	FALSE
G05	3/9/2023	Boron	0.0541	FALSE	FALSE
G05	3/9/2023	Cobalt	0.0074	FALSE	FALSE
G05	3/9/2023	Iron	0.81	TRUE	NA
G05	3/9/2023	Manganese	0.204	TRUE	NA
G05	3/9/2023	H+	0.000000316	FALSE	FALSE
G05	5/3/2023	Alkalinity, bicarbonate	163	FALSE	FALSE
G05	5/3/2023	Calcium	54.4	FALSE	FALSE
G05	5/3/2023	Magnesium	19.3	FALSE	FALSE
G05	5/3/2023	Sodium	46.7	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G05	5/3/2023	Potassium	1.68	FALSE	FALSE
G05	5/3/2023	Chloride	24	FALSE	FALSE
G05	5/3/2023	Sulfate	112	FALSE	FALSE
G05	5/3/2023	Fluoride	0.38	FALSE	FALSE
G05	5/3/2023	Barium	0.212	FALSE	FALSE
G05	5/3/2023	Boron	0.0478	FALSE	FALSE
G05	5/3/2023	Cobalt	0.0103	FALSE	FALSE
G05	5/3/2023	Iron	1.5	FALSE	FALSE
G05	5/3/2023	Manganese	0.191	FALSE	FALSE
G05	5/3/2023	H+	0.000000324	FALSE	FALSE
G06	5/11/2021	Alkalinity, bicarbonate	156	FALSE	FALSE
G06	5/11/2021	Calcium	93.4	FALSE	FALSE
G06	5/11/2021	Magnesium	26.8	FALSE	FALSE
G06	5/11/2021	Sodium	52.8	FALSE	FALSE
G06	5/11/2021	Potassium	2.5	FALSE	FALSE
G06	5/11/2021	Chloride	22	FALSE	FALSE
G06	5/11/2021	Sulfate	219	FALSE	FALSE
G06	5/11/2021	Fluoride	0.26	FALSE	FALSE
G06	5/11/2021	Barium	0.0311	FALSE	FALSE
G06	5/11/2021	Boron	3.37	FALSE	FALSE
G06	5/11/2021	Cobalt	0.0316	FALSE	TRUE
G06	5/11/2021	Iron	0.702	FALSE	FALSE
G06	5/11/2021	Manganese	0.0957	FALSE	FALSE
G06	5/11/2021	H+	0.000000372	FALSE	FALSE
G06	6/1/2021	Alkalinity, bicarbonate	167	FALSE	FALSE
G06	6/1/2021	Calcium	92.6	FALSE	FALSE
G06	6/1/2021	Magnesium	25.3	FALSE	FALSE
G06	6/1/2021	Sodium	46.4	FALSE	FALSE
G06	6/1/2021	Potassium	2.5	FALSE	FALSE
G06	6/1/2021	Chloride	22	FALSE	FALSE
G06	6/1/2021	Sulfate	216	FALSE	FALSE
G06	6/1/2021	Fluoride	0.28	FALSE	FALSE
G06	6/1/2021	Barium	0.0323	FALSE	FALSE
G06	6/1/2021	Boron	3.56	FALSE	FALSE
G06	6/1/2021	Cobalt	0.0316	FALSE	TRUE
G06	6/1/2021	Iron	1.69	FALSE	FALSE
G06	6/1/2021	Manganese	0.0892	FALSE	FALSE
G06	6/1/2021	H+	0.000000275	FALSE	FALSE
G06	6/15/2021	Alkalinity, bicarbonate	170	FALSE	FALSE
G06	6/15/2021	Calcium	91.5	FALSE	FALSE
G06	6/15/2021	Magnesium	25.2	FALSE	FALSE
G06	6/15/2021	Sodium	50.7	FALSE	FALSE
G06	6/15/2021	Potassium	2.57	FALSE	FALSE
G06	6/15/2021	Chloride	21	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G06	6/15/2021	Sulfate	230	FALSE	FALSE
G06	6/15/2021	Fluoride	0.28	FALSE	FALSE
G06	6/15/2021	Barium	0.028	FALSE	FALSE
G06	6/15/2021	Boron	2.97	FALSE	FALSE
G06	6/15/2021	Cobalt	0.0316	FALSE	TRUE
G06	6/15/2021	Iron	0.379	FALSE	FALSE
G06	6/15/2021	Manganese	0.0682	FALSE	FALSE
G06	6/15/2021	H+	0.000000309	FALSE	FALSE
G06	7/6/2021	Alkalinity, bicarbonate	163	FALSE	FALSE
G06	7/6/2021	Calcium	86.7	FALSE	FALSE
G06	7/6/2021	Magnesium	23.7	FALSE	FALSE
G06	7/6/2021	Sodium	50	FALSE	FALSE
G06	7/6/2021	Potassium	2.57	FALSE	FALSE
G06	7/6/2021	Chloride	22	FALSE	FALSE
G06	7/6/2021	Sulfate	223	FALSE	FALSE
G06	7/6/2021	Fluoride	0.27	FALSE	FALSE
G06	7/6/2021	Barium	0.0272	FALSE	FALSE
G06	7/6/2021	Boron	3.93	FALSE	FALSE
G06	7/6/2021	Cobalt	0.0316	FALSE	TRUE
G06	7/6/2021	Iron	0.495	FALSE	FALSE
G06	7/6/2021	Manganese	0.0631	FALSE	FALSE
G06	7/6/2021	H+	0.000000479	FALSE	FALSE
G06	7/20/2021	Alkalinity, bicarbonate	162	FALSE	FALSE
G06	7/20/2021	Calcium	90.6	FALSE	FALSE
G06	7/20/2021	Magnesium	24.4	FALSE	FALSE
G06	7/20/2021	Sodium	47	FALSE	FALSE
G06	7/20/2021	Potassium	2.37	FALSE	FALSE
G06	7/20/2021	Chloride	21	FALSE	FALSE
G06	7/20/2021	Sulfate	213	FALSE	FALSE
G06	7/20/2021	Fluoride	0.26	FALSE	FALSE
G06	7/20/2021	Barium	0.0244	FALSE	FALSE
G06	7/20/2021	Boron	3.41	FALSE	FALSE
G06	7/20/2021	Cobalt	0.0316	FALSE	TRUE
G06	7/20/2021	Iron	0.613	FALSE	FALSE
G06	7/20/2021	Manganese	0.0456	FALSE	FALSE
G06	7/20/2021	H+	0.000000389	FALSE	FALSE
G06	3/9/2023	Alkalinity, bicarbonate	161	FALSE	FALSE
G06	3/9/2023	Calcium	87.6	FALSE	FALSE
G06	3/9/2023	Magnesium	24.1	FALSE	FALSE
G06	3/9/2023	Sodium	42.1	FALSE	FALSE
G06	3/9/2023	Potassium	2.2	FALSE	FALSE
G06	3/9/2023	Chloride	21	FALSE	FALSE
G06	3/9/2023	Sulfate	221	FALSE	FALSE
G06	3/9/2023	Fluoride	0.22	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G06	3/9/2023	Barium	0.0257	FALSE	FALSE
G06	3/9/2023	Boron	2.95	FALSE	FALSE
G06	3/9/2023	Cobalt	0.0006	FALSE	FALSE
G06	3/9/2023	Iron	0.537	TRUE	NA
G06	3/9/2023	Manganese	0.0682	TRUE	NA
G06	3/9/2023	H+	0.000000269	FALSE	FALSE
G07	3/24/2021	Alkalinity, bicarbonate	171	FALSE	FALSE
G07	3/24/2021	Calcium	92.8	FALSE	FALSE
G07	3/24/2021	Magnesium	24.2	FALSE	FALSE
G07	3/24/2021	Sodium	71.4	FALSE	FALSE
G07	3/24/2021	Potassium	3.87	FALSE	FALSE
G07	3/24/2021	Chloride	21	FALSE	FALSE
G07	3/24/2021	Sulfate	258	FALSE	FALSE
G07	3/24/2021	Fluoride	0.42	FALSE	FALSE
G07	3/24/2021	Barium	0.0643	FALSE	FALSE
G07	3/24/2021	Boron	4.67	FALSE	FALSE
G07	3/24/2021	Cobalt	0.0035	FALSE	FALSE
G07	3/24/2021	Iron	2.71	FALSE	FALSE
G07	3/24/2021	Manganese	4.48	FALSE	FALSE
G07	3/24/2021	H+	0.000000398	FALSE	FALSE
G07	4/13/2021	Alkalinity, bicarbonate	164	FALSE	FALSE
G07	4/13/2021	Calcium	126	FALSE	FALSE
G07	4/13/2021	Magnesium	24.4	FALSE	FALSE
G07	4/13/2021	Sodium	90.4	FALSE	FALSE
G07	4/13/2021	Potassium	3.98	FALSE	FALSE
G07	4/13/2021	Chloride	20	FALSE	FALSE
G07	4/13/2021	Sulfate	274	FALSE	FALSE
G07	4/13/2021	Fluoride	0.42	FALSE	FALSE
G07	4/13/2021	Barium	0.0497	FALSE	FALSE
G07	4/13/2021	Boron	5.04	FALSE	FALSE
G07	4/13/2021	Cobalt	0.0024	FALSE	FALSE
G07	4/13/2021	Iron	1.2	FALSE	FALSE
G07	4/13/2021	Manganese	4.56	FALSE	FALSE
G07	4/13/2021	H+	0.000000501	FALSE	FALSE
G07	5/11/2021	Alkalinity, bicarbonate	162	FALSE	FALSE
G07	5/11/2021	Calcium	90.4	FALSE	FALSE
G07	5/11/2021	Magnesium	22.9	FALSE	FALSE
G07	5/11/2021	Sodium	68.6	FALSE	FALSE
G07	5/11/2021	Potassium	3.9	FALSE	FALSE
G07	5/11/2021	Chloride	19	FALSE	FALSE
G07	5/11/2021	Sulfate	248	FALSE	FALSE
G07	5/11/2021	Fluoride	0.41	FALSE	FALSE
G07	5/11/2021	Barium	0.0448	FALSE	FALSE
G07	5/11/2021	Boron	4.55	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G07	5/11/2021	Cobalt	0.00185	FALSE	FALSE
G07	5/11/2021	Iron	0.537	FALSE	FALSE
G07	5/11/2021	Manganese	3.71	FALSE	FALSE
G07	5/11/2021	H+	0.000000525	FALSE	FALSE
G07	6/1/2021	Alkalinity, bicarbonate	173	FALSE	FALSE
G07	6/1/2021	Calcium	96.6	FALSE	FALSE
G07	6/1/2021	Magnesium	22.9	FALSE	FALSE
G07	6/1/2021	Sodium	67.5	FALSE	FALSE
G07	6/1/2021	Potassium	4.32	FALSE	FALSE
G07	6/1/2021	Chloride	22	FALSE	FALSE
G07	6/1/2021	Sulfate	257	FALSE	FALSE
G07	6/1/2021	Fluoride	0.43	FALSE	FALSE
G07	6/1/2021	Barium	0.054	FALSE	FALSE
G07	6/1/2021	Boron	5.23	FALSE	FALSE
G07	6/1/2021	Cobalt	0.0023	FALSE	FALSE
G07	6/1/2021	Iron	2.49	FALSE	FALSE
G07	6/1/2021	Manganese	3.54	FALSE	FALSE
G07	6/1/2021	H+	0.000000562	FALSE	FALSE
G07	6/15/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G07	6/15/2021	Calcium	89.3	FALSE	FALSE
G07	6/15/2021	Magnesium	21.8	FALSE	FALSE
G07	6/15/2021	Sodium	66.7	FALSE	FALSE
G07	6/15/2021	Potassium	3.97	FALSE	FALSE
G07	6/15/2021	Chloride	20	FALSE	FALSE
G07	6/15/2021	Sulfate	246	FALSE	FALSE
G07	6/15/2021	Fluoride	0.41	FALSE	FALSE
G07	6/15/2021	Barium	0.0429	FALSE	FALSE
G07	6/15/2021	Boron	3.91	FALSE	FALSE
G07	6/15/2021	Cobalt	0.0013	FALSE	FALSE
G07	6/15/2021	Iron	0.294	FALSE	FALSE
G07	6/15/2021	Manganese	3.7	FALSE	FALSE
G07	6/15/2021	H+	0.000000562	FALSE	FALSE
G07	7/6/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G07	7/6/2021	Calcium	84.8	FALSE	FALSE
G07	7/6/2021	Magnesium	20.5	FALSE	FALSE
G07	7/6/2021	Sodium	66.5	FALSE	FALSE
G07	7/6/2021	Potassium	3.87	FALSE	FALSE
G07	7/6/2021	Chloride	21	FALSE	FALSE
G07	7/6/2021	Sulfate	258	FALSE	FALSE
G07	7/6/2021	Fluoride	0.4	FALSE	FALSE
G07	7/6/2021	Barium	0.0373	FALSE	FALSE
G07	7/6/2021	Boron	4.95	FALSE	FALSE
G07	7/6/2021	Cobalt	0.0012	FALSE	FALSE
G07	7/6/2021	Iron	0.134	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G07	7/6/2021	Manganese	4.1	FALSE	FALSE
G07	7/6/2021	H+	0.00000105	FALSE	FALSE
G07	7/20/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G07	7/20/2021	Calcium	96.5	FALSE	FALSE
G07	7/20/2021	Magnesium	23	FALSE	FALSE
G07	7/20/2021	Sodium	67.4	FALSE	FALSE
G07	7/20/2021	Potassium	4.03	FALSE	FALSE
G07	7/20/2021	Chloride	21	FALSE	FALSE
G07	7/20/2021	Sulfate	252	FALSE	FALSE
G07	7/20/2021	Fluoride	0.4	FALSE	FALSE
G07	7/20/2021	Barium	0.047	FALSE	FALSE
G07	7/20/2021	Boron	4.48	FALSE	FALSE
G07	7/20/2021	Cobalt	0.0014	FALSE	FALSE
G07	7/20/2021	Iron	0.639	FALSE	FALSE
G07	7/20/2021	Manganese	3.28	FALSE	FALSE
G07	7/20/2021	H+	0.000000724	FALSE	FALSE
G08	4/13/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G08	4/13/2021	Calcium	142	FALSE	FALSE
G08	4/13/2021	Magnesium	31.9	FALSE	FALSE
G08	4/13/2021	Sodium	33.6	FALSE	FALSE
G08	4/13/2021	Potassium	1.6	FALSE	FALSE
G08	4/13/2021	Chloride	15	FALSE	FALSE
G08	4/13/2021	Sulfate	286	FALSE	FALSE
G08	4/13/2021	Fluoride	0.34	FALSE	FALSE
G08	4/13/2021	Barium	0.0772	FALSE	FALSE
G08	4/13/2021	Boron	5.25	FALSE	FALSE
G08	4/13/2021	Cobalt	0.0041	FALSE	FALSE
G08	4/13/2021	Iron	4.82	FALSE	FALSE
G08	4/13/2021	Manganese	6.03	FALSE	FALSE
G08	4/13/2021	H+	0.0000001	FALSE	FALSE
G08	5/11/2021	Alkalinity, bicarbonate	185	FALSE	FALSE
G08	5/11/2021	Calcium	101	FALSE	FALSE
G08	5/11/2021	Magnesium	25.4	FALSE	FALSE
G08	5/11/2021	Sodium	24.3	FALSE	FALSE
G08	5/11/2021	Potassium	1.45	FALSE	FALSE
G08	5/11/2021	Chloride	12	FALSE	FALSE
G08	5/11/2021	Sulfate	203	FALSE	FALSE
G08	5/11/2021	Fluoride	0.36	FALSE	FALSE
G08	5/11/2021	Barium	0.0685	FALSE	FALSE
G08	5/11/2021	Boron	3.77	FALSE	FALSE
G08	5/11/2021	Cobalt	0.0022	FALSE	FALSE
G08	5/11/2021	Iron	1.33	FALSE	FALSE
G08	5/11/2021	Manganese	3.09	FALSE	FALSE
G08	5/11/2021	H+	0.000000115	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G08	6/1/2021	Alkalinity, bicarbonate	201	FALSE	FALSE
G08	6/1/2021	Calcium	114	FALSE	FALSE
G08	6/1/2021	Magnesium	27.2	FALSE	FALSE
G08	6/1/2021	Sodium	25.4	FALSE	FALSE
G08	6/1/2021	Potassium	1.48	FALSE	FALSE
G08	6/1/2021	Chloride	15	FALSE	FALSE
G08	6/1/2021	Sulfate	204	FALSE	FALSE
G08	6/1/2021	Fluoride	0.34	FALSE	FALSE
G08	6/1/2021	Barium	0.0588	FALSE	FALSE
G08	6/1/2021	Boron	4.63	FALSE	FALSE
G08	6/1/2021	Cobalt	0.0041	FALSE	FALSE
G08	6/1/2021	Iron	4.43	FALSE	FALSE
G08	6/1/2021	Manganese	3.15	FALSE	FALSE
G08	6/1/2021	H+	0.00000011	FALSE	FALSE
G08	7/23/2022	Alkalinity, bicarbonate	191	FALSE	FALSE
G08	7/23/2022	Calcium	118	FALSE	FALSE
G08	7/23/2022	Magnesium	29	FALSE	FALSE
G08	7/23/2022	Sodium	30.5	FALSE	FALSE
G08	7/23/2022	Potassium	1.46	FALSE	FALSE
G08	7/23/2022	Chloride	16	FALSE	FALSE
G08	7/23/2022	Sulfate	229	FALSE	FALSE
G08	7/23/2022	Fluoride	0.3	FALSE	FALSE
G08	7/23/2022	Barium	0.0387	FALSE	FALSE
G08	7/23/2022	Boron	4.74	FALSE	FALSE
G08	7/23/2022	Cobalt	0.0028	FALSE	FALSE
G08	7/23/2022	Iron	2.25	FALSE	FALSE
G08	7/23/2022	Manganese	2.89	FALSE	FALSE
G08	7/23/2022	H+	2.57E-08	FALSE	FALSE
G08	3/9/2023	Alkalinity, bicarbonate	174	FALSE	FALSE
G08	3/9/2023	Calcium	119	FALSE	FALSE
G08	3/9/2023	Magnesium	28.9	FALSE	FALSE
G08	3/9/2023	Sodium	28.5	FALSE	FALSE
G08	3/9/2023	Potassium	1.47	FALSE	FALSE
G08	3/9/2023	Chloride	15	FALSE	FALSE
G08	3/9/2023	Sulfate	297	FALSE	FALSE
G08	3/9/2023	Fluoride	0.23	FALSE	FALSE
G08	3/9/2023	Barium	0.0495	FALSE	FALSE
G08	3/9/2023	Boron	4.33	FALSE	FALSE
G08	3/9/2023	Cobalt	0.0036	FALSE	FALSE
G08	3/9/2023	Iron	2.25	TRUE	NA
G08	3/9/2023	Manganese	0.0892	TRUE	NA
G08	3/9/2023	H+	0.000000141	FALSE	FALSE
G08	5/3/2023	Alkalinity, bicarbonate	154	FALSE	FALSE
G08	5/3/2023	Calcium	140	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G08	5/3/2023	Magnesium	32.2	FALSE	FALSE
G08	5/3/2023	Sodium	41.7	FALSE	FALSE
G08	5/3/2023	Potassium	1.67	FALSE	FALSE
G08	5/3/2023	Chloride	16	FALSE	FALSE
G08	5/3/2023	Sulfate	363	FALSE	FALSE
G08	5/3/2023	Fluoride	0.29	FALSE	FALSE
G08	5/3/2023	Barium	0.0974	FALSE	FALSE
G08	5/3/2023	Boron	5.43	FALSE	FALSE
G08	5/3/2023	Cobalt	0.0113	FALSE	FALSE
G08	5/3/2023	Iron	16.8	FALSE	FALSE
G08	5/3/2023	Manganese	2.62	FALSE	FALSE
G08	5/3/2023	H+	0.000000132	FALSE	FALSE
G09	3/4/2021	Alkalinity, bicarbonate	188	FALSE	FALSE
G09	3/4/2021	Calcium	103	FALSE	FALSE
G09	3/4/2021	Magnesium	33.8	FALSE	FALSE
G09	3/4/2021	Sodium	72	FALSE	FALSE
G09	3/4/2021	Potassium	2.78	FALSE	FALSE
G09	3/4/2021	Chloride	24	FALSE	FALSE
G09	3/4/2021	Sulfate	351	FALSE	FALSE
G09	3/4/2021	Fluoride	0.25	FALSE	FALSE
G09	3/4/2021	Barium	0.0675	FALSE	FALSE
G09	3/4/2021	Boron	3.19	FALSE	FALSE
G09	3/4/2021	Cobalt	0.0108	FALSE	FALSE
G09	3/4/2021	Iron	1.93	FALSE	FALSE
G09	3/4/2021	Manganese	4.15	FALSE	FALSE
G09	3/4/2021	H+	0.000000631	FALSE	FALSE
G09	6/1/2021	Alkalinity, bicarbonate	177	FALSE	FALSE
G09	6/1/2021	Calcium	91.3	FALSE	FALSE
G09	6/1/2021	Magnesium	31.4	FALSE	FALSE
G09	6/1/2021	Sodium	65.3	FALSE	FALSE
G09	6/1/2021	Potassium	1.87	FALSE	FALSE
G09	6/1/2021	Chloride	23	FALSE	FALSE
G09	6/1/2021	Sulfate	284	FALSE	FALSE
G09	6/1/2021	Fluoride	0.33	FALSE	FALSE
G09	6/1/2021	Barium	0.0548	FALSE	FALSE
G09	6/1/2021	Boron	3.65	FALSE	FALSE
G09	6/1/2021	Cobalt	0.0096	FALSE	FALSE
G09	6/1/2021	Iron	5.65	FALSE	FALSE
G09	6/1/2021	Manganese	3.87	FALSE	FALSE
G09	6/1/2021	H+	0.000000575	FALSE	FALSE
G09	6/15/2021	Alkalinity, bicarbonate	179	FALSE	FALSE
G09	6/15/2021	Calcium	137	FALSE	FALSE
G09	6/15/2021	Magnesium	49.3	FALSE	FALSE
G09	6/15/2021	Sodium	58.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G09	6/15/2021	Potassium	1.56	FALSE	FALSE
G09	6/15/2021	Chloride	21	FALSE	FALSE
G09	6/15/2021	Sulfate	294	FALSE	FALSE
G09	6/15/2021	Fluoride	0.32	FALSE	FALSE
G09	6/15/2021	Barium	0.0136	FALSE	FALSE
G09	6/15/2021	Boron	0.282	FALSE	FALSE
G09	6/15/2021	Cobalt	0.0011	FALSE	FALSE
G09	6/15/2021	Iron	0.0556	FALSE	FALSE
G09	6/15/2021	Manganese	0.104	FALSE	FALSE
G09	6/15/2021	H+	0.00000107	FALSE	FALSE
G09	7/6/2021	Alkalinity, bicarbonate	163	FALSE	FALSE
G09	7/6/2021	Calcium	79	FALSE	FALSE
G09	7/6/2021	Magnesium	28.7	FALSE	FALSE
G09	7/6/2021	Sodium	68.3	FALSE	FALSE
G09	7/6/2021	Potassium	1.65	FALSE	FALSE
G09	7/6/2021	Chloride	22	FALSE	FALSE
G09	7/6/2021	Sulfate	289	FALSE	FALSE
G09	7/6/2021	Fluoride	0.36	FALSE	FALSE
G09	7/6/2021	Barium	0.0444	FALSE	FALSE
G09	7/6/2021	Boron	4.05	FALSE	FALSE
G09	7/6/2021	Cobalt	0.0089	FALSE	FALSE
G09	7/6/2021	Iron	5.69	FALSE	FALSE
G09	7/6/2021	Manganese	4.06	FALSE	FALSE
G09	7/6/2021	H+	0.000000513	FALSE	FALSE
G09	7/21/2021	Alkalinity, bicarbonate	164	FALSE	FALSE
G09	7/21/2021	Calcium	92.1	FALSE	FALSE
G09	7/21/2021	Magnesium	32	FALSE	FALSE
G09	7/21/2021	Sodium	64.3	FALSE	FALSE
G09	7/21/2021	Potassium	1.55	FALSE	FALSE
G09	7/21/2021	Chloride	21	FALSE	FALSE
G09	7/21/2021	Sulfate	286	FALSE	FALSE
G09	7/21/2021	Fluoride	0.31	FALSE	FALSE
G09	7/21/2021	Barium	0.0454	FALSE	FALSE
G09	7/21/2021	Boron	3.75	FALSE	FALSE
G09	7/21/2021	Cobalt	0.0085	FALSE	FALSE
G09	7/21/2021	Iron	5.11	FALSE	FALSE
G09	7/21/2021	Manganese	3.17	FALSE	FALSE
G09	7/21/2021	H+	0.00000102	FALSE	FALSE
G10	3/4/2021	Alkalinity, bicarbonate	108	FALSE	FALSE
G10	3/4/2021	Calcium	107	FALSE	FALSE
G10	3/4/2021	Magnesium	35.7	FALSE	FALSE
G10	3/4/2021	Sodium	60.3	FALSE	FALSE
G10	3/4/2021	Potassium	2.54	FALSE	FALSE
G10	3/4/2021	Chloride	35	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	3/4/2021	Sulfate	391	FALSE	FALSE
G10	3/4/2021	Fluoride	0.29	FALSE	FALSE
G10	3/4/2021	Barium	0.0608	FALSE	FALSE
G10	3/4/2021	Boron	4.98	FALSE	FALSE
G10	3/4/2021	Cobalt	0.0109	FALSE	FALSE
G10	3/4/2021	Iron	2.38	FALSE	FALSE
G10	3/4/2021	Manganese	1.14	FALSE	FALSE
G10	3/4/2021	H+	0.0000002	FALSE	FALSE
G10	3/24/2021	Alkalinity, bicarbonate	132	FALSE	FALSE
G10	3/24/2021	Calcium	115	FALSE	FALSE
G10	3/24/2021	Magnesium	39.3	FALSE	FALSE
G10	3/24/2021	Sodium	62.1	FALSE	FALSE
G10	3/24/2021	Potassium	2.91	FALSE	FALSE
G10	3/24/2021	Chloride	31	FALSE	FALSE
G10	3/24/2021	Sulfate	369	FALSE	FALSE
G10	3/24/2021	Fluoride	0.3	FALSE	FALSE
G10	3/24/2021	Barium	0.0553	FALSE	FALSE
G10	3/24/2021	Boron	4.31	FALSE	FALSE
G10	3/24/2021	Cobalt	0.0122	FALSE	FALSE
G10	3/24/2021	Iron	4.61	FALSE	FALSE
G10	3/24/2021	Manganese	1.38	FALSE	FALSE
G10	3/24/2021	H+	0.0000002	FALSE	FALSE
G10	5/11/2021	Alkalinity, bicarbonate	134	FALSE	FALSE
G10	5/11/2021	Calcium	120	FALSE	FALSE
G10	5/11/2021	Magnesium	41.1	FALSE	FALSE
G10	5/11/2021	Sodium	56.8	FALSE	FALSE
G10	5/11/2021	Potassium	2.13	FALSE	FALSE
G10	5/11/2021	Chloride	25	FALSE	FALSE
G10	5/11/2021	Sulfate	364	FALSE	FALSE
G10	5/11/2021	Fluoride	0.28	FALSE	FALSE
G10	5/11/2021	Barium	0.0453	FALSE	FALSE
G10	5/11/2021	Boron	3.95	FALSE	FALSE
G10	5/11/2021	Cobalt	0.00754	FALSE	FALSE
G10	5/11/2021	Iron	1.12	FALSE	FALSE
G10	5/11/2021	Manganese	0.702	FALSE	FALSE
G10	5/11/2021	H+	0.000000457	FALSE	FALSE
G10	6/1/2021	Alkalinity, bicarbonate	127	FALSE	FALSE
G10	6/1/2021	Calcium	124	FALSE	FALSE
G10	6/1/2021	Magnesium	38.5	FALSE	FALSE
G10	6/1/2021	Sodium	55	FALSE	FALSE
G10	6/1/2021	Potassium	2.27	FALSE	FALSE
G10	6/1/2021	Chloride	29	FALSE	FALSE
G10	6/1/2021	Sulfate	401	FALSE	FALSE
G10	6/1/2021	Fluoride	0.29	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	6/1/2021	Barium	0.0444	FALSE	FALSE
G10	6/1/2021	Boron	4.73	FALSE	FALSE
G10	6/1/2021	Cobalt	0.0071	FALSE	FALSE
G10	6/1/2021	Iron	2.82	FALSE	FALSE
G10	6/1/2021	Manganese	0.608	FALSE	FALSE
G10	6/1/2021	H+	0.000000316	FALSE	FALSE
G10	6/15/2021	Alkalinity, bicarbonate	149	FALSE	FALSE
G10	6/15/2021	Calcium	128	FALSE	FALSE
G10	6/15/2021	Magnesium	40.8	FALSE	FALSE
G10	6/15/2021	Sodium	59.3	FALSE	FALSE
G10	6/15/2021	Potassium	2.25	FALSE	FALSE
G10	6/15/2021	Chloride	26	FALSE	FALSE
G10	6/15/2021	Sulfate	407	FALSE	FALSE
G10	6/15/2021	Fluoride	0.28	FALSE	FALSE
G10	6/15/2021	Barium	0.0439	FALSE	FALSE
G10	6/15/2021	Boron	3.74	FALSE	FALSE
G10	6/15/2021	Cobalt	0.005	FALSE	FALSE
G10	6/15/2021	Iron	0.864	FALSE	FALSE
G10	6/15/2021	Manganese	0.47	FALSE	FALSE
G10	6/15/2021	H+	0.000000347	FALSE	FALSE
G10	7/6/2021	Alkalinity, bicarbonate	144	FALSE	FALSE
G10	7/6/2021	Calcium	119	FALSE	FALSE
G10	7/6/2021	Magnesium	37.3	FALSE	FALSE
G10	7/6/2021	Sodium	57.6	FALSE	FALSE
G10	7/6/2021	Potassium	2.09	FALSE	FALSE
G10	7/6/2021	Chloride	26	FALSE	FALSE
G10	7/6/2021	Sulfate	415	FALSE	FALSE
G10	7/6/2021	Fluoride	0.27	FALSE	FALSE
G10	7/6/2021	Barium	0.0356	FALSE	FALSE
G10	7/6/2021	Boron	4.81	FALSE	FALSE
G10	7/6/2021	Cobalt	0.0049	FALSE	FALSE
G10	7/6/2021	Iron	0.556	FALSE	FALSE
G10	7/6/2021	Manganese	0.416	FALSE	FALSE
G10	7/6/2021	H+	0.000000309	FALSE	FALSE
G10	7/20/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
G10	7/20/2021	Calcium	132	FALSE	FALSE
G10	7/20/2021	Magnesium	40	FALSE	FALSE
G10	7/20/2021	Sodium	56.5	FALSE	FALSE
G10	7/20/2021	Potassium	2.06	FALSE	FALSE
G10	7/20/2021	Chloride	26	FALSE	FALSE
G10	7/20/2021	Sulfate	410	FALSE	FALSE
G10	7/20/2021	Fluoride	0.26	FALSE	FALSE
G10	7/20/2021	Barium	0.0368	FALSE	FALSE
G10	7/20/2021	Boron	4.2	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G10	7/20/2021	Cobalt	0.0045	FALSE	FALSE
G10	7/20/2021	Iron	0.473	FALSE	FALSE
G10	7/20/2021	Manganese	0.348	FALSE	FALSE
G10	7/20/2021	H+	0.000000324	FALSE	FALSE
G52D	9/20/2021	Alkalinity, bicarbonate	147	FALSE	FALSE
G52D	9/20/2021	Calcium	47.8	FALSE	FALSE
G52D	9/20/2021	Magnesium	16.4	TRUE	NA
G52D	9/20/2021	Sodium	49.2	TRUE	NA
G52D	9/20/2021	Potassium	0.355	TRUE	NA
G52D	9/20/2021	Chloride	13	FALSE	FALSE
G52D	9/20/2021	Sulfate	83	FALSE	FALSE
G52D	9/20/2021	Fluoride	0.26	FALSE	FALSE
G52D	9/20/2021	Barium	0.232	FALSE	FALSE
G52D	9/20/2021	Boron	0.158	FALSE	TRUE
G52D	9/20/2021	Cobalt	0.0011	FALSE	FALSE
G52D	9/20/2021	Iron	0.537	TRUE	NA
G52D	9/20/2021	Manganese	3.71	TRUE	NA
G52D	9/20/2021	H+	0.000000513	FALSE	FALSE
G52D	3/10/2023	Alkalinity, bicarbonate	156	FALSE	FALSE
G52D	3/10/2023	Calcium	49.3	FALSE	FALSE
G52D	3/10/2023	Magnesium	15.3	FALSE	FALSE
G52D	3/10/2023	Sodium	27.7	FALSE	FALSE
G52D	3/10/2023	Potassium	0.768	FALSE	FALSE
G52D	3/10/2023	Chloride	12	FALSE	FALSE
G52D	3/10/2023	Sulfate	74	FALSE	FALSE
G52D	3/10/2023	Fluoride	0.22	FALSE	FALSE
G52D	3/10/2023	Barium	0.307	FALSE	FALSE
G52D	3/10/2023	Boron	0.0319	FALSE	FALSE
G52D	3/10/2023	Cobalt	0.0022	FALSE	FALSE
G52D	3/10/2023	Iron	0.639	TRUE	NA
G52D	3/10/2023	Manganese	3.71	TRUE	NA
G52D	3/10/2023	H+	0.000000288	FALSE	FALSE
G53D	3/25/2021	Alkalinity, bicarbonate	166	FALSE	FALSE
G53D	3/25/2021	Calcium	38.6	FALSE	FALSE
G53D	3/25/2021	Magnesium	15.7	FALSE	FALSE
G53D	3/25/2021	Sodium	50.8	FALSE	FALSE
G53D	3/25/2021	Potassium	0.278	FALSE	FALSE
G53D	3/25/2021	Chloride	19	FALSE	FALSE
G53D	3/25/2021	Sulfate	71	FALSE	FALSE
G53D	3/25/2021	Fluoride	0.71	FALSE	FALSE
G53D	3/25/2021	Barium	0.112	FALSE	FALSE
G53D	3/25/2021	Boron	0.355	FALSE	FALSE
G53D	3/25/2021	Cobalt	0.0026	FALSE	FALSE
G53D	3/25/2021	Iron	1.69	TRUE	NA

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G53D	3/25/2021	Manganese	0.0334	TRUE	NA
G53D	3/25/2021	H+	0.000000295	FALSE	FALSE
G53D	9/20/2021	Alkalinity, bicarbonate	171	FALSE	FALSE
G53D	9/20/2021	Calcium	38.5	FALSE	FALSE
G53D	9/20/2021	Magnesium	16.4	TRUE	NA
G53D	9/20/2021	Sodium	50.8	TRUE	NA
G53D	9/20/2021	Potassium	0.355	TRUE	NA
G53D	9/20/2021	Chloride	19	FALSE	FALSE
G53D	9/20/2021	Sulfate	78	FALSE	FALSE
G53D	9/20/2021	Fluoride	0.7	FALSE	FALSE
G53D	9/20/2021	Barium	0.103	FALSE	FALSE
G53D	9/20/2021	Boron	0.402	FALSE	FALSE
G53D	9/20/2021	Cobalt	0.0021	FALSE	FALSE
G53D	9/20/2021	Iron	1.69	TRUE	NA
G53D	9/20/2021	Manganese	0.0334	TRUE	NA
G53D	9/20/2021	H+	0.000000537	FALSE	FALSE
G53D	3/15/2022	Alkalinity, bicarbonate	176	FALSE	FALSE
G53D	3/15/2022	Calcium	38.1	FALSE	FALSE
G53D	3/15/2022	Magnesium	16.5	FALSE	FALSE
G53D	3/15/2022	Sodium	51.3	FALSE	FALSE
G53D	3/15/2022	Potassium	0.317	FALSE	FALSE
G53D	3/15/2022	Chloride	18	FALSE	FALSE
G53D	3/15/2022	Sulfate	74	FALSE	FALSE
G53D	3/15/2022	Fluoride	0.71	FALSE	FALSE
G53D	3/15/2022	Barium	0.0922	FALSE	FALSE
G53D	3/15/2022	Boron	0.332	FALSE	FALSE
G53D	3/15/2022	Cobalt	0.0022	FALSE	FALSE
G53D	3/15/2022	Iron	1.69	TRUE	NA
G53D	3/15/2022	Manganese	0.0334	TRUE	NA
G53D	3/15/2022	H+	0.000000316	FALSE	FALSE
G53D	7/25/2022	Alkalinity, bicarbonate	149	FALSE	FALSE
G53D	7/25/2022	Calcium	39.7	FALSE	FALSE
G53D	7/25/2022	Magnesium	17	FALSE	FALSE
G53D	7/25/2022	Sodium	49.4	FALSE	FALSE
G53D	7/25/2022	Potassium	0.3	FALSE	FALSE
G53D	7/25/2022	Chloride	19	FALSE	FALSE
G53D	7/25/2022	Sulfate	77	FALSE	FALSE
G53D	7/25/2022	Fluoride	0.72	FALSE	FALSE
G53D	7/25/2022	Barium	0.0913	FALSE	FALSE
G53D	7/25/2022	Boron	0.341	FALSE	FALSE
G53D	7/25/2022	Cobalt	0.0021	FALSE	FALSE
G53D	7/25/2022	Iron	0.281	FALSE	FALSE
G53D	7/25/2022	Manganese	0.137	FALSE	FALSE
G53D	7/25/2022	H+	1.32E-08	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G53D	3/9/2023	Alkalinity, bicarbonate	177	FALSE	FALSE
G53D	3/9/2023	Calcium	38.3	FALSE	FALSE
G53D	3/9/2023	Magnesium	16.4	FALSE	FALSE
G53D	3/9/2023	Sodium	49.2	FALSE	FALSE
G53D	3/9/2023	Potassium	0.355	FALSE	FALSE
G53D	3/9/2023	Chloride	17	FALSE	FALSE
G53D	3/9/2023	Sulfate	72	FALSE	FALSE
G53D	3/9/2023	Fluoride	0.59	FALSE	FALSE
G53D	3/9/2023	Barium	0.101	FALSE	FALSE
G53D	3/9/2023	Boron	0.37	FALSE	FALSE
G53D	3/9/2023	Cobalt	0.0022	FALSE	FALSE
G53D	3/9/2023	Iron	2.25	TRUE	NA
G53D	3/9/2023	Manganese	0.0334	TRUE	NA
G53D	3/9/2023	H+	0.000000347	FALSE	FALSE
G54D	3/24/2021	Alkalinity, bicarbonate	214	FALSE	FALSE
G54D	3/24/2021	Calcium	78.1	FALSE	FALSE
G54D	3/24/2021	Magnesium	24.2	FALSE	FALSE
G54D	3/24/2021	Sodium	62.4	FALSE	FALSE
G54D	3/24/2021	Potassium	1.12	FALSE	FALSE
G54D	3/24/2021	Chloride	23	FALSE	FALSE
G54D	3/24/2021	Sulfate	186	FALSE	FALSE
G54D	3/24/2021	Fluoride	0.32	FALSE	FALSE
G54D	3/24/2021	Barium	0.0941	FALSE	FALSE
G54D	3/24/2021	Boron	0.404	FALSE	FALSE
G54D	3/24/2021	Cobalt	0.0045	FALSE	FALSE
G54D	3/24/2021	Iron	5.11	TRUE	NA
G54D	3/24/2021	Manganese	3.87	TRUE	NA
G54D	3/24/2021	H+	0.000000275	FALSE	FALSE
G54D	9/20/2021	Alkalinity, bicarbonate	207	FALSE	FALSE
G54D	9/20/2021	Calcium	72.8	FALSE	FALSE
G54D	9/20/2021	Magnesium	24.1	TRUE	NA
G54D	9/20/2021	Sodium	49.2	TRUE	NA
G54D	9/20/2021	Potassium	1.12	TRUE	NA
G54D	9/20/2021	Chloride	24	FALSE	FALSE
G54D	9/20/2021	Sulfate	175	FALSE	FALSE
G54D	9/20/2021	Fluoride	0.29	FALSE	FALSE
G54D	9/20/2021	Barium	0.0879	FALSE	FALSE
G54D	9/20/2021	Boron	0.35	FALSE	FALSE
G54D	9/20/2021	Cobalt	0.0083	FALSE	FALSE
G54D	9/20/2021	Iron	5.11	TRUE	NA
G54D	9/20/2021	Manganese	3.87	TRUE	NA
G54D	9/20/2021	H+	0.000000331	FALSE	FALSE
G54D	3/15/2022	Alkalinity, bicarbonate	208	FALSE	FALSE
G54D	3/15/2022	Calcium	83.4	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
G54D	3/15/2022	Magnesium	25.8	FALSE	FALSE
G54D	3/15/2022	Sodium	54.2	FALSE	FALSE
G54D	3/15/2022	Potassium	1.21	FALSE	FALSE
G54D	3/15/2022	Chloride	21	FALSE	FALSE
G54D	3/15/2022	Sulfate	213	FALSE	FALSE
G54D	3/15/2022	Fluoride	0.31	FALSE	FALSE
G54D	3/15/2022	Barium	0.064	FALSE	FALSE
G54D	3/15/2022	Boron	0.451	FALSE	FALSE
G54D	3/15/2022	Cobalt	0.011	FALSE	FALSE
G54D	3/15/2022	Iron	5.11	TRUE	NA
G54D	3/15/2022	Manganese	3.87	TRUE	NA
G54D	3/15/2022	H+	0.000000245	FALSE	FALSE
G54D	9/20/2022	Alkalinity, bicarbonate	171	TRUE	NA
G54D	9/20/2022	Calcium	69.7	FALSE	FALSE
G54D	9/20/2022	Magnesium	19.4	TRUE	NA
G54D	9/20/2022	Sodium	49.2	TRUE	NA
G54D	9/20/2022	Potassium	0.355	TRUE	NA
G54D	9/20/2022	Chloride	22	FALSE	FALSE
G54D	9/20/2022	Sulfate	218	FALSE	FALSE
G54D	9/20/2022	Fluoride	0.27	FALSE	FALSE
G54D	9/20/2022	Barium	0.0768	FALSE	FALSE
G54D	9/20/2022	Boron	0.252	FALSE	FALSE
G54D	9/20/2022	Cobalt	0.0048	FALSE	FALSE
G54D	9/20/2022	Iron	5.11	TRUE	NA
G54D	9/20/2022	Manganese	3.87	TRUE	NA
G54D	9/20/2022	H+	0.000000316	FALSE	FALSE
G54D	5/3/2023	Alkalinity, bicarbonate	206	FALSE	FALSE
G54D	5/3/2023	Calcium	81.5	FALSE	FALSE
G54D	5/3/2023	Magnesium	26.4	FALSE	FALSE
G54D	5/3/2023	Sodium	57	FALSE	FALSE
G54D	5/3/2023	Potassium	1.21	FALSE	FALSE
G54D	5/3/2023	Chloride	22	FALSE	FALSE
G54D	5/3/2023	Sulfate	194	FALSE	FALSE
G54D	5/3/2023	Fluoride	0.3	FALSE	FALSE
G54D	5/3/2023	Barium	0.0794	FALSE	FALSE
G54D	5/3/2023	Boron	0.555	FALSE	FALSE
G54D	5/3/2023	Cobalt	0.0106	FALSE	FALSE
G54D	5/3/2023	Iron	1.39	FALSE	FALSE
G54D	5/3/2023	Manganese	1.19	FALSE	FALSE
G54D	5/3/2023	H+	0.000000158	FALSE	FALSE
XPW01	3/5/2021	Alkalinity, bicarbonate	155	FALSE	FALSE
XPW01	3/5/2021	Calcium	162	FALSE	FALSE
XPW01	3/5/2021	Magnesium	2.25	FALSE	FALSE
XPW01	3/5/2021	Sodium	35.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	3/5/2021	Potassium	31.1	FALSE	FALSE
XPW01	3/5/2021	Chloride	10	FALSE	FALSE
XPW01	3/5/2021	Sulfate	345	FALSE	FALSE
XPW01	3/5/2021	Fluoride	0.67	FALSE	FALSE
XPW01	3/5/2021	Barium	0.165	FALSE	FALSE
XPW01	3/5/2021	Boron	10.4	FALSE	FALSE
XPW01	3/5/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	3/5/2021	Iron	2.18	FALSE	FALSE
XPW01	3/5/2021	Manganese	1.24	FALSE	FALSE
XPW01	3/5/2021	H+	0.00000001	FALSE	FALSE
XPW01	3/24/2021	Alkalinity, bicarbonate	141	FALSE	FALSE
XPW01	3/24/2021	Calcium	158	FALSE	FALSE
XPW01	3/24/2021	Magnesium	1.7	FALSE	FALSE
XPW01	3/24/2021	Sodium	37.2	FALSE	FALSE
XPW01	3/24/2021	Potassium	38.1	FALSE	FALSE
XPW01	3/24/2021	Chloride	9	FALSE	FALSE
XPW01	3/24/2021	Sulfate	355	FALSE	FALSE
XPW01	3/24/2021	Fluoride	0.55	FALSE	FALSE
XPW01	3/24/2021	Barium	0.161	FALSE	FALSE
XPW01	3/24/2021	Boron	9.58	FALSE	FALSE
XPW01	3/24/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	3/24/2021	Iron	1.18	FALSE	FALSE
XPW01	3/24/2021	Manganese	0.59	FALSE	FALSE
XPW01	3/24/2021	H+	3.98E-09	FALSE	FALSE
XPW01	4/14/2021	Alkalinity, bicarbonate	136	FALSE	FALSE
XPW01	4/14/2021	Calcium	156	FALSE	FALSE
XPW01	4/14/2021	Magnesium	1.28	FALSE	FALSE
XPW01	4/14/2021	Sodium	28.3	FALSE	FALSE
XPW01	4/14/2021	Potassium	34.7	FALSE	FALSE
XPW01	4/14/2021	Chloride	7	FALSE	FALSE
XPW01	4/14/2021	Sulfate	355	FALSE	FALSE
XPW01	4/14/2021	Fluoride	0.57	FALSE	FALSE
XPW01	4/14/2021	Barium	0.154	FALSE	FALSE
XPW01	4/14/2021	Boron	9.42	FALSE	FALSE
XPW01	4/14/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	4/14/2021	Iron	1.36	FALSE	FALSE
XPW01	4/14/2021	Manganese	0.725	FALSE	FALSE
XPW01	4/14/2021	H+	6.31E-09	FALSE	FALSE
XPW01	5/12/2021	Alkalinity, bicarbonate	145	FALSE	FALSE
XPW01	5/12/2021	Calcium	166	FALSE	FALSE
XPW01	5/12/2021	Magnesium	1.31	FALSE	FALSE
XPW01	5/12/2021	Sodium	29.3	FALSE	FALSE
XPW01	5/12/2021	Potassium	36.9	FALSE	FALSE
XPW01	5/12/2021	Chloride	6	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	5/12/2021	Sulfate	309	FALSE	FALSE
XPW01	5/12/2021	Fluoride	0.62	FALSE	FALSE
XPW01	5/12/2021	Barium	0.162	FALSE	FALSE
XPW01	5/12/2021	Boron	10.2	FALSE	FALSE
XPW01	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW01	5/12/2021	Iron	1.98	FALSE	FALSE
XPW01	5/12/2021	Manganese	1.09	FALSE	FALSE
XPW01	5/12/2021	H+	3.98E-09	FALSE	FALSE
XPW01	3/15/2022	Alkalinity, bicarbonate	104	FALSE	FALSE
XPW01	3/15/2022	Calcium	159	FALSE	FALSE
XPW01	3/15/2022	Magnesium	0.443	FALSE	FALSE
XPW01	3/15/2022	Sodium	27.4	FALSE	FALSE
XPW01	3/15/2022	Potassium	36.9	FALSE	FALSE
XPW01	3/15/2022	Chloride	5	FALSE	FALSE
XPW01	3/15/2022	Sulfate	360	FALSE	FALSE
XPW01	3/15/2022	Fluoride	0.25	FALSE	FALSE
XPW01	3/15/2022	Barium	0.113	FALSE	FALSE
XPW01	3/15/2022	Boron	10.4	FALSE	FALSE
XPW01	3/15/2022	Cobalt	0.0316	FALSE	TRUE
XPW01	3/15/2022	Iron	1.36	TRUE	NA
XPW01	3/15/2022	Manganese	0.725	TRUE	NA
XPW01	3/15/2022	H+	4.68E-09	FALSE	FALSE
XPW01	3/8/2023	Alkalinity, bicarbonate	64	FALSE	FALSE
XPW01	3/8/2023	Calcium	164	FALSE	FALSE
XPW01	3/8/2023	Magnesium	0.254	FALSE	FALSE
XPW01	3/8/2023	Sodium	27.2	FALSE	FALSE
XPW01	3/8/2023	Potassium	37.2	FALSE	FALSE
XPW01	3/8/2023	Chloride	11	FALSE	FALSE
XPW01	3/8/2023	Sulfate	414	FALSE	FALSE
XPW01	3/8/2023	Fluoride	0.16	FALSE	FALSE
XPW01	3/8/2023	Barium	0.128	FALSE	FALSE
XPW01	3/8/2023	Boron	8.79	FALSE	FALSE
XPW01	3/8/2023	Cobalt	0.0002	FALSE	FALSE
XPW01	3/8/2023	Iron	1.36	TRUE	NA
XPW01	3/8/2023	Manganese	0.725	TRUE	NA
XPW01	3/8/2023	H+	3.39E-09	FALSE	FALSE
XPW01	5/3/2023	Alkalinity, bicarbonate	130	FALSE	FALSE
XPW01	5/3/2023	Calcium	151	FALSE	FALSE
XPW01	5/3/2023	Magnesium	0.405	FALSE	FALSE
XPW01	5/3/2023	Sodium	27	FALSE	FALSE
XPW01	5/3/2023	Potassium	38.5	FALSE	FALSE
XPW01	5/3/2023	Chloride	14	FALSE	FALSE
XPW01	5/3/2023	Sulfate	345	FALSE	FALSE
XPW01	5/3/2023	Fluoride	0.34	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW01	5/3/2023	Barium	0.137	FALSE	FALSE
XPW01	5/3/2023	Boron	10.6	FALSE	FALSE
XPW01	5/3/2023	Cobalt	0.0002	FALSE	FALSE
XPW01	5/3/2023	Iron	1	FALSE	FALSE
XPW01	5/3/2023	Manganese	0.544	FALSE	FALSE
XPW01	5/3/2023	H+	3.89E-09	FALSE	FALSE
XPW02	3/4/2021	Alkalinity, bicarbonate	121	FALSE	FALSE
XPW02	3/4/2021	Calcium	591	FALSE	FALSE
XPW02	3/4/2021	Magnesium	10.9	FALSE	FALSE
XPW02	3/4/2021	Sodium	888	FALSE	FALSE
XPW02	3/4/2021	Potassium	23.4	FALSE	FALSE
XPW02	3/4/2021	Chloride	130	FALSE	FALSE
XPW02	3/4/2021	Sulfate	2380	FALSE	FALSE
XPW02	3/4/2021	Fluoride	0.42	FALSE	FALSE
XPW02	3/4/2021	Barium	0.0342	FALSE	FALSE
XPW02	3/4/2021	Boron	12.1	FALSE	FALSE
XPW02	3/4/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	3/4/2021	Iron	1.63	FALSE	FALSE
XPW02	3/4/2021	Manganese	0.47	FALSE	FALSE
XPW02	3/4/2021	H+	0.00000001	FALSE	FALSE
XPW02	3/24/2021	Alkalinity, bicarbonate	128	FALSE	FALSE
XPW02	3/24/2021	Calcium	484	FALSE	FALSE
XPW02	3/24/2021	Magnesium	11.3	FALSE	FALSE
XPW02	3/24/2021	Sodium	798	FALSE	FALSE
XPW02	3/24/2021	Potassium	26.3	FALSE	FALSE
XPW02	3/24/2021	Chloride	176	FALSE	FALSE
XPW02	3/24/2021	Sulfate	2830	FALSE	FALSE
XPW02	3/24/2021	Fluoride	0.45	FALSE	FALSE
XPW02	3/24/2021	Barium	0.0271	FALSE	FALSE
XPW02	3/24/2021	Boron	12.2	FALSE	FALSE
XPW02	3/24/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	3/24/2021	Iron	1.25	FALSE	FALSE
XPW02	3/24/2021	Manganese	0.499	FALSE	FALSE
XPW02	3/24/2021	H+	0.00000001	FALSE	FALSE
XPW02	4/14/2021	Alkalinity, bicarbonate	128	FALSE	FALSE
XPW02	4/14/2021	Calcium	551	FALSE	FALSE
XPW02	4/14/2021	Magnesium	11.3	FALSE	FALSE
XPW02	4/14/2021	Sodium	705	FALSE	FALSE
XPW02	4/14/2021	Potassium	25.3	FALSE	FALSE
XPW02	4/14/2021	Chloride	110	FALSE	FALSE
XPW02	4/14/2021	Sulfate	2410	FALSE	FALSE
XPW02	4/14/2021	Fluoride	0.44	FALSE	FALSE
XPW02	4/14/2021	Barium	0.0283	FALSE	FALSE
XPW02	4/14/2021	Boron	11.5	FALSE	FALSE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW02	4/14/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	4/14/2021	Iron	1.69	FALSE	FALSE
XPW02	4/14/2021	Manganese	0.583	FALSE	FALSE
XPW02	4/14/2021	H+	1.26E-08	FALSE	FALSE
XPW02	5/12/2021	Alkalinity, bicarbonate	123	FALSE	FALSE
XPW02	5/12/2021	Calcium	495	FALSE	FALSE
XPW02	5/12/2021	Magnesium	11.8	FALSE	FALSE
XPW02	5/12/2021	Sodium	641	FALSE	FALSE
XPW02	5/12/2021	Potassium	24.5	FALSE	FALSE
XPW02	5/12/2021	Chloride	134	FALSE	FALSE
XPW02	5/12/2021	Sulfate	2410	FALSE	FALSE
XPW02	5/12/2021	Fluoride	0.41	FALSE	FALSE
XPW02	5/12/2021	Barium	0.0287	FALSE	FALSE
XPW02	5/12/2021	Boron	10.8	FALSE	FALSE
XPW02	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	5/12/2021	Iron	2.15	FALSE	FALSE
XPW02	5/12/2021	Manganese	0.632	FALSE	FALSE
XPW02	5/12/2021	H+	1.41E-08	FALSE	FALSE
XPW02	7/21/2021	Alkalinity, bicarbonate	139	FALSE	FALSE
XPW02	7/21/2021	Calcium	494	FALSE	FALSE
XPW02	7/21/2021	Magnesium	11.1	FALSE	FALSE
XPW02	7/21/2021	Sodium	762	FALSE	FALSE
XPW02	7/21/2021	Potassium	24.7	FALSE	FALSE
XPW02	7/21/2021	Chloride	179	FALSE	FALSE
XPW02	7/21/2021	Sulfate	2330	FALSE	FALSE
XPW02	7/21/2021	Fluoride	0.4	FALSE	FALSE
XPW02	7/21/2021	Barium	0.0226	FALSE	FALSE
XPW02	7/21/2021	Boron	12	FALSE	FALSE
XPW02	7/21/2021	Cobalt	0.0316	FALSE	TRUE
XPW02	7/21/2021	Iron	2.7	FALSE	FALSE
XPW02	7/21/2021	Manganese	0.744	FALSE	FALSE
XPW02	7/21/2021	H+	1.74E-08	FALSE	FALSE
XPW02	3/15/2022	Alkalinity, bicarbonate	144	FALSE	FALSE
XPW02	3/15/2022	Calcium	483	FALSE	FALSE
XPW02	3/15/2022	Magnesium	10.7	FALSE	FALSE
XPW02	3/15/2022	Sodium	828	FALSE	FALSE
XPW02	3/15/2022	Potassium	27.1	FALSE	FALSE
XPW02	3/15/2022	Chloride	115	FALSE	FALSE
XPW02	3/15/2022	Sulfate	2590	FALSE	FALSE
XPW02	3/15/2022	Fluoride	0.48	FALSE	FALSE
XPW02	3/15/2022	Barium	0.023	FALSE	FALSE
XPW02	3/15/2022	Boron	16	FALSE	FALSE
XPW02	3/15/2022	Cobalt	0.0316	FALSE	TRUE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW02	3/15/2022	Iron	1.69	TRUE	NA
XPW02	3/15/2022	Manganese	0.583	TRUE	NA
XPW02	3/15/2022	H+	1.82E-08	FALSE	FALSE
XPW02	5/3/2023	Alkalinity, bicarbonate	139	FALSE	FALSE
XPW02	5/3/2023	Calcium	451	FALSE	FALSE
XPW02	5/3/2023	Magnesium	12.3	FALSE	FALSE
XPW02	5/3/2023	Sodium	953	FALSE	FALSE
XPW02	5/3/2023	Potassium	27.4	FALSE	FALSE
XPW02	5/3/2023	Chloride	104	FALSE	FALSE
XPW02	5/3/2023	Sulfate	2650	FALSE	FALSE
XPW02	5/3/2023	Fluoride	0.48	FALSE	FALSE
XPW02	5/3/2023	Barium	0.0212	FALSE	FALSE
XPW02	5/3/2023	Boron	13.4	FALSE	FALSE
XPW02	5/3/2023	Cobalt	0.0002	FALSE	FALSE
XPW02	5/3/2023	Iron	3.49	FALSE	FALSE
XPW02	5/3/2023	Manganese	0.748	FALSE	FALSE
XPW02	5/3/2023	H+	1.91E-08	FALSE	FALSE
XPW03	5/12/2021	Alkalinity, bicarbonate	141	TRUE	FALSE
XPW03	5/12/2021	Calcium	16.4	FALSE	FALSE
XPW03	5/12/2021	Magnesium	0.316	FALSE	TRUE
XPW03	5/12/2021	Sodium	113	FALSE	FALSE
XPW03	5/12/2021	Potassium	27.5	FALSE	FALSE
XPW03	5/12/2021	Chloride	25	FALSE	FALSE
XPW03	5/12/2021	Sulfate	155	FALSE	FALSE
XPW03	5/12/2021	Fluoride	0.25	FALSE	FALSE
XPW03	5/12/2021	Barium	0.012	FALSE	FALSE
XPW03	5/12/2021	Boron	11.7	FALSE	FALSE
XPW03	5/12/2021	Cobalt	0.0316	FALSE	TRUE
XPW03	5/12/2021	Iron	0.316	FALSE	TRUE
XPW03	5/12/2021	Manganese	0.0707	FALSE	TRUE
XPW03	5/12/2021	H+	2E-11	FALSE	FALSE
XPW03	7/21/2021	Alkalinity, bicarbonate	141	TRUE	FALSE
XPW03	7/21/2021	Calcium	15.3	FALSE	FALSE
XPW03	7/21/2021	Magnesium	0.224	FALSE	TRUE
XPW03	7/21/2021	Sodium	104	FALSE	FALSE
XPW03	7/21/2021	Potassium	26.9	FALSE	FALSE
XPW03	7/21/2021	Chloride	26	FALSE	FALSE
XPW03	7/21/2021	Sulfate	148	FALSE	FALSE
XPW03	7/21/2021	Fluoride	0.26	FALSE	FALSE
XPW03	7/21/2021	Barium	0.0114	FALSE	FALSE
XPW03	7/21/2021	Boron	11.6	FALSE	FALSE
XPW03	7/21/2021	Cobalt	0.0316	FALSE	TRUE
XPW03	7/21/2021	Iron	0.158	FALSE	TRUE
XPW03	7/21/2021	Manganese	0.0447	FALSE	TRUE

Attachment A.
ELECTRONIC PCA DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Date	Parameter	Result (mg/L)	Imputed Value	Half RL Used
XPW03	7/21/2021	H+	1.07E-10	FALSE	FALSE

Note:
mg/L = milligrams per liter
RL = reporting limit

APPENDIX C
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
G03	Compliance	06/15/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	07/06/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	07/21/2021	Cobalt, total	0.001 U	mg/L
G03	Compliance	06/15/2021	Manganese, total	0.0330	mg/L
G03	Compliance	07/06/2021	Manganese, total	0.0226	mg/L
G03	Compliance	07/21/2021	Manganese, total	0.0334	mg/L
G05	Compliance	03/04/2021	Boron, total	0.181	mg/L
G05	Compliance	03/24/2021	Boron, total	0.195	mg/L
G05	Compliance	04/13/2021	Boron, total	0.190	mg/L
G05	Compliance	05/11/2021	Boron, total	0.158	mg/L
G05	Compliance	06/01/2021	Boron, total	0.157	mg/L
G05	Compliance	06/15/2021	Boron, total	0.140	mg/L
G05	Compliance	07/06/2021	Boron, total	0.148	mg/L
G05	Compliance	07/20/2021	Boron, total	0.131	mg/L
G05	Compliance	07/26/2022	Boron, total	0.0645	mg/L
G05	Compliance	03/09/2023	Boron, total	0.0541	mg/L
G05	Compliance	05/03/2023	Boron, total	0.0478	mg/L
G05	Compliance	03/04/2021	Cobalt, total	0.0101	mg/L
G05	Compliance	03/24/2021	Cobalt, total	0.00960	mg/L
G05	Compliance	04/13/2021	Cobalt, total	0.00950	mg/L
G05	Compliance	05/11/2021	Cobalt, total	0.00870	mg/L
G05	Compliance	06/01/2021	Cobalt, total	0.00780	mg/L
G05	Compliance	06/15/2021	Cobalt, total	0.00570	mg/L
G05	Compliance	07/06/2021	Cobalt, total	0.00910	mg/L
G05	Compliance	07/20/2021	Cobalt, total	0.00590	mg/L
G05	Compliance	07/26/2022	Cobalt, total	0.00750	mg/L
G05	Compliance	03/09/2023	Cobalt, total	0.00740	mg/L
G05	Compliance	05/03/2023	Cobalt, total	0.0103	mg/L
G05	Compliance	03/04/2021	Manganese, total	0.227	mg/L
G05	Compliance	04/13/2021	Manganese, total	0.294	mg/L
G05	Compliance	05/11/2021	Manganese, total	0.256	mg/L
G05	Compliance	06/01/2021	Manganese, total	0.254	mg/L
G05	Compliance	06/15/2021	Manganese, total	0.187	mg/L
G05	Compliance	07/06/2021	Manganese, total	0.270	mg/L
G05	Compliance	07/20/2021	Manganese, total	0.204	mg/L
G05	Compliance	07/26/2022	Manganese, total	0.176	mg/L
G05	Compliance	05/03/2023	Manganese, total	0.191	mg/L
G05	Compliance	03/04/2021	Sulfate, total	94.0	mg/L
G05	Compliance	03/24/2021	Sulfate, total	92.0	mg/L
G05	Compliance	04/13/2021	Sulfate, total	95.0	mg/L
G05	Compliance	05/11/2021	Sulfate, total	109	mg/L
G05	Compliance	06/01/2021	Sulfate, total	83.0	mg/L
G05	Compliance	06/15/2021	Sulfate, total	91.0	mg/L
G05	Compliance	07/06/2021	Sulfate, total	90.0	mg/L
G05	Compliance	07/20/2021	Sulfate, total	87.0	mg/L
G05	Compliance	07/26/2022	Sulfate, total	68.0	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
G05	Compliance	03/09/2023	Sulfate, total	90.0	mg/L
G05	Compliance	05/03/2023	Sulfate, total	112	mg/L
G53D	Compliance	07/25/2022	Cobalt, total	0.00210	mg/L
G53D	Compliance	05/03/2023	Cobalt, total	0.00180	mg/L
G53D	Compliance	07/25/2022	Manganese, total	0.137	mg/L
G53D	Compliance	05/03/2023	Manganese, total	0.133	mg/L
XPW01	Porewater	03/05/2021	Boron, total	10.4	mg/L
XPW01	Porewater	03/24/2021	Boron, total	9.58	mg/L
XPW01	Porewater	04/14/2021	Boron, total	9.42	mg/L
XPW01	Porewater	05/12/2021	Boron, total	10.2	mg/L
XPW01	Porewater	07/21/2021	Boron, total	10.1	mg/L
XPW01	Porewater	03/15/2022	Boron, total	10.4	mg/L
XPW01	Porewater	03/08/2023	Boron, total	8.79	mg/L
XPW01	Porewater	05/03/2023	Boron, total	10.6	mg/L
XPW01	Porewater	03/05/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW01	Porewater	03/08/2023	Cobalt, total	0.0002 J	mg/L
XPW01	Porewater	05/03/2023	Cobalt, total	0.0002 J	mg/L
XPW01	Porewater	03/05/2021	Sulfate, total	345	mg/L
XPW01	Porewater	03/24/2021	Sulfate, total	355	mg/L
XPW01	Porewater	04/14/2021	Sulfate, total	355	mg/L
XPW01	Porewater	05/12/2021	Sulfate, total	309	mg/L
XPW01	Porewater	07/21/2021	Sulfate, total	328	mg/L
XPW01	Porewater	03/15/2022	Sulfate, total	360	mg/L
XPW01	Porewater	03/08/2023	Sulfate, total	414	mg/L
XPW01	Porewater	05/03/2023	Sulfate, total	345	mg/L
XPW02	Porewater	03/04/2021	Boron, total	12.1	mg/L
XPW02	Porewater	03/24/2021	Boron, total	12.2	mg/L
XPW02	Porewater	04/14/2021	Boron, total	11.5	mg/L
XPW02	Porewater	05/12/2021	Boron, total	10.8	mg/L
XPW02	Porewater	07/21/2021	Boron, total	12.0	mg/L
XPW02	Porewater	03/15/2022	Boron, total	16.0	mg/L
XPW02	Porewater	03/08/2023	Boron, total	10.8	mg/L
XPW02	Porewater	05/03/2023	Boron, total	13.4	mg/L
XPW02	Porewater	03/04/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW02	Porewater	03/08/2023	Cobalt, total	0.0003 J	mg/L
XPW02	Porewater	05/03/2023	Cobalt, total	0.0002 J	mg/L

APPENDIX C.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Well ID	Well Type	Date	Parameter	Result	Unit
XPW02	Porewater	03/04/2021	Sulfate, total	2,380	mg/L
XPW02	Porewater	03/24/2021	Sulfate, total	2,830	mg/L
XPW02	Porewater	04/14/2021	Sulfate, total	2,410	mg/L
XPW02	Porewater	05/12/2021	Sulfate, total	2,410	mg/L
XPW02	Porewater	07/21/2021	Sulfate, total	2,330	mg/L
XPW02	Porewater	03/15/2022	Sulfate, total	2,590	mg/L
XPW02	Porewater	03/08/2023	Sulfate, total	2,450	mg/L
XPW02	Porewater	05/03/2023	Sulfate, total	2,650	mg/L
XPW03	Porewater	03/04/2021	Boron, total	12.2	mg/L
XPW03	Porewater	03/24/2021	Boron, total	11.6	mg/L
XPW03	Porewater	04/14/2021	Boron, total	9.30	mg/L
XPW03	Porewater	05/12/2021	Boron, total	11.7	mg/L
XPW03	Porewater	07/21/2021	Boron, total	11.6	mg/L
XPW03	Porewater	03/15/2022	Boron, total	11.1	mg/L
XPW03	Porewater	03/09/2023	Boron, total	8.06	mg/L
XPW03	Porewater	05/03/2023	Boron, total	9.22	mg/L
XPW03	Porewater	03/04/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/24/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	04/14/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	05/12/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	07/21/2021	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/15/2022	Cobalt, total	0.001 U	mg/L
XPW03	Porewater	03/09/2023	Cobalt, total	0.0001 U	mg/L
XPW03	Porewater	05/03/2023	Cobalt, total	0.0001 U	mg/L
XPW03	Porewater	03/04/2021	Sulfate, total	133	mg/L
XPW03	Porewater	03/24/2021	Sulfate, total	138	mg/L
XPW03	Porewater	04/14/2021	Sulfate, total	152	mg/L
XPW03	Porewater	05/12/2021	Sulfate, total	155	mg/L
XPW03	Porewater	07/21/2021	Sulfate, total	148	mg/L
XPW03	Porewater	03/15/2022	Sulfate, total	152	mg/L
XPW03	Porewater	03/09/2023	Sulfate, total	142	mg/L
XPW03	Porewater	05/03/2023	Sulfate, total	144	mg/L

APPENDIXC.
SUPPORTING GROUNDWATER AND POREWATER ANALYTICAL DATA
35 I.A.C. § 845: ALTERNATIVE SOURCE DEMONSTRATION
JOPPA POWER PLANT
EAST ASH POND
JOPPA, IL

Notes:
mg/L = milligrams per liter
J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.
U = The analyte was analyzed for, but was not detected above the level of the adjusted detection limit or quantitation limit, as appropriate.

APPENDIX D
GEOCHEMICAL ANALYSIS OF JOPPA EAST ASH POND GROUNDWATER IN SUPPORT OF AN ALTERNATIVE SOURCE DEMONSTRATION (LIFE CYCLE GEO, LLC, 2023)

TECHNICAL MEMORANDUM

DATE October 21, 2023 **Reference No.** 23RAM01-1

TO Brian G. Hennings - Ramboll
Frances Ackerman - Ramboll
Allison Kreinberg - Geosyntec

CC Stu Cravens - Vistra

FROM Shannon Zahuranec, Allie Wyman, Tom Meuzelaar **EMAIL:** shannon@lifecyclegeo.com

GEOCHEMICAL ANALYSIS OF JOPPA EAST ASH POND GROUNDWATER IN SUPPORT OF AN ALTERNATIVE SOURCE DEMONSTRATION

1.0 EXECUTIVE SUMMARY

This document serves as an Appendix to the October 21, 2023, Alternative Source Demonstration (ASD) for Joppa (JOP) Power Plant East Ash Pond (EAP) for monitoring Event 1 (E001) (referred to as the E001 ASD), completed to fulfill the requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.650(e). Life Cycle Geo, LLC (LCG) has completed a review of geochemical conditions to evaluate the feasibility of an ASD at monitoring wells G11 and G51D associated with the JOP EAP. Compliance wells G11 and G51D monitor conditions in the Uppermost Aquifer (UA) to the west of the EAP and currently exhibit pH levels lower than the groundwater protection standard (GWPS) range for pH. This technical evaluation considered all available groundwater and solid-phase chemical analyses and utilized multivariate statistical analysis to conclude that low pH levels at G11 and G51D are not attributed to influence from the EAP. Further, observed pH levels are likely the result of the oxidation of dissolved iron released from chemically reducing conditions in the upgradient area to the north and west of the G11 and G51D monitoring wells (also referred to in this document as exceedance wells). Oxidation of dissolved ferrous iron and subsequent precipitation of solid-phase iron generates acidity through fundamentally established geochemical reactions discussed in Section 4.0. This scope of work was executed by subcontract to Ramboll Americas Engineering Solutions, Inc. (Ramboll) on behalf of Electric Energy, Inc.

2.0 HYDROGEOLOGY AND GROUNDWATER CONDITION

Monitoring wells G11 and G51D are screened in the UA. The UA is composed predominantly of sand and is overlain by the upper confining unit (UCU), a clay-rich, low permeability stratigraphic unit (Ramboll, 2021). Monitoring wells G11 and G51D are on the western border of the EAP, hydraulically upgradient of the EAP and the other EAP monitoring wells (Attachment 1). Monitoring wells G11 and G51D are downgradient of the northernmost part of the JOP West Ash Pond (WAP), and the sewage treatment pond (Attachment 2) situated on the northwest corner of the WAP.

Table 1: Concentration Ranges for Select Constituents in Joppa Groundwater and CCR Ponds.

	pH	Boron (mg/L)	Magnesium (mg/L)
G11	5.78-6.33	0.25-0.42	27.8-72.4
G51D	5.30-6.92	0.03-0.96	12.3-14.4
CCR porewater	6.76-11.1	4.02-34.3	ND-27.8
Western Groundwater*	5.04-7.4	ND-24.7	4.0-126
Eastern Groundwater	5.62-7.88	ND-5.43	7.1-49.3
TPZ120	2.77-3.63	2.08-3.55	52.4-63.5

ND=Not Detected
Data provided in Appendix D-1
*Western groundwater ranges presented do not include TPZ120, which is listed separately.

From March 2021 through May 2023, pH at G11 and G51D is generally below the GWPS lower limit of 6.0 standard pH units (SU) (Attachment 3). Groundwater pH elsewhere at the site has been measured as low as 5.0 SU (Table 1) but is typically between 6 and 8 SU (Attachment 3; Appendix D-1). The UCU monitoring well TPZ120 is an exception with a much lower groundwater pH (less than 4.0 SU).

This analysis focused predominantly on assessing the source of acidity in G11 and G51D as originating from either east or west of the exceedance wells to determine if the EAP (east of the exceedance wells) is the source of the low pH levels observed. To this end, monitoring wells to the east of the exceedance wells are discussed as the Eastern Wells and the monitoring wells to the west are discussed as the Western Wells. The Eastern Wells include the EAP porewater wells [XPW01, XPW02, and XPW03] as an endmember for evaluation, EAP compliance-based groundwater wells [G03, G05, G06, G07, G08, G09, G10, G52D, G53D, and G54D], and two EAP monitoring wells [G04 and G06S] that are not included in the regulatory network but are in close proximity to the compliance EAP monitoring wells. While most of these wells are downgradient of G11 and G51D, they provide a necessary comparison for assessing potential EAP impacts to G11 and G51D. The Western Wells are hydraulically upgradient or side-gradient of G11 and G51D and are used to evaluate potential alternate sources for the pH exceedances originating to the west. Western Wells included in this analysis are installed in the UA [TPZ118D, TPZ118DD, TPZ119D, TPZ119DD, TPZ120D, TPZ123, and TPZ124D] and UCU [TPZ118, TPZ120, and TPZ124], as well as the WAP porewater wells [XTPW01, XTPW02, XTPW03, and XTPW04]. The upgradient background wells G01D and G02D are assessed as the upgradient endmember reflective of groundwater uninfluenced by activity at the JOP site. This selection of Eastern and Western wells provides the best analysis of geochemical conditions and potential sources in the immediate area of G11 and G51D. Potential sources of acidity (which could drive the observed low pH levels at G11 and G51D) are assessed through comprehensive geochemical analysis, including time series analysis, correlation plots (scatterplot comparisons), Principal Components Analysis (PCA), and spatial and chemical distribution of iron.

3.0 GEOCHEMICAL ANALYSIS

3.1 CCR INDICATOR CONSTITUENT BORON

Boron is commonly used as an indicator parameter for contaminant transport of CCR because: (i) it is commonly present at elevated concentrations in coal ash leachate; (ii) it is mobile and typically not very

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

reactive but conservative (i.e., low rates of sorption or degradation) in groundwater; and (iii) it is less likely than other constituents to be present at elevated concentrations in background groundwater from natural or other anthropogenic sources. Boron is often assessed in groundwater to identify possible end-member sources of influence in downgradient areas that could be attributed to CCR. Porewater samples collected from both the EAP and WAP exhibit elevated concentrations of boron, whereas boron concentrations in monitoring wells G11 and G51D are low relative to CCR porewater and most groundwater monitoring wells located both to the east and west (Attachment 3). While boron concentrations suggest no immediate influence from either of the CCR units, it is not otherwise relied upon for distinguishing influence as originating from either the east (i.e., EAP) or west.

3.2 OTHER PERTINENT CHEMICAL TRACERS OF INFLUENCE

Magnesium is not commonly used as a CCR indicator, yet the substantial range in magnesium concentrations observed in groundwater to the west relative to east makes it a particularly useful tracer of influence (Attachment 3). Table 1 presents the range in magnesium measured for several different endmember components assessed for influence in relation to exceedance wells G11 and G51D.

Magnesium concentrations are notably elevated in several of the western groundwater monitoring wells, both within the UA and UCU stratigraphic units. Magnesium concentrations in G11 are similarly elevated when contrasted with groundwater concentrations measured to the east. Concentrations of magnesium at G51D are more similar to background (i.e., overall low). While some Eastern Wells do exhibit magnesium concentrations above background, the range is substantially lower than G11 and the Western Wells overall. The low magnesium concentrations observed in background groundwater, eastern groundwater, and CCR porewater lead in the direction of the western groundwater as a source of high magnesium to, and therefore a dominant influence on, the exceedance wells (G11 in particular).

A strong linear relationship is observed between sulfate and magnesium in groundwater (Attachment 4; Appendix D-1), except TPZ120, which appears as an outlier for the JOP groundwater. The linear relationship between magnesium and sulfate is observed in both western and eastern groundwaters, though the magnitude of measured concentrations in the Western Wells extends beyond that of the Eastern Wells, as discussed in the previous paragraph. Concentrations from monitoring well G11 plot among the Western Wells and are distinctly separate from Eastern Wells. Furthermore, the G11 magnesium-sulfate relationship is similar to Western UCU wells. This data suggests that G11 groundwater chemistry is more similar to western groundwater chemistry than eastern groundwater chemistry. Conditions at G51D are suspected to be under the same influence from the western groundwater chemistry, but are simultaneously influenced from upgradient background groundwater, discussed further in Section 4.0. This mixing of groundwaters produces a lower magnesium concentration in G51D relative to G11.

3.3 MULTIVARIATE DATA ANALYSIS

3.3.1 METHOD

Groundwater chemistry data are by nature multivariate datasets given the high number of parameters observed per sampling location and within a given timeframe. With such a large number of variables, advanced statistical analysis of multivariate groundwater data can provide important insights into spatial,

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

temporal, and chemical relationships influencing constituent distribution and compliance in groundwater. The multivariate technique Principal Component Analysis (PCA) is used to interrogate the groundwater chemistry around the exceedance wells.

PCA is a multivariate technique that reduces dataset dimensionality to its principal, independent components thereby revealing the inner structure of the dataset. Multivariate techniques such as PCA are valuable because they identify variables that are highly dependent on each other but do not inherently provide insights into water origin, type, or evolution. Reducing multivariate data dimensionality reduces redundant information, revealing inner structures in the data that might otherwise be obscured by these dependencies. These structures might include groups of related variables, chemical evolution through time, or spatial locations with similar chemical signatures.

PCA results are most easily viewed on a biplot (such as those provided in Attachment 5), which depicts the sample population plotted on two axes, each representing a principal component. The principal components are created from a linear combination of the original variables in the dataset and variance in the data. For natural compositional datasets, approximately 70% of the population variance can often be expressed in the first three or four principal components (in some cases less and in others, more), each representing decreasing amounts of variance in the data while remaining uncorrelated to previous principal components. The first two principal components often represent the majority of the dataset and are visualized using biplots with the variables expressed as vectors; the location of groups of samples (i.e., factor scores) relative to component vectors provides insight into geochemical relationships among groups of variables and samples.

3.3.2 DATA PREPARATION

When conducting multivariate analysis, it is first necessary to prepare the dataset. Raw chemical data requires preparation prior to analysis because the data often contains values in two forms unsuitable for advanced analytics: 1) measurements reported below a method detection limit (MDL), referred to as censored data, and 2) missing values. For this work, any sample or analyte with a high percentage (≥40%) of missing and/or censored data was assessed for meaningful statistical variance. If overall analyte variance was determined to be low, the analyte was removed, otherwise the data was included in the analysis. Any remaining censored data was converted to half the MDL. Remaining missing values were imputed, a method of assigning an estimated value that accounts for the entire distribution of the material's composition (Sanford et al., 1993) and also takes into consideration the values associated with samples of similar composition. Imputation was done with a nearest neighbor algorithm (Troyanskaya, 2001) and resulting values were checked against the overall data distribution for both the analyte and sample to ensure representative results. Imputed data represents 1.9% or less of the overall dataset in the PCA biplots presented here. Processed data for the PCA are presented in Electronic Attachment 1 and 2.

PCA also requires transformation of the dataset to address the numeric closure problem inherent within chemical compositional datasets (Aitchison, 1986). Numeric closure can often occur in water quality data since water quality concentrations are not completely independent. To address this issue, all data was converted to the same units (mg/L) and the centered-log ratio transformation (CLR; Aitchison 1986; Egozcue et al. 2011) was applied to the cleaned dataset. In practice, closure only significantly affects elements present in large concentrations (e.g., major ions in typical water quality samples), but for consistency the entire dataset (i.e., including trace metals) was CLR-transformed.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

The resulting dataset includes both compliance wells and other monitoring wells and spans sampling events from 2017 through 2023. The dataset contains 18 measured analytes, including the hydrogen ion (H+), which represents acidity in groundwater and is proportional to pH. This data represents both the most recent data measured at JOP as well as the most complete set of regularly measured and detectable analytes. All data preparation was conducted using python programming language. Only total concentrations of major ions and metals were used in this analysis as those data are both relatively complete and consistent across the wells on site and are the parameters of interest for regulatory purposes.

3.3.3 RESULTS

Biplots showing principal components 1 and 2 (PC1 and PC2) are provided in Attachment 5. The PC1 and PC2 are represented on the X and Y axis and explain approximately 30% and 25% of the statistical variance in the water quality dataset, respectively. For each biplot, the first three components explain over 65% variance in the dataset, while the first four explain over 70%. Constituent variables are expressed as vectors. The grouping of samples relative to the component vectors is useful for providing immediate insight into geochemical relationships among groups of variables and samples.

Two iterations of biplots are provided; Attachment 5a depicts all Western and Eastern Wells and porewater locations with sufficient data. Attachment 5b depicts all potential endmember influences on the pH exceedances at G11 and G51D, as represented by background groundwater, EAP porewater, WAP porewater, and hydraulically upgradient groundwater wells (all of which exist to the north and west). Side-gradient western well TPZ120 is also included as it represents a geochemical endmember. While constituent vectors are arranged in a similar orientation across both biplots, biplot 5A which includes the downgradient eastern groundwater contains more noise in the dataset making it difficult to decipher meaningful inter-well trends. This biplot is provided as a reference but is not discussed further. The remaining analysis focuses on biplot 5B which contains hydraulically upgradient wells, background wells, and porewater wells as geochemical endmembers of G11 and G51D (Attachment 5b). This biplot exhibits the following key features:

- Exceedance wells G51D and G11 exhibit a high degree of similarity with the Western Wells screened in the UA.
- Groundwater samples are distributed linearly from the bottom right to the middle of the upper left quadrant, with clear separation between stratigraphic units within the spread of data. Background data plots as an endmember in the lower right quadrant, transitions into UA wells in the lower left quadrant, and continues through the UCU wells in the middle upper left quadrant.
- The EAP and WAP porewaters dominate the upper right quadrant and are distinctly separate from the groundwater samples. There is also a clear separation between EAP and WAP porewaters. The WAP porewater has a strong association with the boron and lithium vectors whereas the EAP porewater is more closely associated with arsenic, potassium, molybdenum, and selenium.
- The WAP UCU monitoring well TPZ120 plots alone in the upper left corner of the plot at the far end of the iron vector, indicating (a) iron is a key contributor to the variance associated with this location and (b) TPZ120 has a distinct chemical composition relative to the other groundwater compositions considered.

The linear spread of groundwater data suggests chemical evolution and/or communication within the aquifer system. The western UCU groundwater composition is dominated by redox sensitive vectors such as manganese, iron, and sulfate. The UA groundwater is observed to undergo a gradual chemical evolution from the UCU redox-sensitive composition endmember back to background conditions, which are dominated by

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

alkalinity, sodium, chloride, and fluoride. The exceedance wells plot among the western UA groundwater, suggesting geochemistry is broadly similar in these wells. Furthermore, the exceedance wells plot in near association with the background groundwater wells, also indicating some multi-variate geochemical similarity to background. This positioning may indicate potential mixing between reduced upgradient groundwaters from the northwest with oxidized background water from the north, discussed further in Section 4.0. Exceedance wells G51D and G11 do not demonstrate association with the EAP porewater composition, supporting the conclusion that the EAP porewater is not a primary influence on the groundwater composition observed at G51D and G11, and is therefore not found to be responsible for the pH exceedances.

4.0 POTENTIAL ALTERNATE SOURCES

This technical review identified the likely source of acidity contributing to the low pH levels at G11 and G51D is dissolved iron in groundwater under reducing conditions and the redox transition that occurs in groundwater immediately upgradient of the G11 and G51D monitoring wells. This is demonstrated in Attachment 6, which includes figures depicting the redox condition at the site. The map included in Attachment 6A (Appendix D-2) demonstrates a distinct redox transition from more reducing conditions in upgradient waters and more oxidizing conditions near the exceedance wells. The reducing upgradient waters are characterized by lower oxidation reduction potential (ORP) and higher iron concentrations, while downgradient waters are largely the opposite with higher ORP and lower iron concentrations. This spatial gradient in redox conditions is also reflected in the Pourbaix diagram for the upgradient western groundwater network (Attachment 68; Appendix D-3). This diagram demonstrates the predominant iron species and mineral forms under changing pH and Eh conditions (Eh is calculated from field measurements of ORP using the AquaTROLL conversion rate). There is a clear gradient from more reducing conditions in the north and west to more oxidized conditions in G11 and G51D with dissolved iron (Fe^{++}) and iron hydroxide ($Fe(OH)_3$) as the dominant forms of iron. Simultaneously, there is a drop in pH as conditions become more oxidizing.

The source of the dissolved iron and reducing condition could be attributed to three possible upgradient influences existing to the west and north of the two exceedance wells: 1) low pH and relatively high dissolved iron existing in the general area around Western Well TPZ120, 2) the WAP, and 3) the sewage treatment pond. Results of the PCA suggest groundwater monitored in the area of Western Well TPZ120 and the WAP are both potential geochemical endmembers of the chemical evolution observed upgradient and to the west (Attachment 5). Monitoring well TPZ120 has an average iron concentration of 1.2 mg/L (determined from samples with turbidity <10 NTU) and is near enough in proximity to the exceedance wells to suggest cross-gradient flow between these wells may be possible (Attachment 2). The WAP and the sewage treatment pond are both upgradient sources of reduced groundwater, though high turbidity in field samples limits the use of existing iron data for full understanding of transport and speciation of dissolved iron in response to the redox gradient. These three locations represent possible alternate sources of reduced iron to the exceedance wells.

This change in redox condition is the likely source of acidity in G11 and G51D. It is interpreted that dissolved iron is released from the sediments through the process of reductive dissolution by upgradient waters, in response to the reducing conditions (as observed by low ORP). The dissolved iron is transported downgradient with groundwater and subsequently oxidizes and precipitates when it moves into an area with sufficient dissolved oxygen to drive the oxidation reaction.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

The oxidation of dissolved iron to iron hydroxide is known to produce acidity via the following reactions:

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

Acidity is highlighted in red, and the equations demonstrate a net increase in acidity through iron oxidation and precipitation. In this way, reduced upgradient waters from the north and west provides the constituent (i.e., reduced iron) necessary to cause a drop in pH (i.e., through iron oxidation) in G11 and G51D. The oxidized environment near the exceedance wells results from sufficient mixing with the upgradient oxidized background groundwater. This is particularly evident in G51D, which has a more immediate influence of dissolved iron from reduced upgradient wells and has a compositional similarity to background wells (as seen in PCA and magnesium concentrations) resulting in the lowest pH in the JOP EAP groundwater network.

5.0 CONCLUSIONS

This technical review presents evidence that demonstrates the EAP is not the source of pH exceedances at compliance wells G11 and G51D. Results of the geochemical and multivariate analysis (i.e., PCA) demonstrate that groundwater associated with monitoring wells G11 and G51D are more similar to upgradient groundwater to the north and west than the EAP porewater. This analysis was supported by examination of magnesium concentrations and the magnesium-sulfate relationship, both of which indicate G11 and G51D have a chemical signature indicative of western groundwater and background groundwater. The pH exceedances are found to be the result of chemically reduced upgradient waters carrying dissolved iron (released from the aquifer solids through the geochemical process of reductive dissolution) subsequently mixing with oxidized background groundwater in the area of G51D and G11. Further analysis revealed three potential sources of dissolved iron to the north and west of the exceedance locations; however, this investigation did not attempt to identify the primary or singular source of dissolved iron driving the pH exceedances. Upon mixing, the dissolved iron originating from more reducing groundwater subsequently oxidizes and precipitates as iron hydroxide, consequently generating acidity and lowering the groundwater pH in this specific area. The information and analysis presented thus rules out the EAP as the source of the acidity, and therefore pH exceedances, in this area.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

6.0 ABBREVIATIONS

Alk	Total Alkalinity
As	Arsenic
B	Boron
Ca	Calcium
CCR	Coal combustion residual
Cl	Chloride
Co	Cobalt
Cr	Chromium
EAP	East Ash Pond
F	Fluoride
Fe	Iron
H+	Hydrogen ion, represents acidity in groundwater
JOP	Joppa
K	Potassium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
ORP	Oxidation reduction potential
PCA	Principal components analysis
Redox	Oxidation-Reduction
Se	Selenium
SO4	Sulfate
UA	Upper Aquifer
UCU	Upper confining unit
WAP	West Ash Pond

729 Main Street, Longmont, CO 80501 720 550 0745 contact@lifecyclegeo.com www.lifecyclegeo.com

7.0 REFERENCES

Aitchison, J. 1986. The Statistical Analysis of Compositional Data. Chapman and Hall. London

Egozcue J.J. and V. Pawlowsky-Glahn. 2011. Basic concepts and procedures. In: Pawlowsky-Glahn V, Buccianti A, editors. Compositional data analysis: theory and applications. Chichester: Wiley; 2011. pp. 12–28.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. Hydrogeologic Site Characterization Report. East Ash Pond. Joppa Power Plant. Joppa, Illinois.

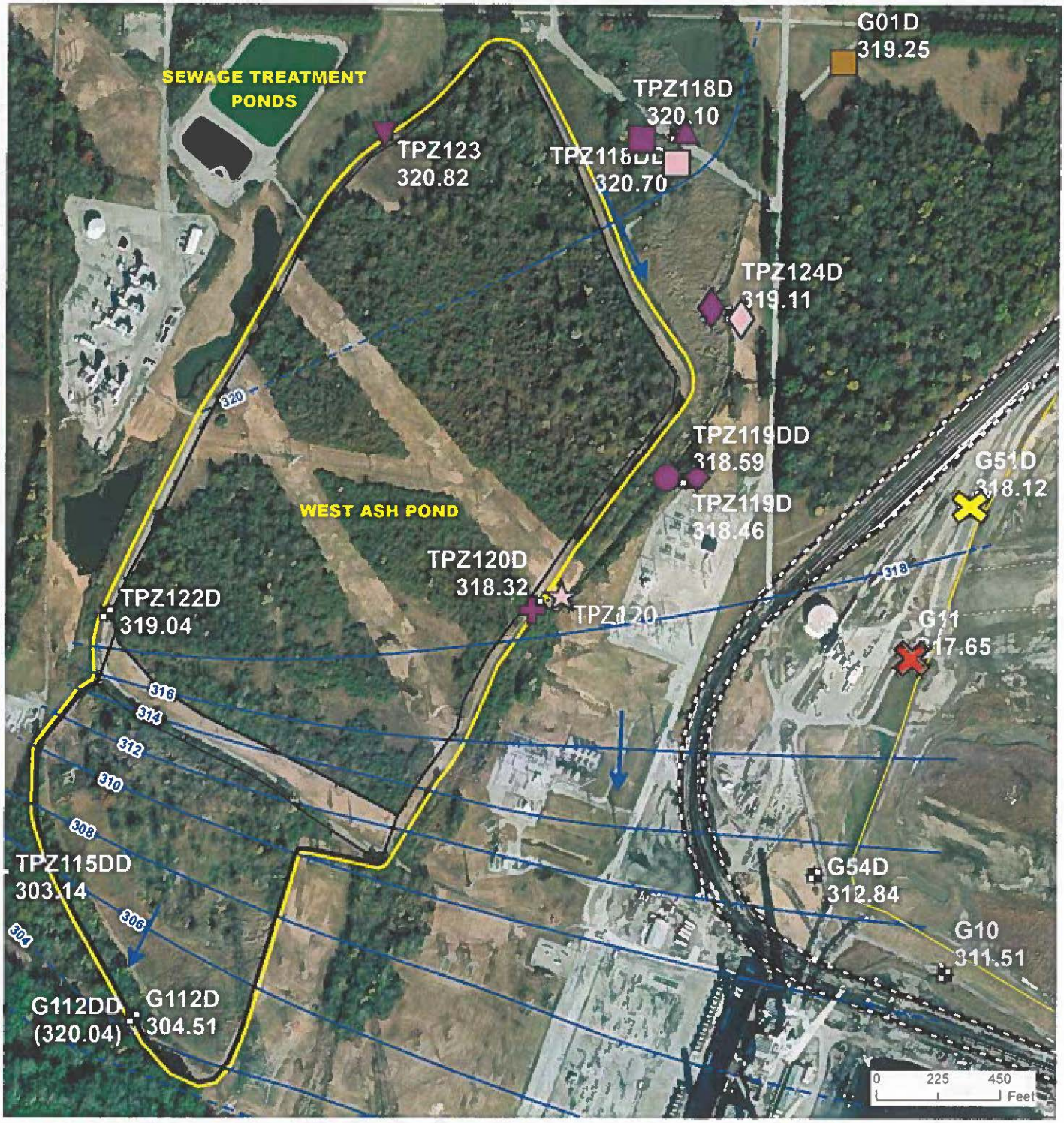
Olga Troyanskaya, Michael Cantor, Gavin Sherlock, Pat Brown, Trevor Hastie, Robert Tibshirani, David Botstein and Russ B. Altman, Missing value estimation methods for DNA microarrays, BIOINFORMATICS Vol. 17 no. 6, 2001 Pages 520-525.

Sanford, R. F., C.T. Pierson, and R.A. Crovelli. 1993. An objective replacement method for censored geochemical data: Math. Geol., 2S(1), p. 59–80.

729 Main Street, Longmont, CO 80501 720.550.0745 contact@lifecyclegeo.com www.lifecyclegeo.com

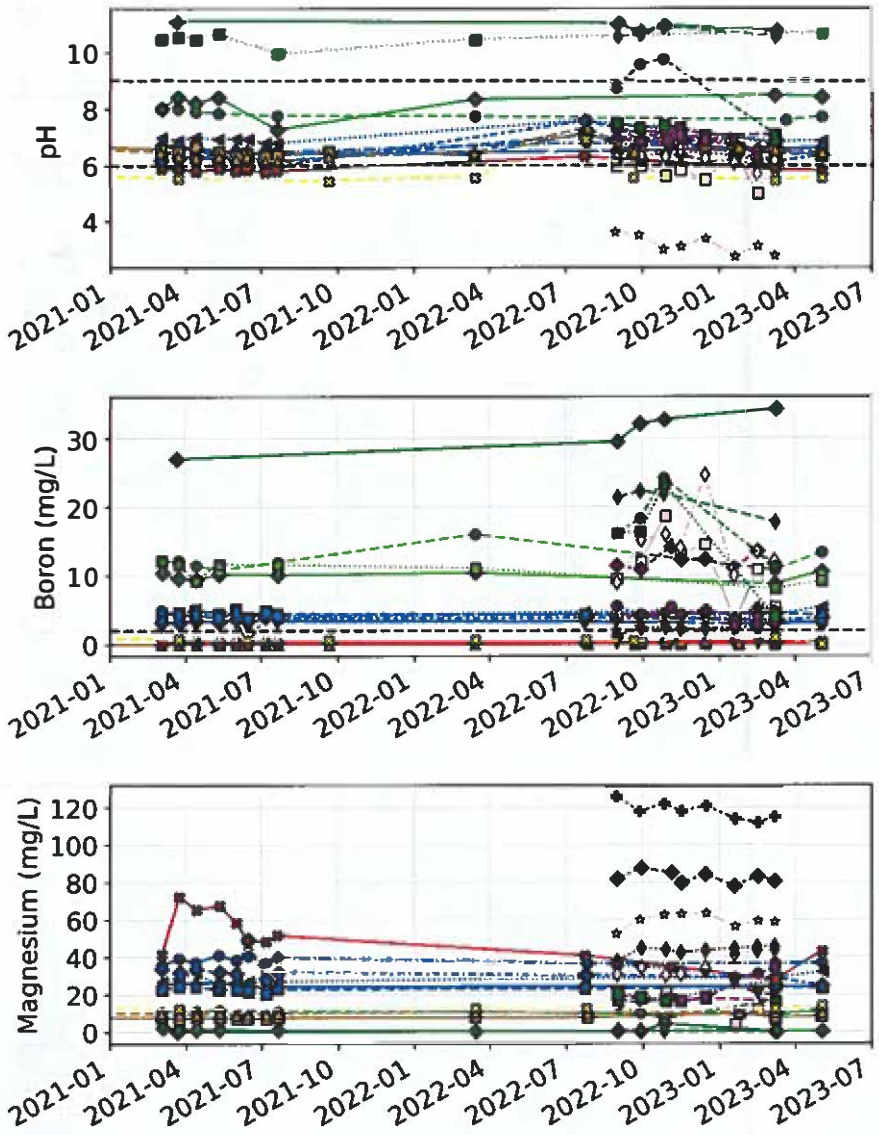
Notes:
Wells with pH exceedances are shown with an X.
East ash pond compliance wells are light blue and monitoring wells are dark blue.
Western monitoring wells are purple (UA) and pink (UCU).
Background wells are brown. Ash ponds are outlined in yellow.
Contours are from March 2023.

LIFECYCLEGEO	Title: Joppa East Ash Pond Well Locations and Hydrology		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 1
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	



Notes:
Wells with pH exceedances are shown with an X.
Western wells are purple (UA) and pink (UCU).
Background wells are brown. Ash ponds are outlined in yellow.
Contours are from September 2022.

LIFECYCLEGEO	Title: Joppa West Ash Pond Well Locations and Upper Aquifer Groundwater Elevation		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 2
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	



Notes:
Data is colored according to well classification.
All data shown is for eastern compliance wells, upgradient western upgradient wells, background, and porewaters

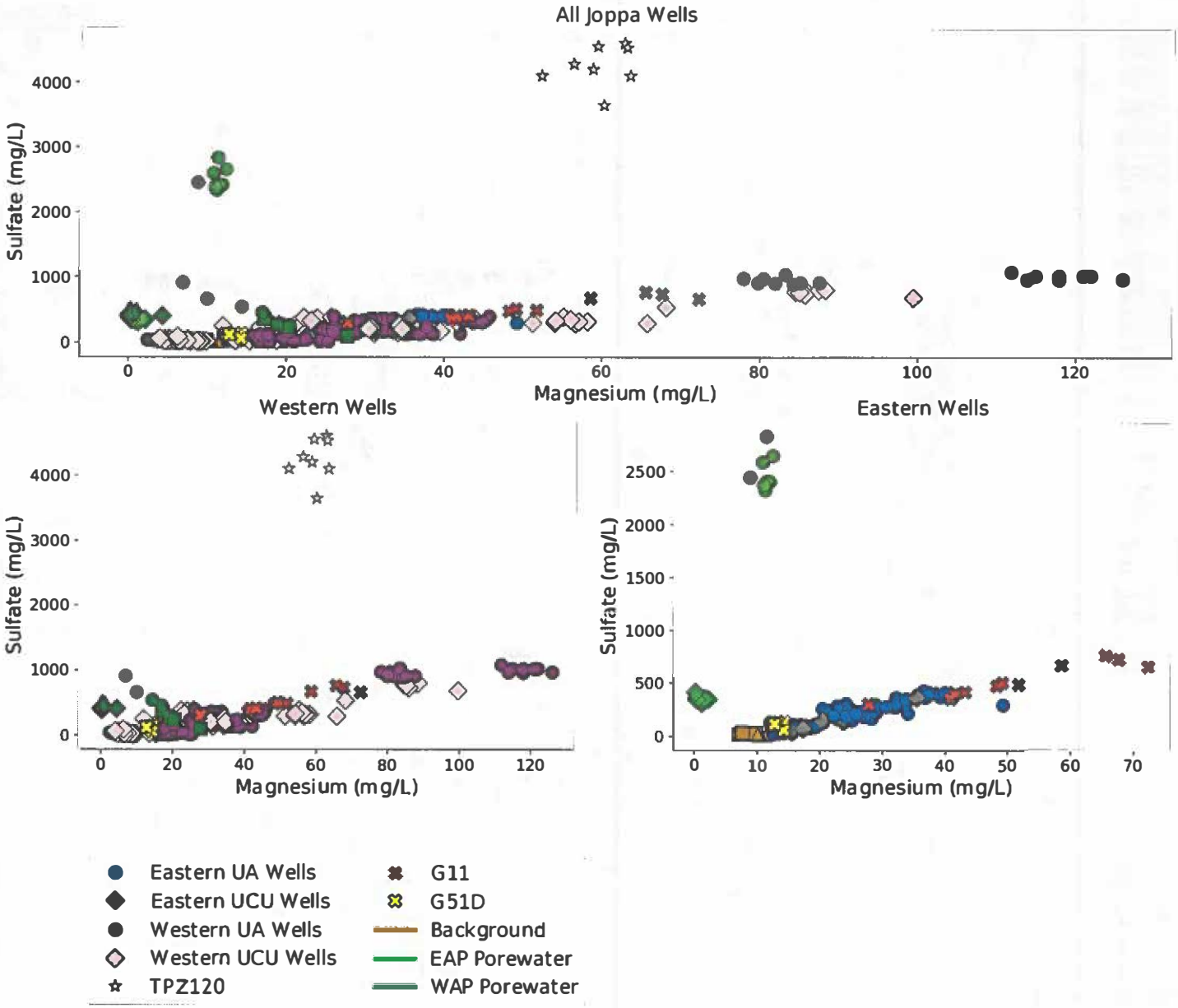
Well ID

G06	TPZ118DD	XTPW01
G07	TPZ119D	XTPW02
G08	TPZ119DD	XTPW03
G09	TPZ120	XTPW04
G10	TPZ120D	G01D
XPW01	TPZ123	G02D
XPW02	TPZ124	G11
XPW03	TPZ124D	G51D
TPZ118		

- Background
- Eastern Compliance Well
- Western UA Well
- Western UCU Well
- EAP Porewater
- WAP Porewater
- GWPS
- Exceedance

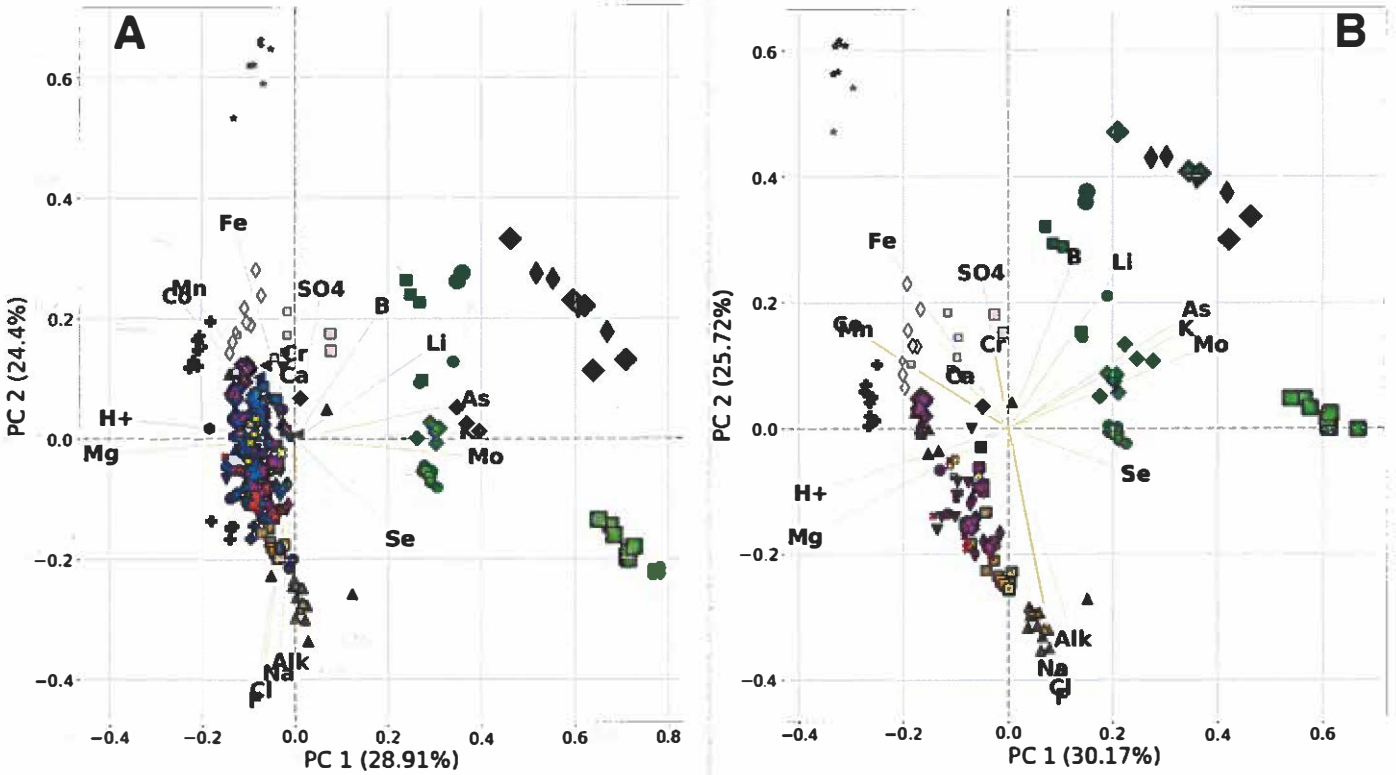
LIFECYCLEGEO

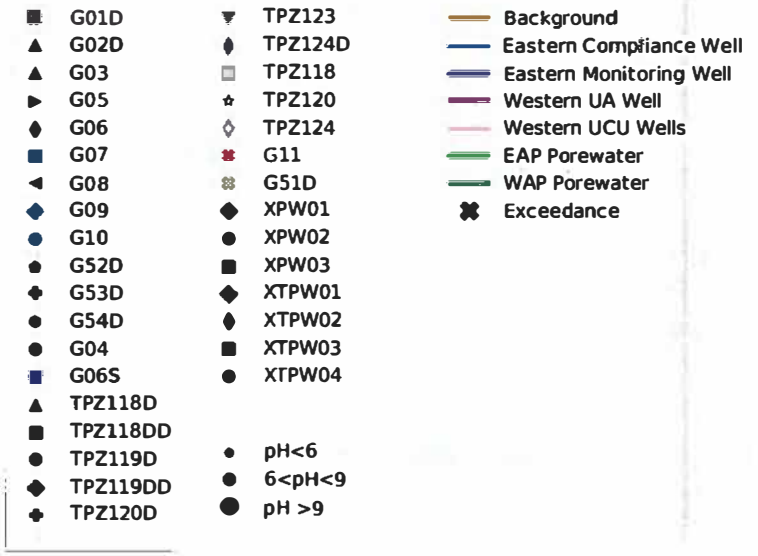
Title: Time Series for pH, Boron, and Magnesium		
Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 3
Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	



Scatterplots of magnesium and sulfate for all Joppa wells (top), the western wells (bottom left) and eastern wells (bottom right).

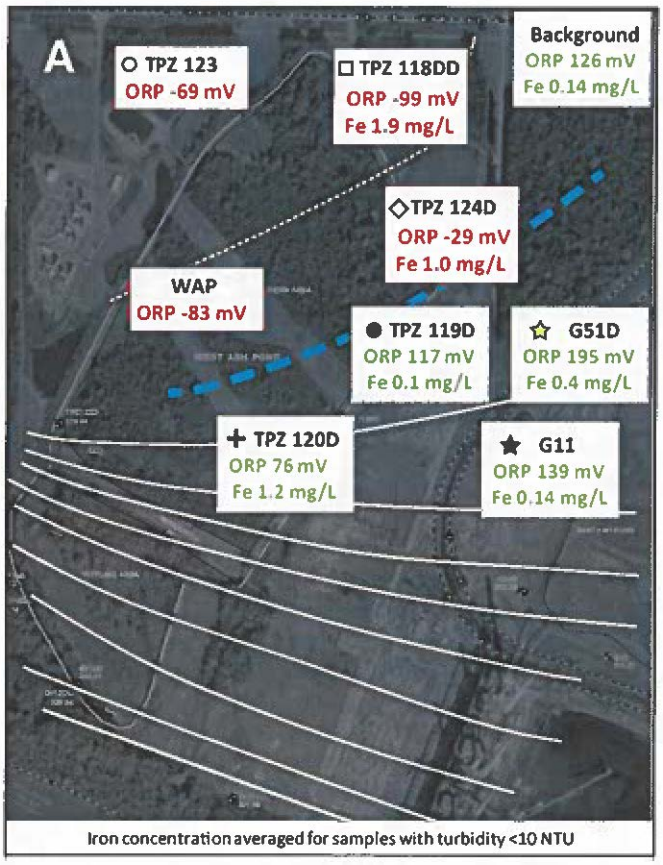
LIFECYCLEGEO	Title: Joppa Magnesium-Sulfate Scatterplot		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 4
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	

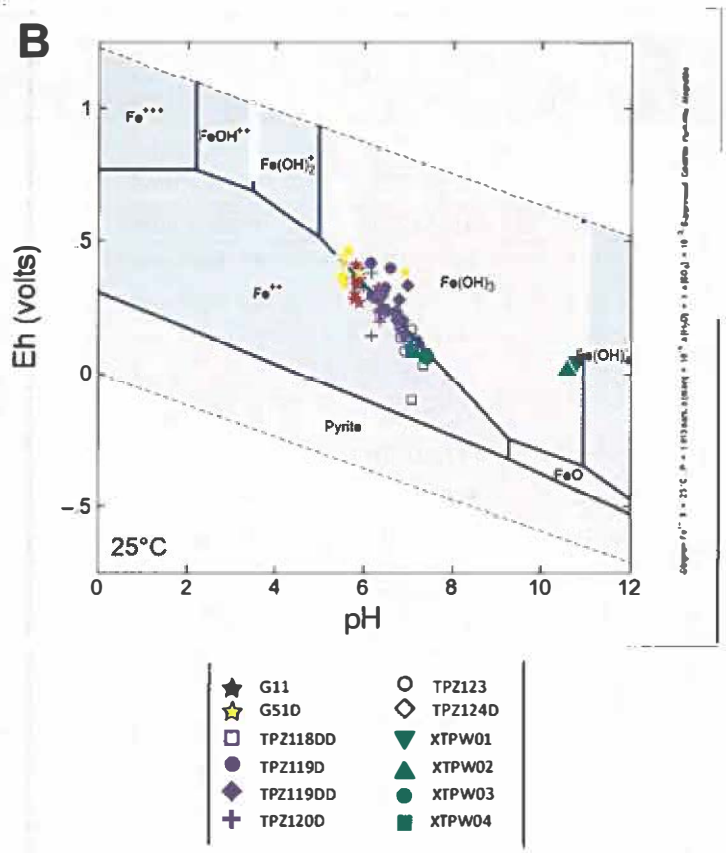




Notes:
Data is colored according to well classification and sized according to pH. See abbreviations list for complete analyte and unit names.
A) PCA with all eastern and western wells, including porewater.
B) PCA with only western wells, background, and porewater.

LIFECYCLEGEO	Title: Joppa Principal Components Analysis Results		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 5
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	





Notes:

A) Redox conditions upgradient of G11 and G51D. White lines are upper aquifer groundwater contours, blue line indicates where conditions change from reducing to oxidizing. Contours from September 2022. Iron concentration not shown where turbidity >10 NTU.

B) Pourbaix diagram depicting iron solubility upgradient of G11 and G51D. WAP porewater is shown in green, western monitoring wells are shown in purple, G11 is red, and G51D is yellow. Blue areas are indicate aqueous phase iron; brown areas indicate solid phase iron.

LIFECYCLEGEO	Title: Joppa Oxidation Reduction Conditions		
	Project Name: Joppa- East Ash Pond Evaluation	Project Number: [23RAM01-1] Vistra CCR	Attachment: 6
	Client Name: Ramboll Americas Engineering Solutions, Inc.	Date: 10/21/2023	

LIFECYCLEGEO

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G01D	12/3/2015	Background	6.7	<0.025	--	20
G01D	3/15/2016	Background	6.7	0.036	--	126
G01D	6/15/2016	Background	6.9	0.0296	--	157
G01D	9/14/2016	Background	6.8	0.0416	--	129
G01D	12/14/2016	Background	6.8	<0.025	--	53
G01D	3/7/2017	Background	6.2	<0.025	--	72
G01D	6/15/2017	Background	6.7	<0.025	--	56
G01D	7/20/2017	Background	6.8	<0.025	9.87	31
G01D	11/30/2017	Background	6.8	<0.025	--	117
G01D	6/19/2018	Background	6.8	<0.025	--	70
G01D	9/5/2018	Background	7	<0.025	--	94
G01D	3/27/2019	Background	6.7	<0.025	--	30
G01D	9/9/2019	Background	6.4	<0.025	--	37
G01D	3/30/2020	Background	6.8	<0.025	7.6	35
G01D	9/23/2020	Background	6.72	<0.025	--	34
G02D	7/6/2021	Background	6.17	0.0431	9.77	22
G02D	7/21/2021	Background	6.18	0.0329	10.1	20
G02D	6/1/2021	Background	6.23	0.0433	9.39	23
G02D	4/14/2021	Background	6.3	0.0318	9.39	19
G02D	9/20/2021	Background	6.32	0.0313	--	19
G01D	7/6/2021	Background	6.33	<0.025	7.18	20
G01D	6/1/2021	Background	6.34	<0.025	7.36	18
G01D	5/2/2023	Background	6.34	0.021	8.43	26
G02D	3/24/2021	Background	6.35	0.033	9.76	18
G02D	5/12/2021	Background	6.35	0.0356	10.4	27
G02D	6/14/2021	Background	6.36	0.0352	9.84	23
G01D	7/21/2021	Background	6.37	<0.025	7.54	18
G01D	3/14/2022	Background	6.37	<0.025	7.77	22
G02D	5/3/2023	Background	6.46	0.0412	10.4	13
G01D	6/14/2021	Background	6.46	<0.025	7.41	20
G02D	12/3/2015	Background	6.7	0.0536	--	16
G02D	3/15/2016	Background	6.6	0.0494	--	17
G02D	6/15/2016	Background	6.8	0.0508	--	15
G02D	9/14/2016	Background	6.6	0.0534	--	22
G02D	12/14/2016	Background	6.3	0.0552	--	22
G02D	7/20/2017	Background	6.7	0.044	11.4	12
G02D	11/30/2017	Background	6.9	0.0496	--	17
G02D	6/19/2018	Background	6.7	0.0404	--	17
G02D	9/5/2018	Background	6.6	0.0468	--	19

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G02D	3/27/2019	Background	6.6	0.0473	--	20
G02D	9/9/2019	Background	6.5	0.0429	--	20
G02D	3/30/2020	Background	6.59	0.0449	9.96	22
G02D	9/23/2020	Background	6.62	0.0442	--	22
G02D	3/14/2022	Background	6.47	0.0283	10.6	11
G02D	9/21/2022	Background	6.48	0.0266	--	15
G01D	5/12/2021	Background	6.49	0.0167	7.55	20
G01D	3/24/2021	Background	6.49	<0.025	7.06	21
G02D	3/3/2021	Background	6.5	0.0296	9.98	21
G01D	9/20/2022	Background	6.5	<0.014	--	23
G01D	9/20/2021	Background	6.51	<0.025	--	18
G01D	3/7/2023	Background	6.53	0.029	7.66	36
G02D	3/8/2023	Background	6.56	0.027	10.3	11
G01D	3/3/2021	Background	6.6	<0.025	7.79	18
G01D	1/24/2023	Background	6.62	<0.022	9.75	24
G02D	3/8/2017	Background	6.9	0.0546	--	18
G02D	6/14/2017	Background	6.3	0.0467	--	20
G02D	1/24/2023	Background	6.64	0.0311	10.2	12
G01D	4/14/2021	Background	6.7	<0.025	7.56	39
G01D	7/26/2022	Background	7.17	<0.015	7.74	36
G02D	7/27/2022	Background	7.35	0.0322	10.1	19
G03	3/24/2021	Eastern Compliance	6.3	0.343	17.6	104
G03	4/14/2021	Eastern Compliance	6.2	0.603	28.3	168
G03	5/12/2021	Eastern Compliance	6.39	0.26	15.8	112
G03	6/1/2021	Eastern Compliance	6.35	0.232	14.9	73
G03	7/6/2021	Eastern Compliance	6.34	0.235	14	77
G03	7/21/2021	Eastern Compliance	6.36	0.294	15.7	92
G03	7/26/2022	Eastern Compliance	6.51	0.532	22.9	164
G03	5/3/2023	Eastern Compliance	6.18	0.38	16.6	97
G03	3/5/2021	Eastern Compliance	6.4	0.213	15.1	66
G03	6/15/2021	Eastern Compliance	6.24	0.225	15.1	79
G03	3/9/2023	Eastern Compliance	6.23	0.33	15.2	82
G04	3/24/2021	Eastern Monitoring	6.5	<0.025	14.6	41
G04	7/26/2022	Eastern Monitoring	6.82	<0.0092	34.1	216
G04	3/4/2021	Eastern Monitoring	6.5	<0.025	12.6	21
G04	4/13/2021	Eastern Monitoring	6.5	<0.025	17.3	63
G04	5/11/2021	Eastern Monitoring	6.28	0.0157	17.6	73
G04	7/20/2021	Eastern Monitoring	6.33	<0.025	20.6	131
G05	3/24/2021	Eastern Compliance	6.4	0.195	18.8	92

LIFECYCLEGEO

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G05	6/1/2021	Eastern Compliance	6.48	0.157	18.6	83
G05	7/6/2021	Eastern Compliance	6.42	0.148	17.6	90
G05	7/26/2022	Eastern Compliance	6.63	0.0645	17.6	68
G05	5/3/2023	Eastern Compliance	6.49	0.0478	19.3	112
G05	6/15/2021	Eastern Compliance	6.34	0.14	18.4	91
G05	3/9/2023	Eastern Compliance	6.5	0.0541	19.4	90
G05	3/4/2021	Eastern Compliance	6.5	0.181	17.2	94
G05	4/13/2021	Eastern Compliance	6.5	0.19	19.5	95
G05	5/11/2021	Eastern Compliance	6.38	0.158	19.4	109
G05	7/20/2021	Eastern Compliance	6.35	0.131	18.5	87
G06	3/24/2021	Eastern Compliance	6.6	3.4	26.6	215
G06	6/1/2021	Eastern Compliance	6.56	3.56	25.3	216
G06	7/6/2021	Eastern Compliance	6.32	3.93	23.7	223
G06	5/3/2023	Eastern Compliance	6.63	3.28	24.4	208
G06	6/15/2021	Eastern Compliance	6.51	2.97	25.2	230
G06	3/9/2023	Eastern Compliance	6.57	2.95	24.1	221
G06	3/4/2021	Eastern Compliance	6.7	2.9	25.1	250
G06	4/13/2021	Eastern Compliance	6.6	3.27	26	229
G06	5/11/2021	Eastern Compliance	6.43	3.37	26.8	219
G06	7/20/2021	Eastern Compliance	6.41	3.41	24.4	213
G06	7/23/2022	Eastern Compliance	--	3.29	24.5	216
G06S	3/24/2021	Eastern Monitoring	5.8	0.253	13.5	31
G06S	3/4/2021	Eastern Monitoring	6.2	0.229	12.9	35
G06S	4/13/2021	Eastern Monitoring	5.8	0.265	14.3	30
G06S	5/11/2021	Eastern Monitoring	5.62	0.245	15.6	31
G06S	7/20/2021	Eastern Monitoring	5.73	0.248	13	30
G06S	7/23/2022	Eastern Monitoring	6.54	0.269	13.5	30
G07	3/24/2021	Eastern Compliance	6.4	4.67	24.2	258
G07	6/1/2021	Eastern Compliance	6.25	5.23	22.9	257
G07	7/6/2021	Eastern Compliance	5.98	4.95	20.5	258
G07	5/3/2023	Eastern Compliance	6.38	4.27	23.4	260
G07	6/15/2021	Eastern Compliance	6.25	3.91	21.8	246
G07	3/9/2023	Eastern Compliance	6.42	4.55	24.3	308
G07	3/4/2021	Eastern Compliance	6.5	4.37	22.9	285
G07	4/13/2021	Eastern Compliance	6.3	5.04	24.4	274
G07	5/11/2021	Eastern Compliance	6.28	4.55	22.9	248
G07	7/20/2021	Eastern Compliance	6.14	4.48	23	252
G07	7/23/2022	Eastern Compliance	7.06	4.35	23.2	246
G08	3/24/2021	Eastern Compliance	6.9	4.39	29	225

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G08	6/1/2021	Eastern Compliance	6.96	4.63	27.2	204
G08	7/6/2021	Eastern Compliance	6.81	4.56	26.2	227
G08	5/3/2023	Eastern Compliance	6.88	5.43	32.2	363
G08	6/15/2021	Eastern Compliance	6.94	3.97	27.2	226
G08	3/9/2023	Eastern Compliance	6.85	4.33	28.9	297
G08	3/4/2021	Eastern Compliance	7	4.53	27.2	241
G08	4/13/2021	Eastern Compliance	7	5.25	31.9	286
G08	5/11/2021	Eastern Compliance	6.94	3.77	25.4	203
G08	7/20/2021	Eastern Compliance	6.81	3.98	27.1	227
G08	7/23/2022	Eastern Compliance	7.59	4.74	29	229
G09	4/14/2021	Eastern Compliance	6.3	3.48	33.7	297
G09	5/12/2021	Eastern Compliance	6.45	3.26	32.1	272
G09	6/1/2021	Eastern Compliance	6.24	3.65	31.4	284
G09	7/6/2021	Eastern Compliance	6.29	4.05	28.7	289
G09	7/21/2021	Eastern Compliance	5.99	3.75	32	286
G09	5/3/2023	Eastern Compliance	6.37	3.87	24.7	241
G09	6/15/2021	Eastern Compliance	5.97	0.282	49.3	294
G09	3/9/2023	Eastern Compliance	6.13	3.49	28.9	295
G09	3/4/2021	Eastern Compliance	6.2	3.19	33.8	351
G09	3/25/2021	Eastern Compliance	6.3	3.15	32	286
G09	7/24/2022	Eastern Compliance	7.57	3.89	30.6	278
G10	3/24/2021	Eastern Compliance	6.7	4.31	39.3	369
G10	6/1/2021	Eastern Compliance	6.5	4.73	38.5	401
G10	7/6/2021	Eastern Compliance	6.51	4.81	37.3	415
G10	7/26/2022	Eastern Compliance	6.81	4.4	36.6	388
G10	3/8/2023	Eastern Compliance	6.55	3.28	36.6	425
G10	5/3/2023	Eastern Compliance	6.6	3.08	36.9	365
G10	6/15/2021	Eastern Compliance	6.46	3.74	40.8	407
G10	3/4/2021	Eastern Compliance	6.7	4.98	35.7	391
G10	4/13/2021	Eastern Compliance	6.6	4.26	37.2	382
G10	5/11/2021	Eastern Compliance	6.34	3.95	41.1	364
G10	7/20/2021	Eastern Compliance	6.49	4.2	40	410
G11	3/8/2023	Exceedance	5.87	0.327	27.8	303
G11	7/23/2022	Exceedance	6.33	0.31	40.9	352
G11	3/4/2021	Exceedance	5.9	0.247	41.6	400
G11	5/3/2023	Exceedance	5.82	0.373	43.2	416
G11	7/6/2021	Exceedance	5.78	0.358	48.3	474
G11	7/20/2021	Exceedance	5.82	0.302	51.8	487
G11	6/14/2021	Exceedance	5.86	0.266	49.2	505

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G11	3/24/2021	Exceedance	5.9	0.42	72.4	658
G11	6/1/2021	Exceedance	5.82	0.309	58.6	671
G11	5/12/2021	Exceedance	5.9	0.321	67.7	730
G11	4/14/2021	Exceedance	5.8	0.411	65.6	761
G51D	12/3/2015	Exceedance	6.2	0.117	--	117
G51D	3/15/2016	Exceedance	5.9	0.184	--	145
G51D	6/15/2016	Exceedance	5.8	0.213	--	139
G51D	9/14/2016	Exceedance	5.6	0.263	--	136
G51D	12/14/2016	Exceedance	5.9	0.171	--	101
G51D	6/15/2017	Exceedance	5.6	0.58	--	149
G51D	7/20/2017	Exceedance	5.9	0.332	14.4	140
G51D	11/30/2017	Exceedance	5.6	0.302	--	138
G51D	6/19/2018	Exceedance	5.7	0.337	--	124
G51D	9/5/2018	Exceedance	6	0.263	--	134
G51D	3/27/2019	Exceedance	5.7	0.778	--	125
G51D	9/9/2019	Exceedance	5.3	0.501	--	109
G51D	3/30/2020	Exceedance	5.62	0.697	13.4	130
G51D	9/23/2020	Exceedance	5.72	0.863	--	121
G51D	9/20/2021	Exceedance	5.46	0.689	--	131
G51D	3/8/2023	Exceedance	5.49	0.963	12.3	131
G51D	3/24/2021	Exceedance	5.56	0.786	12.5	122
G51D	3/8/2017	Exceedance	6.2	0.309	--	146
G51D	5/3/2023	Exceedance	5.57	0.0297	14.3	59
G51D	3/15/2022	Exceedance	5.57	0.689	12.9	123
G51D	9/20/2022	Exceedance	5.58	0.551	--	125
G51D	7/25/2022	Exceedance	6.92	0.663	12.8	116
G52D	12/3/2015	Eastern Compliance	6.5	<0.025	--	65
G52D	3/15/2016	Eastern Compliance	6.3	<0.025	--	99
G52D	6/15/2016	Eastern Compliance	6.6	<0.025	--	88
G52D	9/14/2016	Eastern Compliance	6.4	<0.025	--	84
G52D	12/14/2016	Eastern Compliance	6.7	<0.025	--	82
G52D	3/7/2017	Eastern Compliance	5.9	<0.025	--	115
G52D	11/30/2017	Eastern Compliance	6	<0.025	--	97
G52D	6/19/2018	Eastern Compliance	6.4	<0.025	--	97
G52D	9/5/2018	Eastern Compliance	6.3	<0.025	--	101
G52D	3/27/2019	Eastern Compliance	6.4	<0.025	--	81
G52D	9/9/2019	Eastern Compliance	6	<0.025	--	78
G52D	3/30/2020	Eastern Compliance	6.38	<0.025	15.3	84
G52D	9/23/2020	Eastern Compliance	6.54	<0.025	--	84

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field), (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G52D	9/20/2021	Eastern Compliance	6.29	<0.025	--	83
G52D	6/14/2017	Eastern Compliance	6.2	<0.025	--	112
G52D	9/21/2022	Eastern Compliance	6.26	<0.011	--	72
G52D	5/3/2023	Eastern Compliance	6.31	0.682	12.1	129
G52D	3/25/2021	Eastern Compliance	6.25	<0.025	14.6	75
G52D	3/15/2022	Eastern Compliance	6.22	<0.025	15.1	68
G52D	3/10/2023	Eastern Compliance	6.54	0.0319	15.3	74
G52D	7/19/2017	Eastern Compliance	6.4	<0.025	17	108
G53D	12/3/2015	Eastern Compliance	6.8	0.332	--	103
G53D	3/15/2016	Eastern Compliance	6.7	0.334	--	107
G53D	6/15/2016	Eastern Compliance	6.6	0.342	--	107
G53D	9/14/2016	Eastern Compliance	6.5	0.368	--	104
G53D	12/14/2016	Eastern Compliance	6.8	0.364	--	106
G53D	6/15/2017	Eastern Compliance	6.6	0.309	--	79
G53D	7/20/2017	Eastern Compliance	6.8	0.366	19.2	94
G53D	11/30/2017	Eastern Compliance	6.6	0.427	--	98
G53D	6/19/2018	Eastern Compliance	6.6	0.361	--	84
G53D	9/5/2018	Eastern Compliance	6.8	0.392	--	81
G53D	3/27/2019	Eastern Compliance	6.6	0.269	--	54
G53D	9/9/2019	Eastern Compliance	6.2	0.385	--	80
G53D	3/30/2020	Eastern Compliance	6.7	0.334	15.7	66
G53D	9/23/2020	Eastern Compliance	6.67	0.411	--	79
G53D	9/20/2021	Eastern Compliance	6.27	0.402	--	78
G53D	9/20/2022	Eastern Compliance	6.48	0.431	--	79
G53D	3/8/2017	Eastern Compliance	7.2	0.138	--	35
G53D	5/3/2023	Eastern Compliance	6.48	0.367	15.3	68
G53D	3/9/2023	Eastern Compliance	6.46	0.37	16.4	72
G53D	3/25/2021	Eastern Compliance	6.53	0.355	15.7	71
G53D	7/25/2022	Eastern Compliance	7.88	0.341	17	77
G53D	3/15/2022	Eastern Compliance	6.5	0.332	16.5	74
G54D	12/3/2015	Eastern Compliance	7	0.663	--	191
G54D	3/15/2016	Eastern Compliance	6.8	0.513	--	176
G54D	6/15/2016	Eastern Compliance	6.6	0.508	--	160
G54D	9/14/2016	Eastern Compliance	6.6	0.557	--	149
G54D	12/14/2016	Eastern Compliance	6.7	0.564	--	144
G54D	6/15/2017	Eastern Compliance	6.8	0.685	--	170
G54D	7/20/2017	Eastern Compliance	6.8	0.58	25.2	151
G54D	11/30/2017	Eastern Compliance	6.7	0.646	--	136
G54D	6/19/2018	Eastern Compliance	6.7	0.631	--	146

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G54D	9/5/2018	Eastern Compliance	6.5	0.66	--	152
G54D	3/27/2019	Eastern Compliance	6.8	1.03	--	142
G54D	9/9/2019	Eastern Compliance	6.4	0.614	--	136
G54D	3/30/2020	Eastern Compliance	6.78	0.766	27.1	184
G54D	9/23/2020	Eastern Compliance	6.7	0.819	--	173
G54D	3/24/2021	Eastern Compliance	6.56	0.404	24.2	186
G54D	9/20/2021	Eastern Compliance	6.48	0.35	--	175
G54D	7/26/2022	Eastern Compliance	7.09	0.178	22.3	188
G54D	9/20/2022	Eastern Compliance	6.5	0.252	--	218
G54D	3/8/2017	Eastern Compliance	7.1	0.499	--	131
G54D	5/3/2023	Eastern Compliance	6.8	0.555	26.4	194
G54D	3/9/2023	Eastern Compliance	6.52	0.555	26.4	231
G54D	3/15/2022	Eastern Compliance	6.61	0.451	25.8	213
G101	7/26/2022	Other	7.31	<0.0092	5.09	30
G101	3/7/2023	Other	6.58	0.0294	5.4	28
G101	3/22/2021	Other	6.99	<0.02	7.65	39
G101	8/31/2022	Other	6.64	<0.0092	5.88	37
G101	9/28/2022	Other	6.49	<0.019	5.77	30
G101	10/26/2022	Other	6.9	0.0366	5.21	56
G101	11/15/2022	Other	6.85	<0.0092	5.51	37
G101	12/14/2022	Other	6.63	<0.0092	5.19	37
G101	1/18/2023	Other	6.58	<0.0092	5.01	32
G101	2/14/2023	Other	6.24	<0.0092	5.29	41
G101	12/14/2016	Other	6.7	<0.025	--	35
G101	3/7/2017	Other	6	<0.025	--	37
G101	11/30/2017	Other	6.6	<0.025	--	35
G101	6/19/2018	Other	6.7	<0.025	--	49
G101	3/27/2019	Other	6.7	<0.025	--	46
G101	9/9/2019	Other	6.3	<0.025	--	35
G101	3/30/2020	Other	6.76	<0.025	3.79	41
G101	9/23/2020	Other	6.51	<0.025	--	37
G101	9/20/2021	Other	6.4	<0.025	--	36
G101	3/14/2022	Other	6.48	<0.025	4.34	38
G101	9/20/2022	Other	6.58	<0.0092	--	38
G101	6/14/2017	Other	6.4	<0.025	--	51
G101	3/25/2021	Other	6.51	<0.025	4.36	37
G101	7/19/2017	Other	6.7	<0.025	4.68	52
G101	12/22/2015	Other	6.5	<0.025	--	33
G101	3/16/2016	Other	6.6	<0.025	--	86

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G101	6/14/2016	Other	6.3	<0.025	--	53
G101	9/13/2016	Other	6.4	<0.025	--	47
G101	12/6/2018	Other	6.7	<0.025	--	54
G101	3/21/2023	Other	6.59	0.0525	13.2	49
G102	3/7/2017	Other	5.8	<0.025	--	22
G102	11/30/2017	Other	6.3	<0.025	--	20
G102	6/19/2018	Other	6.5	<0.025	--	50
G102	3/27/2019	Other	6.5	<0.025	--	44
G102	9/9/2019	Other	6.1	<0.025	--	34
G102	3/30/2020	Other	6.48	<0.025	2.5	38
G102	9/23/2020	Other	6.24	<0.025	--	34
G102	9/20/2021	Other	6.38	<0.025	--	38
G102	3/14/2022	Other	6.37	<0.025	3.21	30
G102	9/20/2022	Other	6.44	<0.0092	--	41
G102	6/14/2017	Other	6.1	<0.025	--	27
G102	3/25/2021	Other	6.46	<0.025	2.64	35
G102	3/10/2023	Other	6.31	<0.02	3.6	40
G102	7/19/2017	Other	6.4	<0.025	3.3	28
G102	12/22/2015	Other	6.9	<0.025	--	15
G102	3/16/2016	Other	6.4	<0.025	--	58
G102	6/14/2016	Other	6.1	<0.025	--	65
G102	9/13/2016	Other	5.8	<0.025	--	49
G102	12/6/2018	Other	6.4	<0.025	--	28
G102	12/15/2016	Other	6.2	<0.025	--	24
G103	12/23/2015	Other	7.25	--	--	--
G104	6/23/2014	Other	6.8	<0.02	--	<50.0
G104	9/9/2014	Other	6.89	<0.02	--	<50.0
G104	12/9/2014	Other	6.9	0.0837	--	<50.0
G104	3/20/2015	Other	6.29	<0.02	--	--
G105	3/7/2017	Other	5.7	<0.025	--	12
G105	11/30/2017	Other	6.3	<0.025	--	12
G105	6/19/2018	Other	6.3	<0.025	--	12
G105	3/27/2019	Other	6.3	<0.025	--	11
G105	9/9/2019	Other	6.1	<0.025	--	12
G105	3/30/2020	Other	6.32	<0.025	9.11	13
G105	9/23/2020	Other	6.22	<0.025	--	16
G105	9/20/2021	Other	6.06	<0.025	--	13
G105	3/14/2022	Other	6.18	<0.025	8.95	12
G105	9/20/2022	Other	6.14	<0.0092	--	11

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G105	6/14/2017	Other	6.1	<0.025	--	16
G105	3/25/2021	Other	6.13	<0.025	8.53	12
G105	3/10/2023	Other	6.03	<0.011	8.78	12
G105	7/19/2017	Other	6.4	<0.025	8.8	13
G105	12/22/2015	Other	6.6	<0.025	--	12
G105	3/16/2016	Other	6.4	<0.025	--	11
G105	6/14/2016	Other	6.4	<0.025	--	12
G105	9/13/2016	Other	6.4	<0.025	--	13
G105	12/6/2018	Other	6.2	<0.025	--	11
G105	12/15/2016	Other	6.2	<0.025	--	11
G106	12/23/2015	Other	6.34	--	--	--
G107	3/7/2017	Other	6.1	<0.025	--	93
G107	11/30/2017	Other	6.5	0.0295	--	88
G107	6/19/2018	Other	6.6	<0.025	--	77
G107	3/27/2019	Other	6.4	<0.025	--	30
G107	9/9/2019	Other	6.5	0.0373	--	112
G107	3/30/2020	Other	6.68	<0.025	24.8	89
G107	9/23/2020	Other	6.73	0.0353	--	101
G107	9/20/2021	Other	6.64	0.0282	--	67
G107	3/14/2022	Other	6.42	<0.025	21.3	40
G107	9/20/2022	Other	6.59	<0.023	--	49
G107	6/14/2017	Other	6.4	<0.025	--	50
G107	3/25/2021	Other	6.48	0.0291	19.5	54
G107	3/10/2023	Other	6.42	<0.023	20.6	42
G107	7/19/2017	Other	6.8	<0.025	26.7	123
G107	12/22/2015	Other	6.9	0.0365	--	29
G107	3/16/2016	Other	6.3	<0.025	--	11
G107	6/14/2016	Other	6.9	0.0311	--	58
G107	9/13/2016	Other	6.7	<0.025	--	127
G107	12/6/2018	Other	6.6	0.027	--	72
G107	12/15/2016	Other	6.6	<0.025	--	67
G108	12/23/2015	Other	7.04	--	--	--
G109	3/7/2017	Other	6	<0.025	--	37
G109	11/30/2017	Other	6.5	<0.025	--	48
G109	6/19/2018	Other	6.9	0.0277	--	100
G109	9/5/2018	Other	7	--	--	77
G109	3/27/2019	Other	6.7	0.0309	--	55
G109	9/9/2019	Other	6.5	0.0255	--	59
G109	3/30/2020	Other	6.76	0.0272	8.21	41

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G109	9/23/2020	Other	6.6	<0.025	--	42
G109	9/20/2021	Other	6.54	<0.025	--	27
G109	3/14/2022	Other	6.55	<0.025	7.91	30
G109	9/20/2022	Other	6.49	<0.014	--	21
G109	6/14/2017	Other	6.5	<0.025	--	68
G109	3/25/2021	Other	6.35	<0.025	6.16	32
G109	3/10/2023	Other	6.32	<0.018	7.7	37
G109	7/19/2017	Other	6.7	<0.025	7.34	65
G109	12/22/2015	Other	6.7	0.0315	--	23
G109	3/16/2016	Other	6.5	<0.025	--	22
G109	6/14/2016	Other	6.4	<0.025	--	29
G109	9/13/2016	Other	6.5	<0.025	--	41
G109	12/6/2018	Other	6.7	<0.025	--	68
G109	12/15/2016	Other	6.5	<0.025	--	33
G110	12/23/2015	Other	6.87	--	--	--
G111	3/7/2023	Other	7.05	<0.0092	8.94	16
G111	3/22/2021	Other	7.34	<0.02	9.48	17
G111	1/18/2023	Other	6.88	<0.0092	8.76	14
G111	9/1/2022	Other	7.02	0.0873	9.92	16
G111	9/27/2022	Other	7.03	0.0341	9	14
G111	10/28/2022	Other	6.9	0.0389	9.32	13
G111	11/16/2022	Other	7.11	<0.0092	8.67	16
G111	12/15/2022	Other	6.89	<0.0092	8.89	15
G111	2/15/2023	Other	6.48	<0.0092	9.14	16
G111	3/7/2017	Other	6.2	0.0308	--	29
G111	11/30/2017	Other	6.7	<0.025	--	<10.0
G111	6/19/2018	Other	6.8	<0.025	--	40
G111	3/27/2019	Other	6.8	0.0256	--	46
G111	9/9/2019	Other	5.9	0.0258	--	33
G111	3/30/2020	Other	6.68	0.03	7.49	44
G111	9/23/2020	Other	6.63	<0.025	--	31
G111	9/20/2021	Other	6.51	<0.025	--	21
G111	3/14/2022	Other	6.49	<0.025	6.03	29
G111	9/20/2022	Other	6.53	<0.013	--	19
G111	6/14/2017	Other	6.6	<0.025	--	37
G111	3/25/2021	Other	6.4	<0.025	6.06	33
G111	7/19/2017	Other	6.8	<0.025	5.97	29
G111	12/22/2015	Other	6.5	<0.025	--	27
G111	3/16/2016	Other	6.5	<0.025	--	37

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
G111	6/14/2016	Other	6.7	0.0265	--	39
G111	9/13/2016	Other	6.8	0.0251	--	23
G111	12/6/2018	Other	6.5	0.0404	--	32
G111	3/21/2023	Other	6.56	0.047	4.71	23
G111	12/15/2016	Other	6.8	<0.025	--	13
G112C	3/8/2023	Other	6.41	4.8	85.6	822
G112C	3/22/2021	Other	6.85	4.25	68.2	532
G112C	9/28/2022	Other	6.31	4.82	99.5	682
G112C	10/26/2022	Other	6.69	4.86	84.7	820
G112C	12/14/2022	Other	6.63	4.99	87.5	791
G112C	1/18/2023	Other	6.49	4.31	84.6	769
G112C	2/15/2023	Other	6.26	5.04	88.4	797
G112C	8/30/2022	Other	6.62	4.26	85.8	726
G112C	11/17/2022	Other	6.76	4.6	85.1	764
G112D	3/8/2023	Other	6.62	0.0464	24.3	13
G112D	9/28/2022	Other	6.8	0.101	26	<8.0
G112D	10/26/2022	Other	6.97	0.0457	24.3	<8.0
G112D	12/14/2022	Other	6.81	<0.0092	24.7	<6.0
G112D	1/18/2023	Other	6.71	0.0268	24.3	11
G112D	2/15/2023	Other	6.49	<0.0092	25.4	13
G112D	8/30/2022	Other	6.89	0.0367	24.8	<9.0
G112D	11/17/2022	Other	6.95	<0.012	24	<8.0
G112DD	3/8/2023	Other	7.03	0.104	17.7	10
G112DD	9/28/2022	Other	7.24	0.162	21	12
G112DD	10/26/2022	Other	7.42	0.12	18.6	13
G112DD	12/14/2022	Other	8.06	0.116	18.3	10
G112DD	8/30/2022	Other	7.31	0.109	19.9	12
G112DD	11/17/2022	Other	7.41	0.135	17.5	11
G113	3/7/2023	Other	6.53	<0.013	55.2	386
G113	3/22/2021	Other	6.86	<0.02	51.3	292
G113	9/28/2022	Other	6.36	0.0258	65.8	289
G113	10/26/2022	Other	6.57	0.0919	56.7	288
G113	9/1/2022	Other	6.6	<0.022	58.2	316
G113	11/16/2022	Other	6.58	<0.014	54.1	296
G113	12/15/2022	Other	6.38	<0.0092	57.1	314
G113	2/15/2023	Other	6.21	<0.0092	56.1	346
G113	1/19/2023	Other	6.32	<0.0092	54.2	327
TPZ114	3/10/2023	Other	6.15	<0.024	6.82	20
TPZ114	3/22/2021	Other	7.42	0.177	15.4	19

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ114	9/1/2022	Other	6.32	0.0746	7.86	13
TPZ114	9/27/2022	Other	6.02	0.0451	7.95	19
TPZ114	11/16/2022	Other	6.51	0.0269	8.71	21
TPZ114	12/15/2022	Other	6.22	<0.0092	7.5	24
TPZ114	2/15/2023	Other	6.09	0.0254	6.36	24
TPZ114	1/19/2023	Other	6.26	<0.0092	6.42	19
TPZ114	10/27/2022	Other	6.21	0.0251	6.52	21
TPZ115	3/8/2023	Other	6.96	<0.015	38.4	197
TPZ115	1/18/2023	Other	6.93	<0.0092	36.6	178
TPZ115	9/27/2022	Other	6.91	0.0383	34.2	147
TPZ115	12/15/2022	Other	6.87	<0.0092	38.1	180
TPZ115	2/15/2023	Other	6.68	<0.0092	37.6	179
TPZ115	8/30/2022	Other	7.12	0.0354	31.2	135
TPZ115	11/17/2022	Other	7.16	<0.013	35.5	181
TPZ115	10/27/2022	Other	6.93	0.0267	39.6	170
TPZ115D	3/8/2023	Other	7.11	0.356	21.8	37
TPZ115D	1/18/2023	Other	7.13	0.349	20.8	37
TPZ115D	9/27/2022	Other	7.24	0.467	22.5	35
TPZ115D	12/15/2022	Other	7.1	0.387	22.4	39
TPZ115D	2/15/2023	Other	6.79	0.4	22.3	37
TPZ115D	8/30/2022	Other	7.13	0.382	21.9	38
TPZ115D	11/17/2022	Other	7.37	0.387	20.9	37
TPZ115D	10/27/2022	Other	7.13	0.421	22.6	36
TPZ115DD	3/8/2023	Other	7.18	0.0915	17	13
TPZ115DD	9/27/2022	Other	7.34	0.0563	17.6	11
TPZ115DD	12/15/2022	Other	7.2	0.0657	19.2	12
TPZ115DD	8/30/2022	Other	7.36	0.0423	17.7	<8.0
TPZ115DD	11/17/2022	Other	7.36	0.0684	16.4	11
TPZ115DD	10/27/2022	Other	7.24	0.0847	18.3	11
TPZ116	3/22/2021	Other	6.99	<0.02	13.6	24
TPZ117	3/22/2021	Other	6.67	<0.02	18.8	32
TPZ117D	3/7/2023	Other	6.54	0.724	29.3	228
TPZ117D	7/27/2022	Other	7.56	0.409	36.3	134
TPZ117D	3/22/2021	Other	7.09	0.0763	19.3	187
TPZ117D	11/15/2022	Other	6.7	0.36	35.6	133
TPZ117D	12/14/2022	Other	6.53	0.353	37	127
TPZ117D	1/18/2023	Other	6.48	0.495	29.8	186
TPZ117D	9/1/2022	Other	6.62	0.41	38.7	124
TPZ117D	2/15/2023	Other	6.29	0.331	35.1	126

LIFECYCLEGEO

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ117D	9/29/2022	Other	6.57	0.394	42.1	130
TPZ117D	11/4/2022	Other	6.69	0.423	35.2	135
TPZ118	3/8/2023	Western UCU	6.56	5.44	6.3	88
TPZ118	8/31/2022	Western UCU	5.97	9.54	21.6	242
TPZ118	11/15/2022	Western UCU	5.84	13.1	16.7	233
TPZ118	12/14/2022	Western UCU	5.52	14.6	19.1	263
TPZ118	10/28/2022	Western UCU	5.65	18.7	21.1	259
TPZ118	2/15/2023	Western UCU	5.04	10.9	12	250
TPZ118	1/19/2023	Western UCU	6.41	3.35	4.04	63
TPZ118	9/29/2022	Western UCU	5.99	12.1	18.6	215
TPZ118D	3/8/2023	Western UA	6.28	7.44	30.7	358
TPZ118D	8/31/2022	Western UA	6.3	5.41	32.7	351
TPZ118D	11/15/2022	Western UA	6.55	6.13	29.8	332
TPZ118D	12/14/2022	Western UA	6.6	5.85	27.1	300
TPZ118D	10/28/2022	Western UA	6.35	7.08	31.3	352
TPZ118D	2/15/2023	Western UA	6.07	7.56	30.8	329
TPZ118D	1/19/2023	Western UA	6.31	6.35	28.7	329
TPZ118D	9/29/2022	Western UA	6.17	5.74	33.6	357
TPZ118DD	3/8/2023	Western UA	7.09	0.0776	16.8	10
TPZ118DD	8/31/2022	Western UA	7.4	0.831	19.5	73
TPZ118DD	11/15/2022	Western UA	7.34	0.054	16.4	12
TPZ118DD	12/14/2022	Western UA	7.08	0.122	17.9	12
TPZ118DD	10/28/2022	Western UA	7.26	0.112	16.5	10
TPZ118DD	9/29/2022	Western UA	6.84	0.146	17.9	17
TPZ119D	3/7/2023	Western UA	6.34	4.76	33.7	175
TPZ119D	8/31/2022	Western UA	6.49	5.58	35.5	192
TPZ119D	12/14/2022	Western UA	6.44	4.59	33.6	156
TPZ119D	1/18/2023	Western UA	6.35	3.32	29	142
TPZ119D	11/16/2022	Western UA	6.48	4.35	32.4	159
TPZ119D	2/15/2023	Western UA	6.16	4.22	31.2	154
TPZ119D	9/29/2022	Western UA	6.19	4.37	35	186
TPZ119D	11/4/2022	Western UA	6.61	5.48	33.7	156
TPZ119DD	3/7/2023	Western UA	6.76	11.8	80.5	969
TPZ119DD	8/31/2022	Western UA	6.9	11.5	82	899
TPZ119DD	12/14/2022	Western UA	6.81	12.4	84.3	886
TPZ119DD	1/18/2023	Western UA	6.74	11.1	78	972
TPZ119DD	11/16/2022	Western UA	6.94	12.3	79.8	906
TPZ119DD	2/15/2023	Western UA	6.54	13.6	83.3	1030
TPZ119DD	9/29/2022	Western UA	6.88	10.9	87.6	907

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ119DD	11/4/2022	Western UA	7	14.2	85.2	906
TPZ120	3/7/2023	Western UCU	2.8	2.36	58.8	4200
TPZ120	10/26/2022	Western UCU	3.02	3.13	62.8	4600
TPZ120	9/27/2022	Western UCU	3.53	2.53	60.2	3650
TPZ120	11/16/2022	Western UCU	3.13	2.21	63.1	4530
TPZ120	12/15/2022	Western UCU	3.4	3.55	63.5	4100
TPZ120	2/15/2023	Western UCU	3.14	2.1	59.4	4550
TPZ120	8/30/2022	Western UCU	3.63	2.08	52.4	4100
TPZ120	1/19/2023	Western UCU	2.77	2.1	56.4	4280
TPZ120D	3/7/2023	Western UA	6.2	4.77	115	1020
TPZ120D	10/26/2022	Western UA	6.35	4.51	122	1020
TPZ120D	9/27/2022	Western UA	6.37	4.14	118	960
TPZ120D	11/16/2022	Western UA	6.37	4.39	118	1020
TPZ120D	12/15/2022	Western UA	6.16	5.09	121	1020
TPZ120D	2/15/2023	Western UA	6.01	5.31	112	1080
TPZ120D	8/30/2022	Western UA	6.18	3.52	126	967
TPZ120D	1/19/2023	Western UA	6.17	3.9	114	964
TPZ122	3/7/2023	Other	6.77	5.15	27	214
TPZ122	8/31/2022	Other	6.52	0.806	19.7	234
TPZ122	1/18/2023	Other	6.12	1.17	22.3	379
TPZ122	9/27/2022	Other	6.46	1.16	18.2	270
TPZ122	11/16/2022	Other	6.35	0.945	23.4	332
TPZ122	12/15/2022	Other	6.2	1.32	24	367
TPZ122	2/15/2023	Other	5.73	1.34	25.8	381
TPZ122	10/27/2022	Other	6.24	0.988	23.2	325
TPZ122D	3/7/2023	Other	6.11	1.32	26.1	395
TPZ122D	8/31/2022	Other	6.95	4.66	26.4	193
TPZ122D	1/18/2023	Other	6.77	4.36	24.7	225
TPZ122D	9/27/2022	Other	6.65	5.43	25.7	193
TPZ122D	11/16/2022	Other	6.94	5.25	25.4	193
TPZ122D	12/15/2022	Other	6.76	4.92	25.9	213
TPZ122D	2/15/2023	Other	6.46	5.54	26.8	215
TPZ122D	10/27/2022	Other	6.78	6.6	27.7	191
TPZ123	3/7/2023	Western UA	6.84	<0.023	20.5	156
TPZ123	11/3/2022	Western UA	7.2	0.027	17.6	102
TPZ123	8/31/2022	Western UA	7.21	0.0691	17.1	85
TPZ123	1/18/2023	Western UA	6.93	0.0384	26	163
TPZ123	9/27/2022	Western UA	7.2	0.0934	15.9	89
TPZ123	11/16/2022	Western UA	7.11	<0.015	16.8	121

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
TPZ123	12/15/2022	Western UA	6.95	0.0457	17.8	122
TPZ123	2/15/2023	Western UA	6.38	0.0337	20.2	166
TPZ124	3/7/2023	Western UCU	6.17	12.2	44	357
TPZ124	8/31/2022	Western UCU	6.27	8.99	30.8	219
TPZ124	11/15/2022	Western UCU	6.57	14.1	30.8	221
TPZ124	12/14/2022	Western UCU	6.25	24.7	34.4	257
TPZ124	1/18/2023	Western UCU	6.09	10	41.6	311
TPZ124	2/14/2023	Western UCU	5.71	13.6	43.6	331
TPZ124	10/28/2022	Western UCU	6.31	16	30.5	205
TPZ124	9/29/2022	Western UCU	6.35	15.2	34.7	202
TPZ124D	3/7/2023	Western UA	6.77	2.88	45.8	394
TPZ124D	8/31/2022	Western UA	7.04	1.31	37.8	238
TPZ124D	11/15/2022	Western UA	7.07	2.21	42.5	321
TPZ124D	12/14/2022	Western UA	6.88	2.22	43.6	314
TPZ124D	1/18/2023	Western UA	6.8	2.41	44.7	313
TPZ124D	2/14/2023	Western UA	6.4	2.59	45.4	341
TPZ124D	10/28/2022	Western UA	6.84	2.46	43.9	306
TPZ124D	9/29/2022	Western UA	6.91	2.34	44.9	303
XPW01	7/21/2021	Eastern Porewater	7.27	10.1	0.917	328
XPW02	3/21/2023	Eastern Porewater	7.6	--	--	--
XPW02	5/3/2023	Eastern Porewater	7.72	13.4	12.3	2650
XPW02	3/15/2022	Eastern Porewater	7.74	16	10.7	2590
XPW02	7/21/2021	Eastern Porewater	7.76	12	11.1	2330
XPW02	5/12/2021	Eastern Porewater	7.85	10.8	11.8	2410
XPW02	4/14/2021	Eastern Porewater	7.9	11.5	11.3	2410
XPW01	3/5/2021	Eastern Porewater	8	10.4	2.25	345
XPW02	3/4/2021	Eastern Porewater	8	12.1	10.9	2380
XPW02	3/24/2021	Eastern Porewater	8	12.2	11.3	2830
XPW01	4/14/2021	Eastern Porewater	8.2	9.42	1.28	355
XPW01	3/15/2022	Eastern Porewater	8.33	10.4	0.443	360
XPW01	5/12/2021	Eastern Porewater	8.4	10.2	1.31	309
XPW01	3/24/2021	Eastern Porewater	8.4	9.58	1.7	355
XPW01	5/3/2023	Eastern Porewater	8.41	10.6	0.405	345
XPW01	3/8/2023	Eastern Porewater	8.47	8.79	0.254	414
XPW03	7/21/2021	Eastern Porewater	9.97	11.6	<0.05	148
XPW03	3/4/2021	Eastern Porewater	10.5	12.2	<0.05	133
XPW03	3/15/2022	Eastern Porewater	10.5	11.1	<0.05	152
XPW03	4/14/2021	Eastern Porewater	10.5	9.3	<0.05	152
XPW03	3/24/2021	Eastern Porewater	10.6	11.6	<0.05	138

Appendix D-1. Supporting groundwater analytical data for Table 1 and Attachments 3 and 4.

Well ID	Date	Well Type	pH (field) (SU)	Boron, total (mg/L)	Magnesium, total (mg/L)	Sulfate, total (mg/L)
XPW03	3/9/2023	Eastern Porewater	10.7	8.06	<0.021	142
XPW03	5/3/2023	Eastern Porewater	10.7	9.22	<0.03	144
XPW03	5/12/2021	Eastern Porewater	10.7	11.7	<0.1	155
XPW02	3/8/2023	Eastern Porewater	--	10.8	8.75	2450
XTPW01	3/10/2023	Western Porewater	10.8	34.3	0.0986	420
XTPW01	3/22/2021	Western Porewater	11.13	27	0.122	387
XTPW01	9/28/2022	Western Porewater	10.71	32.1	0.29	395
XTPW01	9/1/2022	Western Porewater	11.03	29.5	0.292	402
XTPW01	10/27/2022	Western Porewater	10.95	32.7	4.36	403
XTPW02	3/8/2023	Western Porewater	10.6	17.8	0.123	462
XTPW02	9/28/2022	Western Porewater	10.65	22.3	0.7	427
XTPW02	10/26/2022	Western Porewater	10.91	21.9	0.381	478
XTPW02	9/1/2022	Western Porewater	10.56	21.4	1.1	461
XTPW03	3/7/2023	Western Porewater	6.76	4.02	27.8	89
XTPW03	9/28/2022	Western Porewater	7.33	16.4	18.9	269
XTPW03	9/1/2022	Western Porewater	7.5	16.2	20.4	234
XTPW03	10/27/2022	Western Porewater	7.42	23.3	17.2	356
XTPW04	3/8/2023	Western Porewater	7.09	11.3	17	452
XTPW04	9/28/2022	Western Porewater	9.58	18.3	10	658
XTPW04	10/26/2022	Western Porewater	9.77	24.2	6.91	907
XTPW04	9/1/2022	Western Porewater	8.73	16.2	14.4	539

Notes:

mg/L = milligrams per liter

SU= standard units

< = less than analytical detection limit; data not included in Attachment 3 and 4 analyses.

-- = data not measured

Well Type: Western and Eastern as defined in main text, UA=uppermost aquifer, UCU= upper confining unit

Attachment 3: pH, boron, and magnesium data from March 2021 to May 2023. See Attachment 3 legend for full list of included wells.

Attachment 4: Magnesium and sulfate data for all sampling dates and all wells listed here.

Table 1: Inline Table 1 presents pH, boron, and magnesium data for G11, G51D, CCR Porewater, Western Groundwater, Eastern Groundwater, and TPZ120. G11, G51D, and TPZ120 data are from from March 2021 to May 2023 for those individual wells. For the same time frame, CCR Porewater includes both eastern and western porewater; Western Groundwater includes all Western UA and UCU wells except TPZ120; Eastern Groundwater includes all Eastern Compliance and Background Wells.

LIFECYCLEGEO

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G11	2021/07/06	0.071	78
G11	2021/04/14	0.084	100
G11	2021/07/20	0.036	135
G11	2023/05/03	*3.35*	207
G11	2021/06/01	0.086	159
G11	2021/06/14	0.052	149
G11	2023/03/08	--	166
G11	2021/03/04	0.51	69.0
G11	2021/03/24	<0.025	154
G11	2021/05/12	<0.1	194
G11	2022/07/23	0.16	122
G51D	2023/03/08	--	167
G51D	2021/03/24	--	136
G51D	2022/07/25	0.41	178
G51D	2022/03/15	--	165
G51D	2020/03/30	--	261
G51D	2023/05/03	*0.82*	214
G51D	2017/07/20	--	180
G51D	2019/09/09	--	157
G51D	2021/09/20	--	238
G51D	2022/09/20	--	215
G51D	2016/09/14	--	231
G51D	2017/06/15	--	168
G51D	2017/11/30	--	168
G51D	2018/06/19	--	247
G51D	2019/03/27	--	130
G51D	2020/09/23	--	292
G51D	2016/06/15	--	213
G51D	2016/12/14	--	134
G51D	2016/03/15	--	122
G51D	2018/09/05	--	217
G51D	2015/12/03	--	133
G51D	2017/03/08	--	282
TPZ118DD	2022/09/29	*0.97*	-65.5
TPZ118DD	2022/12/14	2.07	<-300.0
TPZ118DD	2023/03/08	*2.11*	-36.2
TPZ118DD	2022/10/28	1.88	-103
TPZ118DD	2022/11/15	1.60	-168

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
TPZ118DD	2022/08/31	*1.70*	-124
TPZ119D	2023/02/15	0.10	217
TPZ119D	2022/09/29	0.12	90.1
TPZ119D	2023/03/07	0.051	104
TPZ119D	2023/01/18	0.12	76.0
TPZ119D	2022/12/14	0.095	96.0
TPZ119D	2022/11/16	*0.086*	38.0
TPZ119D	2022/08/31	*0.80*	123
TPZ119D	2022/11/04	--	196
TPZ120D	2023/02/15	0.89	123
TPZ120D	2022/12/15	1.30	212
TPZ120D	2023/01/19	1.30	178
TPZ120D	2022/08/30	*16.5*	-59.2
TPZ120D	2023/03/07	*1.30*	83.1
TPZ120D	2022/10/26	1.51	32.0
TPZ120D	2022/11/16	1.32	-3.20
TPZ120D	2022/09/27	2.68	43.2
TPZ123	2022/08/31	*31.9*	-78.4
TPZ123	2022/11/03	--	-89.2
TPZ123	2022/09/27	*5.11*	-81.7
TPZ123	2023/03/07	*2.74*	-24.2
TPZ123	2023/01/18	*102*	-116
TPZ123	2022/11/16	*2.46*	-116
TPZ123	2022/12/15	*5.56*	-64.0
TPZ123	2023/02/15	*2.17*	21.0
TPZ124D	2023/02/14	0.40	35.0
TPZ124D	2023/03/07	0.32	11.6
TPZ124D	2023/01/18	0.32	-8.00
TPZ124D	2022/10/28	1.13	-32.9
TPZ124D	2022/12/14	0.76	-24.0
TPZ124D	2022/09/29	*1.71*	-42.7
TPZ124D	2022/08/31	3.14	-63.7
TPZ124D	2022/11/15	0.82	-106
G01D	2017/03/07	--	80.0
G01D	2021/07/06	*1.79*	139
G01D	2023/05/02	*4.09*	145

LIFECYCLEGEO

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well ID	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G01D	2021/06/01	*1.92*	164
G01D	2021/07/21	*1.35*	122
G01D	2022/03/14	--	117
G01D	2019/09/09	--	193
G01D	2021/06/14	*0.83*	160
G01D	2021/03/24	*1.15*	160
G01D	2021/05/12	*0.65*	180
G01D	2022/09/20	--	173
G01D	2021/09/20	--	170
G01D	2023/03/07	--	195
G01D	2021/03/03	*1.09*	145
G01D	2023/01/24	*7.38*	114
G01D	2016/03/15	--	-103
G01D	2017/06/15	--	123
G01D	2015/12/03	--	60.0
G01D	2019/03/27	--	118
G01D	2021/04/14	0.70	134
G01D	2020/09/23	--	202
G01D	2016/09/14	--	-26.0
G01D	2017/11/30	--	21.0
G01D	2016/12/14	--	113
G01D	2018/06/19	--	29.0
G01D	2017/07/20	--	102
G01D	2020/03/30	--	138
G01D	2016/06/15	--	-110
G01D	2018/09/05	--	131
G01D	2022/07/26	*1.85*	15.5
G02D	2021/07/06	<0.025	128
G02D	2021/07/21	0.059	100
G02D	2021/06/01	0.043	140
G02D	2017/06/14	--	95.0
G02D	2021/04/14	<0.025	151
G02D	2016/12/14	--	218
G02D	2021/09/20	--	191
G02D	2021/03/24	0.026	175
G02D	2021/05/12	<0.1	183

Appendix D-2. Supporting groundwater analytical data for Attachment 6A.

Well	Date	Iron (mg/L)	Oxidation Reduction Potential (mV)
G02D	2021/06/14	0.071	169
G02D	2023/05/03	0.049	182
G02D	2022/03/14	--	138
G02D	2022/09/21	--	199
G02D	2021/03/03	0.11	151
G02D	2019/09/09	--	186
G02D	2023/03/08	--	49.1
G02D	2020/03/30	--	179
G02D	2016/03/15	--	28.0
G02D	2016/09/14	--	69.0
G02D	2018/09/05	--	169
G02D	2019/03/27	--	130
G02D	2020/09/23	--	246
G02D	2023/01/24	<0.0115	109.8
G02D	2015/12/03	--	146
G02D	2018/06/19	--	187
G02D	2017/07/20	--	132
G02D	2016/06/15	--	82.0
G02D	2017/03/08	--	254
G02D	2017/11/30	--	70.0
G02D	2022/07/27	0.03	97.3
XTPW03	2023/03/07	*0.49*	50.0
XTPW03	2022/09/28	*12.8*	-69.5
XTPW03	2022/10/27	*5.64*	-136
XTPW03	2022/09/01	*18.7*	-174

Notes:

mg/L = milligrams per liter

mV = millivolts ; V = volts

Italicized samples not included in average iron presented in Attachment 6a due to turbidity >10NTU

WAP: West ash pond, represented by data from XTPW03

Backgroud: Represented by data from G01D and G02D

LIFECYCLEGEO

Appendix D-3. Supporting groundwater analytical data for Attachment 6B.

Well ID	Date	pH (SU)	Temperature (Celcius)	Oxidation Reduction Potential (mV)	Eh (V)
G11	3/4/2021	5.90	16.30	69.0	0.276
G11	3/24/2021	5.90	16.50	154	0.361
G11	4/14/2021	5.80	16.10	100	0.307
G11	5/12/2021	5.90	16.50	194	0.401
G11	6/1/2021	5.82	16.40	159	0.366
G11	6/14/2021	5.86	16.60	149	0.355
G11	7/6/2021	5.78	16.70	78.0	0.284
G11	7/20/2021	5.82	16.90	135	0.341
G11	7/23/2022	6.33	17.32	122	0.328
G11	3/8/2023	5.87	16.00	166	0.373
G11	5/3/2023	5.82	16.50	207	0.414
G51D	7/20/2017	5.90	18.92	180	0.384
G51D	3/30/2020	5.62	16.40	261	0.468
G51D	3/24/2021	5.56	17.00	136	0.342
G51D	9/20/2021	5.46	17.70	238	0.443
G51D	3/15/2022	5.57	16.10	165	0.372
G51D	7/25/2022	6.92	18.07	178	0.383
G51D	3/8/2023	5.49	15.90	167	0.374
G51D	5/3/2023	5.57	16.30	214	0.421
TPZ118DD	8/31/2022	7.40	15.94	-124	0.083
TPZ118DD	9/29/2022	6.84	15.83	-65.5	0.142
TPZ118DD	10/28/2022	7.26	15.70	-103	0.104
TPZ118DD	11/15/2022	7.34	14.77	-168	0.040
TPZ118DD	12/14/2022	7.08	14.80	-300	-0.092
TPZ118DD	3/8/2023	7.09	14.70	-36.2	0.172
TPZ119D	8/31/2022	6.49	16.55	123	0.329
TPZ119D	9/29/2022	6.19	16.92	90.1	0.296
TPZ119D	11/4/2022	6.61	16.12	196	0.403
TPZ119D	11/16/2022	6.48	14.41	38.0	0.246
TPZ119D	12/14/2022	6.44	14.80	96.0	0.304
TPZ119D	1/18/2023	6.35	14.30	76.0	0.285
TPZ119D	2/15/2023	6.16	15.10	217	0.425
TPZ119D	3/7/2023	6.34	14.90	104	0.312
TPZ119DD	8/31/2022	6.90	17.25	-1.3	0.205
TPZ119DD	9/29/2022	6.88	18.56	-3.0	0.202
TPZ119DD	11/4/2022	7.00	17.05	131	0.337
TPZ119DD	11/16/2022	6.94	12.75	-54.0	0.156
TPZ119DD	12/14/2022	6.81	14.60	76.0	0.284
TPZ119DD	1/18/2023	6.74	14.00	32.0	0.241

Appendix D-3. Supporting groundwater analytical data for Attachment 6B.

Well ID	Date	pH (SU)	Temperature (Celcius)	Oxidation Reduction Potential (mV)	Eh (V)
TPZ119DD	2/15/2023	6.54	14.90	36.0	0.244
TPZ119DD	3/7/2023	6.76	14.60	2.0	0.210
TPZ120D	8/30/2022	6.18	16.31	-59.2	0.148
TPZ120D	9/27/2022	6.37	17.00	43.2	0.249
TPZ120D	10/26/2022	6.35	17.60	32.0	0.238
TPZ120D	11/16/2022	6.37	15.23	-3.2	0.204
TPZ120D	12/15/2022	6.16	14.70	212	0.420
TPZ120D	1/19/2023	6.17	14.80	178	0.386
TPZ120D	2/15/2023	6.01	15.50	123	0.330
TPZ120D	3/7/2023	6.20	14.90	83.1	0.291
TPZ123	8/31/2022	7.21	17.13	-78.4	0.128
TPZ123	9/27/2022	7.20	16.42	-81.7	0.125
TPZ123	11/3/2022	7.20	19.43	-89.2	0.115
TPZ123	11/16/2022	7.11	13.87	-116	0.093
TPZ123	12/15/2022	6.95	14.70	-64.0	0.144
TPZ123	1/18/2023	6.93	14.30	-116	0.093
TPZ123	2/15/2023	6.38	14.70	21.0	0.229
TPZ123	3/7/2023	6.84	14.60	-24.2	0.184
TPZ124D	8/31/2022	7.04	16.98	-63.7	0.142
TPZ124D	9/29/2022	6.91	16.40	-42.7	0.164
TPZ124D	10/28/2022	6.84	14.80	-32.9	0.175
TPZ124D	11/15/2022	7.07	13.82	-106	0.103
TPZ124D	12/14/2022	6.88	14.50	-24.0	0.184
TPZ124D	1/18/2023	6.80	14.00	-8.0	0.201
TPZ124D	2/14/2023	6.40	14.00	35.0	0.244
TPZ124D	3/7/2023	6.77	14.40	11.6	0.220
XTPW01	3/10/2023	10.80	14.00	-156	0.053
XTPW02	3/8/2023	10.60	13.90	-182	0.027
XTPW03	10/27/2022	7.42	14.40	-136	0.072
XTPW04	3/8/2023	7.09	13.50	-118	0.091

Notes:

SU= standard units

mV = millivolts ; V = volts

DOCUMENT 16

Dynegy ASD Discussion 10/20/23

- Ramboll + Vistra for Dynegy ASD
- Joppa + Newton need similar things
- Either appeal or Corrective measures
- Use of aerial photos in order to determine pore water
- All GW Section - Lynn, me, Lauren, Justin, + Matt, Mikes

DOCUMENT 17

Rees, Jeromy

From: Hunt, Lauren
Sent: Thursday, October 26, 2023 10:40 AM
To: Phil.Morris@vistracorp.com; Voelker, Brian; Cravens, Stuart
Cc: Mullenax, Heather; Garee, Matthew J.; Dunaway, Lynn; Summers, Michael
Subject: Newton and Joppa ASD Questions

Follow Up Flag: Follow up
Flag Status: Completed

Hi Phil.
Heather and I are looking for technical contact information for the Newton (Heather) and Joppa (me) ASD. We have a few questions and requests and would like to discuss with your technical folks.
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 18

Hunt, Lauren

From: Hunt, Lauren
Sent: Thursday, October 26, 2023 1:09 PM
To: Fuller, Rhys
Cc: Dunaway, Lynn; Mullenax, Heather
Subject: Joppa and Newton ASD data gap discussion

Hi Rhys.
As discussed, here are our data gap requests for the Joppa ASD.

1. Source characterization of the CCR at the East Ash Pond must include total solids sampling, analysis and reporting in accordance with SW846.
2. Hydraulic conductivities from laboratory or insitu testing must be collected, analyzed and presented with hydrogeologic characterization of all units including aquifers and confining units. Hydraulic conductivity data must include field and software analysis.
3. Characterization to include sample and analysis in accordance with 35 IAC 845.640 of alternative source must be provided with the ASD.

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.

DOCUMENT 19

Strauss, Rebecca Y.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Friday, October 27, 2023 3:12 PM
To: Dunaway, Lynn
Subject: RE: Baldwin Power Plant ASD submittal notice

I don't know that we would hear about it. I replied to the email about where documents will be stored with a comprehensive list of the documents that have to do with Subpart F and are our business. Could you respond to that email and make a request that we are notified every time any of those types of documents are submitted?
We also didn't get notified about the SSIR for Joppa. And we should be seeing a lot more documents than Permits will ever see because of the nature of 845.

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: Friday, October 27, 2023 2:57 PM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Subject: RE: Baldwin Power Plant ASD submittal notice

I talked to Derek and he and Josiah were getting the Baldwin ASD on the listserv, but I'm wondering if we'll see an email saying it arrived? We only know it's here because you were on the original incoming email from Dynegy. The other documents that arrived today have been announced.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Friday, October 27, 2023 11:39 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: FW: Baldwin Power Plant ASD submittal notice

Hi Lynn.
Please advise on who should be reviewing the Baldwin ASD. See below.
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: Voelker, Brian <Brian.Voelker@vistracorp.com>
Sent: Friday, October 27, 2023 10:51 AM
To: EPA.CCR.Part845.Coordinator <EPA.CCR.Part845.Coordinator@Illinois.gov>; EPA.CCR.Part845.Notify <EPA.CCR.Part845.Notify@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Cc: Morris, Phil <Phil.Morris@vistracorp.com>; Fuller, Rhys <Rhys.Fuller@vistracorp.com>; Modeer, Victor <Victor.Modeer@vistracorp.com>; Cravens, Stuart <Stuart.Cravens@txu.com>; Davies, Sam <SAMANTHA.DAVIES@vistracorp.com>; Mitchell, David <David.Mitchell@vistracorp.com>
Subject: [External] Baldwin Power Plant ASD submittal notice

Lauren,
As a courtesy this email is to provide notice that an ASD for the Baldwin Power Plant Bottom Ash Pond ASD was submitted/delivered to IEPA via FedEx on October 27, 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%2FBaldwin%2F2023

Please let me know if you have questions or concerns.

Thanks,
Brian

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 20

Rees, Jeromy

Subject: ASD discussions with Dynegy
Location: https://illinois.webex.com/illinois/j.php?MTID=m31ebeb6a3d16bd9e64a0fa7b531d3907

Start: Tue 10/31/2023 1:00 PM
End: Tue 10/31/2023 2:00 PM

Recurrence: (none)

Meeting Status: Accepted

Organizer: Hunt, Lauren
Required Attendees: Hunt, Lauren; Dunaway, Lynn; Garee, Matthew J.; Mullenax, Heather; Bierwagen, Justin; Summers, Michael; Fuller, Rhys
Optional Attendees: Cravens, Stuart; Voelker, Brian; Morris, Phil; Modeer, Victor; Brian Hennings; Nathaniel R Keller

Categories: Meetings for EPA

-~-

-- Do not delete or change any of the following text. --

When it's time, join your Webex meeting here.

Join meeting

More ways to join:

Join from the meeting link
https://illinois.webex.com/illinois/j.php?MTID=m31ebeb6a3d16bd9e64a0fa7b531d3907

Join by meeting number
Meeting number (access code): 2634 381 5550
Meeting password: piJUfMi7F98

Tap to join from a mobile device (attendees only)
+1-312-535-8110,,26343815550## United States Toll (Chicago)
+1-415-655-0002,,26343815550## US Toll

Join by phone
+1-312-535-8110 United States Toll (Chicago)
+1-415-655-0002 US Toll
Global call-in numbers

Join from a video system or application
Dial 26343815550@illinois.webex.com
You can also dial 173.243.2.68 and enter your meeting number.

If you are a host, click here and login site to view host information.

Need help? Go to https://help.webex.com

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 21

Rees, Jeromy

From: Summers, Michael
Sent: Wednesday, November 1, 2023 3:32 PM
To: Hunt, Lauren; Dunaway, Lynn
Cc: Mullenax, Heather; Garee, Matthew J.; Bierwagen, Justin
Subject: RE: Joppa West Adjusted Standard Recommendation Meeting follow up

Added to clarify for lawyers in red

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, November 1, 2023 3:22 PM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Joppa West Adjusted Standard Recommendation Meeting follow up

Final draft for Lynn to pass on:

As filed, the Recommendation allows a 6-year temp. AS to allow sampling (5 years) and modeling/reporting (1 year) to prove monitored natural attenuation (MNA) will work.
USEPA has been very non-receptive to MNA demonstrations at other sites around the country.
Therefore, IEPA needs to amend the Rec to withdraw the Alt Standard suggested or not amend in which case Joppa maybe subject to USEPA enforcement. (Note: This was where the upper management decision came in, considering our goal to get primacy)

IEPA also asked for source monitoring, Joppa did install and has been doing total metals monitoring, but is not done yet, so the ask would be:
Please provide the groundwater sampling and analysis results for total metals at site wells listed in the Attachment B from Ramboll and Associates dated December 19, 2022 for 8 quarters of groundwater sampling along with the precipitation, infiltration and leaching analysis. [Note: unlikely that they have completed this at this time since we are just under two years since the submittal of our recommendation]

IEPA also asked for CCR characterization. Joppa provided 6 CCR samples with analysis. The issue is that there are roughly 5 million cubic yards of CCR in Joppa West, so the ask would be:
Please provide further CCR solids sampling and analysis to include a minimum of 1 sample location per 10% of the total cubic yards of CCR, ~~and~~ with ~~one-third of the~~ 3 samples collected from each location: ~~must be~~ one (1) from the upper 1/3 of the CCR by depth from ground surface, ~~one-third collected~~ one (1) from the middle 1/3 of the CCR by depth from ground surface, and ~~one-third collected~~ one (1) from the bottom 1/3 of the CCR by depth from ground surface. This would 30 samples over the entire site. The SPLP analysis in accordance with SW846 using the lowest pH on site of 3.5. ~~the samples must be spread out as follows:~~

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: Wednesday, November 1, 2023 3:11 PM
To: Summers, Michael <Michael.Summers@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Joppa West Adjusted Standard Recommendation Meeting follow up

How about something like this:

1 sample per 10% of the volume with one-third of the samples being collected as follows:
upper 1/3 of the CCR by depth from ground surface,
middle 1/3 of the CCR by depth from ground surface, and
bottom 1/3 of the CCR by depth from ground surface.

From: Summers, Michael <Michael.Summers@Illinois.gov>
Sent: Wednesday, November 1, 2023 2:43 PM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Joppa West Adjusted Standard Recommendation Meeting follow up

Do we have an rational for 50,000 cubic yards? If its 5 million cubic yards and one sample per 50,000 would equal 100 samples. is this an amount we want to look at?

When using a volume are we likely to run into a “disagreement” with the site on how actual large the site is? Would it be more appropriate to base sample on the surface area of the site. Or since we do have volumes (ie depth estimates) we could do a percentage of the entire volume. It is easily quantifiable, no argument on the size of the facility. Something like a shallow, mid-point and deep (3) samples collected per acre? 3 Per every 5 acres of surface area? take a look at what is a reasonable number of samples to characterize the site.

If we to end up asking for a set number of samples, we still need to make sure that various depth are mentioned in the request for samples to adequately characterize the site.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, November 1, 2023 11:54 AM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: RE: Joppa West Adjusted Standard Recommendation Meeting follow up

For the attorneys I would break this out more like this:

As filed, the Recommendation allows a 6-year temp. AS to allow sampling (5 years) and modeling/reporting (1 year) to prove monitored natural attenuation (MNA) will work.
USEPA has been very non-receptive to MNA demonstrations at other sites around the country.

Therefore, IEPA needs to amend the Rec to withdraw the Alt Standard suggested or not amend in which case Joppa maybe subject to USEPA enforcement. (Note: This was where the upper management decision came in, considering our goal to get primacy)

IEPA also asked for source monitoring, Joppa did install and has been doing total metals monitoring, but is not done yet, so the ask would be:
Please provide the groundwater sampling and analysis results for total metals at site wells listed in the Attachment B from Ramboll and Associates dated December 19, 2022 for 8 quarters of groundwater sampling along with the precipitation, infiltration and leaching analysis. [Note: unlikely that they have completed this at this time since we are just under two years since the submittal of our recommendation]

IEPA also asked for CCR characterization. Joppa provided 6 CCR samples with analysis. The issue is that there are roughly 5 million cubic yards of CCR in Joppa West, so the ask would be:
Please provide further CCR solids sampling and analysis to include a minimum of 1 sample per 50,000? cubic yards of CCR and SPLP analysis in accordance with SW846 using the lowest pH on site of 3.5. [Note: Mike I'll let you weigh in on volume of CCR per sample that is appropriate.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Wednesday, November 1, 2023 11:31 AM
To: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>; Summers, Michael <Michael.Summers@Illinois.gov>
Cc: Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>
Subject: Joppa West Adjusted Standard Recommendation Meeting follow up

Hi Mike and Lynn.
Please review the following for Sara and Stefanie:

1. Please provide the groundwater sampling and analysis results for total metals at site wells listed in the Attachment B from Ramboll and Associates dated December 19, 2022 for 8 quarters of groundwater sampling along with the precipitation, infiltration and leaching analysis. [unlikely that they have completed this at this time since we are just under two years since the submittal of our recommendation].
2. Please provide further CCR solids sampling and analysis to include a minimum of 1 sample per 50,000? cubic yards of CCR and SPLP analysis in accordance with SW846 using the lowest pH on site of 3.5. [Current status is 6 total samples for approximately 5 million cubic yards (or 103.5 acres and 30 feet deep).]

Please note: EEI shows that the hydraulic conductivities are downward from the CCR unit through the UCU (Upper confining unit) into the Upper Aquifer (UA). Total solids CCR samples show that the CCR contains all of the constituents in 845.600 whereas the surrounding formations do not contain some of those and generally contain less of the 845.600 constituents than the CCR where present.

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.

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 22

Strauss, Rebecca Y.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, November 1, 2023 3:40 PM
To: Diers, Stefanie; Terranova, Sara
Cc: Summers, Michael; Hunt, Lauren; Bierwagen, Justin; Mullenax, Heather; Garee, Matthew J.; Sofat, Sanjay
Subject: Joppa AS

Mike and I have both reviewed this and Mike asked me to send this along to you.

As filed, the Recommendation allows a 6-year temp. AS to allow sampling (5 years) and modeling/reporting (1 year) to prove monitored natural attenuation (MNA) will work.
USEPA has been very non-receptive to MNA demonstrations at other sites around the country.
Therefore, IEPA needs to amend the Rec to withdraw the Alt Standard suggested or not amend in which case Joppa maybe subject to USEPA enforcement. (Note: This was where the upper management decision came in, considering our goal to get primacy)

IEPA also asked for source monitoring, Joppa did install and has been doing total metals monitoring, but is not done yet, so the ask would be:
Please provide the groundwater sampling and analysis results for total metals at site wells listed in the Attachment B from Ramboll and Associates dated December 19, 2022 for 8 quarters of groundwater sampling along with the precipitation, infiltration and leaching analysis. [Note: unlikely that they have completed this at this time since we are just under two years since the submittal of our recommendation]

IEPA also asked for CCR characterization. Joppa provided 6 CCR samples with analysis. The issue is that there are roughly 5 million cubic yards of CCR in Joppa West, so the ask would be:
Please provide further CCR solids sampling and analysis to include a minimum of 1 sample location per 10% of the total cubic yards of CCR, with 3 samples collected from each location: one (1) from the upper 1/3 of the CCR by depth from ground surface, one (1) from the middle 1/3 of the CCR by depth from ground surface, and one (1) from the bottom 1/3 of the CCR by depth from ground surface. This would 30 samples over the entire Joppa West site. The SPLP analysis in accordance with SW846 using the lowest pH on site of 3.5.

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 23

Rees, Jeromy

From: Diers, Stefanie
Sent: Thursday, November 2, 2023 7:52 AM
To: Dunaway, Lynn; Terranova, Sara
Cc: Summers, Michael; Hunt, Lauren; Bierwagen, Justin; Mullenax, Heather; Garee, Matthew J.; Sofat, Sanjay
Subject: RE: Joppa AS

Thanks. Sara and I will review and follow up with questions we have.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Wednesday, November 1, 2023 3:40 PM
To: Diers, Stefanie <Stefanie.Diers@Illinois.gov>; Terranova, Sara <Sara.Terranova@Illinois.gov>
Cc: Summers, Michael <Michael.Summers@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Bierwagen, Justin <Justin.Bierwagen@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Garee, Matthew J. <Matthew.Garee@Illinois.gov>; Sofat, Sanjay <Sanjay.Sofat@Illinois.gov>
Subject: Joppa AS

Mike and I have both reviewed this and Mike asked me to send this along to you.

As filed, the Recommendation allows a 6-year temp. AS to allow sampling (5 years) and modeling/reporting (1 year) to prove monitored natural attenuation (MNA) will work.
USEPA has been very non-receptive to MNA demonstrations at other sites around the country.
Therefore, IEPA needs to amend the Rec to withdraw the Alt Standard suggested or not amend in which case Joppa maybe subject to USEPA enforcement. (Note: This was where the upper management decision came in, considering our goal to get primacy)

IEPA also asked for source monitoring, Joppa did install and has been doing total metals monitoring, but is not done yet, so the ask would be:
Please provide the groundwater sampling and analysis results for total metals at site wells listed in the Attachment B from Ramboll and Associates dated December 19, 2022 for 8 quarters of groundwater sampling along with the precipitation, infiltration and leaching analysis. [Note: unlikely that they have completed this at this time since we are just under two years since the submittal of our recommendation]

IEPA also asked for CCR characterization. Joppa provided 6 CCR samples with analysis. The issue is that there are roughly 5 million cubic yards of CCR in Joppa West, so the ask would be:
Please provide further CCR solids sampling and analysis to include a minimum of 1 sample location per 10% of the total cubic yards of CCR, with 3 samples collected from each location: one (1) from the upper 1/3 of the CCR by depth from ground surface, one (1) from the middle 1/3 of the CCR by depth from ground surface, and one (1) from the bottom 1/3 of the CCR by depth from ground surface. This would 30 samples over the entire Joppa West site. The SPLP analysis in accordance with SW846 using the lowest pH on site of 3.5.

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 24

Strauss, Rebecca Y.

From: Jenny Cassel <jcassel@earthjustice.org>
Sent: Monday, November 6, 2023 1:13 PM
To: lauren.hunt@illinois.gov; heather.mullenax@illinois.gov; Dunaway, Lynn
Cc: Faith Bugel; arehn; Mychal Ozaeta; Lauren Piette
Subject: [External] Environmental Groups' Comments on Joppa, Baldwin, and Newton ASDs
Attachments: FINAL 11.6.23 Earthjustice, PRN and SC comments on ASDs for Joppa, Newton, and Baldwin.pdf

Ms. Hunt, Ms. Mullenax, and Mr. Dunaway,

Please see attached comments from Earthjustice. Prairie Rivers Network, and Sierra Club on proposed Alternative Source Determinations (ASDs) for CCR surface impoundments at the Joppa, Newton, and Baldwin facilities. Please don't hesitate to reach out if you have any questions or would like to discuss further.

Thank you,
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

DOCUMENT 25

November 6, 2023

Lauren Hunt
Illinois Environmental Protection Agency
lauren.hunt@Illinois.gov

Heather Mullenax
Illinois Environmental Protection Agency
heather.mullenax@Illinois.gov

RE: Public Comments on Alternative Source Demonstrations for Joppa, Baldwin, and Newton CCR surface impoundments

Dear Ms. Hunt and Ms. Mullenax,

Pursuant to 35 I.A.C. § 845.650(e)(3), Earthjustice, Prairie Rivers Network, and Sierra Club (collectively, "Commenters") respectfully submit these public comments concerning the "alternative source demonstrations" submitted for the Joppa, Newton, and Baldwin facilities.

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).

Commenters cannot meaningfully comment on the ASD submissions because Illinois EPA has not yet, for any of these facilities, issued an operating permit that sets out an approved groundwater monitoring program. Without an approved groundwater monitoring program, the Agency likewise cannot make a supported decision that the purported "demonstration" in fact establishes that the impoundment has not contributed to the contamination. Accordingly, the Agency should deny the ASDs.

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[1] – 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, among other things, full compliance with the CCR rule at the entire facility where the CCR surface impoundment is located.[2] As of this writing, USEPA has issued thirteen proposed decisions on Part A applications, one of which it finalized.[3] It evaluated compliance with the groundwater monitoring mandates of the CCR rule at eight of those facilities.[4]

At *every* site that USEPA reviewed as part of its Part A evaluations, 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.[5]

- 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.[6]

[1] *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).
[2] 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).
[3] *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).
[4] *See id*. (noting proposed decisions, including complete and incomplete or ineligible applications).
[5] *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.
[6] *See* proposed Waukegan Part A decision at 31-47, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2023-0209-0001.

- 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.[7]

- 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.[8]

- 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.[9]

- 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.[10]

USEPA has likewise identified severe deficiencies in the groundwater monitoring programs at multiple CCR facilities in Alabama[11] and at one facility in Kansas to which it sent a letter summarizing conversations regarding compliance concerns.[12] 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 groundwater monitoring programs for Joppa, Baldwin, and Newton, **ASDs for those sites should be denied**.

Commenters reserve the right to provide additional comment on these or any other ASDs for Joppa, Newton, or Baldwin once approved groundwater monitoring systems, set out in IEPA-approved operating permits, are in place.

---

[7] *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;

[8] *See* proposed A.B. Brown Part A decision at 31-47, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2022-0335-0001.

[9] *See* proposed Mountaineer Part A decision at 33-48, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2021-0842-0001.

[10] See proposed Calaveras Part A decision at 47-55, available at https://www.regulations.gov/document/EPA-HQ-OLEM-2022-0333-0001.

[11] 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).

[12] USEPA, Letter re: Notice of Potential Violations/Opportunity to Confer, Tecumseh Energy Center, Tecumseh, Kansas, Enclosure 1 at 1-4 (Jan. 2021), attached hereto.

Thank you kindly for taking these comments into consideration.

Best,

Jennifer Cassel
Mychal Ozaeta
Lauren Piette
jcassel@earthjustice.org
mozaeta@earthjustice.org
lpiette@earthjustice.org

On behalf of Earthjustice

Andrew Rehn
arehn@prairierivers.org

Prairie Rivers Network

Faith Bugel
fbugel@gmail.com

On behalf of Sierra Club

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)

Printed on Recycled Paper

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 26

Strauss, Rebecca Y.

From: Seif, Josiah <Josiah.Seif@Illinois.gov>
Sent: Monday, November 6, 2023 2:49 PM
To: Hunt, Lauren; MacDonna, Keegan; Mullenax, Heather; Bierwagen, Justin; Garee, Matthew J.
Cc: Summers, Michael; Dunaway, Lynn; LeCrone, Darin
Subject: Joppa Power Plant notification letter-Exceedance of Boron in Groundwater

Hard copy of the **Joppa Power Plant notification letter-Exceedance of Boron in Groundwater** has been received and placed in the Impoundment. The electronic version was received last week and placed on the N:Drive already. If you have any questions please let me know.

Thank you,

Josiah M. Seif
Josiah M. Seif
CCR Office Coordinator
Bureau of Water
Illinois Environmental Protection Agency
217-782-0610
Josiah.Seif@illinois.gov

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 27

Strauss, Rebecca Y.

From: Voelker, Brian <Brian.Voelker@vistracorp.com>
Sent: Monday, November 6, 2023 6:29 PM
To: EPA.CCR.Part845.Notify; EPA.CCR.Part845.Coordinator; Hunt, Lauren
Cc: Morris, Phil; Mitchell, David; More, Joshua; Fuller, Rhys; Modeer, Victor; Cravens, Stuart; Davies, Sam; Vodopivec, Cynthia
Subject: [External] RE: Alternate Source Demonstration - Joppa Power Plant
Attachments: Joppa ASD Nov 6 2023 Comment Letter.pdf

Lauren,
Electric Energy, Inc. is submitting the additional information (attached) as follow-up to communication with the agency regarding the ASD submitted for the Joppa Power Plant East Ash Pond on October 21, 2023.

The listserve notice was received on October 23, and this submittal is within the 14-day period allowed for written comments.

Let me know if you have issues opening the attachment.

Note: I tried sending this to the lauren.martin@epa.gov email address as listed on the listserv and received an undeliverable message stating that email address was not found.

Thanks,

Brian Voelker
Environmental Manager
(217) 412-6605
brian.voelker@vistrcorp.com

DOCUMENT 28

Luminant

Electric Energy, Inc.
1500 Eastport Plaza Drive
Collinsville, IL 62234

November 6, 2023

VIA E-MAIL
Lauren.Martin@epa.gov
EPA.CCR.PART845.COORDINATOR@ILLINOIS.GOV
EPA.CCR.Part845.Notify@Illinois.gov

Re: Alternative Source Demonstration ("ASD") for Joppa Power Plant East Ash Pond

To Whom It May Concern:

On October 21, 2023, Electric Energy, Inc. ("EEI") submitted an ASD for the Joppa Power Plant East Ash Pond ("Joppa EAP") to the Illinois Environmental Protection Agency ("IEPA") pursuant to 35 Ill. Admin. Code 845.650(e). On October 23, 2023, IEPA provided notice to its listserve regarding the posting of the ASD submittal, triggering a 14-day period for written comments on the ASD submittal pursuant to 35 Ill Admin. Code 845.650(e)(3). After submittal of the Joppa EAP ASD, EEI and IEPA engaged in communications regarding the Joppa EAP ASD submittal. EEI submits this letter and its attachments, within the 14-day period for written comments, to provide additional information to IEPA in response to those communications. As explained below and in the attached materials, EEI's October 21 ASD submittal was comprehensive in scope and used scientifically supported, industry standard methodologies.

IEPA requested certain additional data as part of its communications with EEI. While EEI does not agree that any additional data is necessary in support of the ASD submittal, EEI has compiled and is providing, as Attachment 1 to this letter, the hydraulic conductivity and boring log data requested by IEPA. No specific boring locations were referenced by IEPA in its request, therefore, boring logs for subject wells G05, G11, and G151/G51D and borings from which solid samples were collected (G03, G07, G08, G09M, and G11) have been included. Attachment 1 also includes hydraulic conductivity data referenced and provided in the October 2017 Hydrogeologic Monitoring Plan for the Joppa EAP. All of the information in Attachment 1 was previously provided or referenced in the Joppa EAP operating permit application and/or construction permit application. Additional site characterization data can also be found in the previously provided April 2023 supplemental site investigation report for the Joppa EAP. Because the supplemental site investigation report, operating permit application and construction permit application were used and relied upon in preparing the Joppa EAP ASD and all contain information IEPA has sought in connection with its review of the ASD, EEI (with this letter) is incorporating by reference the entirety of its April 2023 supplemental site investigation report, October 25, 2021 operating permit application and July 28, 2022 construction permit application for the Joppa EAP into its Joppa EAP ASD submittal.

In its communications with EEI, IEPA also requested (1) source characterization of CCR that includes total solids sampling, analysis and reporting in accordance with SW-846 leach testing methods and (2) sampling and analysis in accordance with 35 Ill. Admin. Code 845.640 of the alternative source. Collecting this information would be a considerable undertaking that EEI would not be able to complete prior to the decision deadline or within the comment period for the Joppa EAP ASD. Additionally, this information is not required by law and is unnecessary to support the Joppa EAP ASD. First, there is no requirement under Part 845 that source characterization of CCR be conducted in accordance with SW-846. While Part 845.150 incorporates by reference SW-846, that incorporation does not create an affirmative obligation to analyze all samples in accordance with SW-846. As set forth in Chapter 2 of SW-846, the methods are not "mandatory" unless specifically specified in the regulation. Groundwater samples taken under Part 845 are the only samples specifically required by Part 845 to be analyzed using SW-846. In particular, Part 845.640(e) requires groundwater samples taken under a groundwater monitoring program be analyzed in accordance with SW-846. Notably, samples collected under the Joppa EAP's groundwater monitoring program have been analyzed in accordance with SW-846 (and were otherwise collected and analyzed in accordance with 35 Ill. Admin. Code 845.640). Attachment 2 to this letter explains how CCR source characterization was conducted for the Joppa EAP ASD and explains why the methodology used is more appropriate than SW-846 leach testing methods for characterizing the source material.

Second, there is no requirement under 35 Ill Admin. Code 845.640, 35 Ill. Admin. Code 845.650 or elsewhere in Part 845 to identify, sample or analyze an alternative source. Section 845.650(e), which governs alternative source demonstrations, simply requires a determination that a source other than the CCR surface impoundment caused the contamination and that the CCR surface impoundment did not contribute to the contamination. As described in Attachment 2, this demonstration is made through a multiple lines of evidence analysis in the Joppa EAP ASD submittal. The multiple lines of evidence analysis for the Joppa EAP ASD demonstrates, among other findings, that the cobalt contamination in well G05 is likely from naturally occurring cobalt in soil and that pH exceedances in wells G11 and G51D are consistent with iron oxidization. However, identification and a full characterization of an alternative source is not required for the ASD or necessary to determine that a source other than the Joppa EAP caused the cobalt contamination in well G05 and pH contamination in wells G11 and G51D, and that the Joppa EAP did not contribute to that contamination.

Finally, given that this submittal responds to questions and requests raised by IEPA regarding the Joppa EAP ASD, EEI hereby incorporates this letter and its attachments (including the references set forth in those attachments) into its Joppa EAP submittal.

Should you have any questions regarding the information contained in this letter or its attachments, please feel free to reach out.

Sincerely,

Dianna Tickner

Dianna Tickner
Sr. Director – Decommission and Demolition

Attachments

ATTACHMENT 1
ADDITIONAL INFORMATION REQUESTED BY IEPA

FIELD HYDRAULIC CONDUCTIVITY TABLE AND SOFTWARE REPORTS

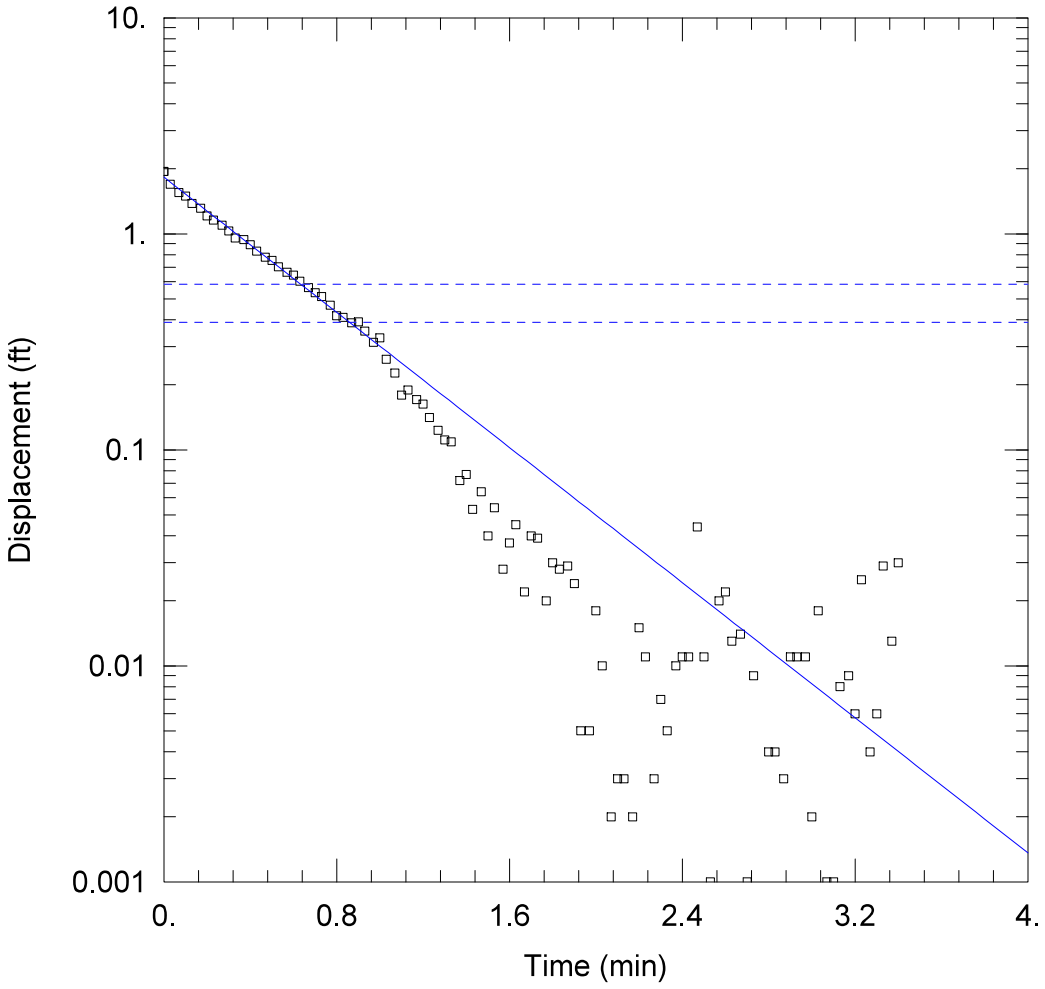
TABLE 3-3. FIELD HYDRAULIC CONDUCTIVITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
JOPPA POWER PLANT
EAST ASH POND
JOPPA, ILLINOIS

Well ID	Gradient Position	Bottom of Screen Elevation (ft NAVD88)	Screen Length [1] (ft)	Field Identified Screened Material	Slug Type	Analysis Method	Falling Head (Slug In) K (cm/s)			Rising Head (Slug Out) K (cm/s)			Average Hydraulic Conductivity (cm/s)	Minimum Hydraulic Conductivity (cm/s)	Maximum Hydraulic Conductivity (cm/s)	Hydraulic Conductivity Geometric Mean (cm/s)
							1	2	3	1	2	3				
Uppermost Aquifer																
G06	D	267.60	10.0	Gravely Silty Clay	Solid	Bouwer-Rice	1.20E-03	1.02E-03	---	1.03E-03	8.14E-04	---	1.02E-03	4.84E-04	1.18E-02	3.10E-03
G07	D	290.34	10.0	Sand	Solid	Bouwer-Rice	6.96E-03	1.18E-02	8.98E-03	8.22E-03	1.05E-02	1.02E-02	9.45E-03			
G08	D	256.72	10.0	Sand	Solid	Bouwer-Rice	5.51E-03	5.82E-03	---	2.92E-03	3.69E-03	---	4.49E-03			
G09	D	279.19	10.0	Sandy Gravel	Solid	Bouwer-Rice	2.62E-03	---	---	1.55E-03	---	---	2.08E-03			
G10	D	280.45	10.0	Sand and Sandy Gravel	Solid	Bouwer-Rice	1.36E-03	8.69E-04	---	4.84E-04	5.25E-04	---	8.08E-04			
G11	U	297.68	10.0	Sand	Solid	Bouwer-Rice	7.15E-03	6.36E-03	---	6.72E-03	7.23E-03	---	6.86E-03			
Lower Aquifer Unit																
G09M	D	193.60	10.0	Bedrock	Solid	Bouwer-Rice	2.73E-04	5.82E-04	---	3.78E-04	4.16E-04	---	4.12E-04	2.73E-04	5.82E-04	3.97E-04
CCR Fill																
XPW-02	NA	343.53	5.0	Ash	Solid	Bouwer-Rice	9.82E-03	9.25E-03	---	4.46E-03	5.39E-03	---	7.23E-03	4.46E-03	1.65E-01	1.29E-02
XPW-03	NA	341.95	5.0	Ash	Solid	Springer-Gelhar	---	---	---	1.65E-01	---	---	1.65E-01			

Notes:
[O: XXX MM/DD/YY; U: CJC 08/24/21; C: LDC 08/30/21]
[1] All wells are constructed from 2 inch PVC with 0.01 inch slotted screens.
--- = Test not analyzed/performed
CCR = coal combustion residuals
cm/s = centimeters per second
D = downgradient
ft = foot/feet
NA = Not Applicable
NAVD88 = North American Vertical Datum of 1988
U = upgradient

RAMBOLL

R001691



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:36:29

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

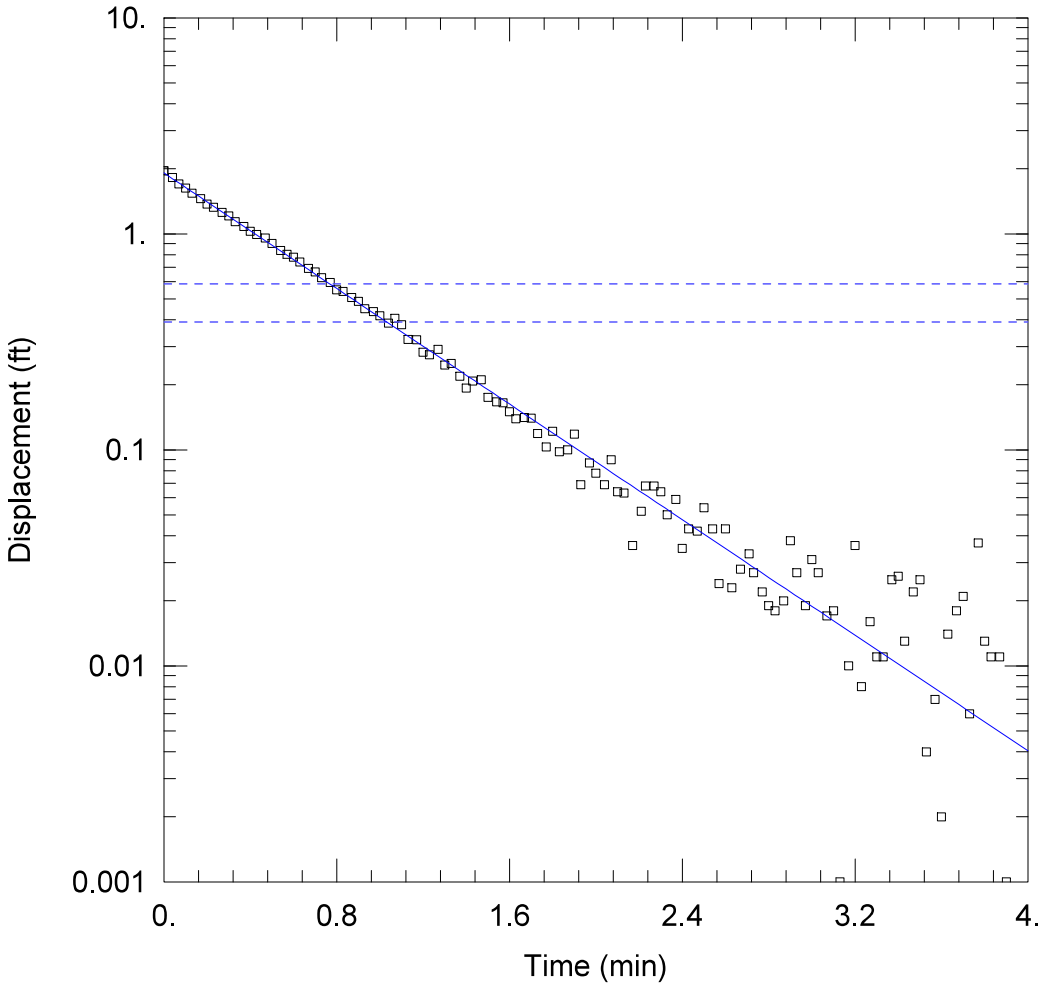
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 1 slug in))

Initial Displacement: 1.945 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001199 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.829 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:37:34

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

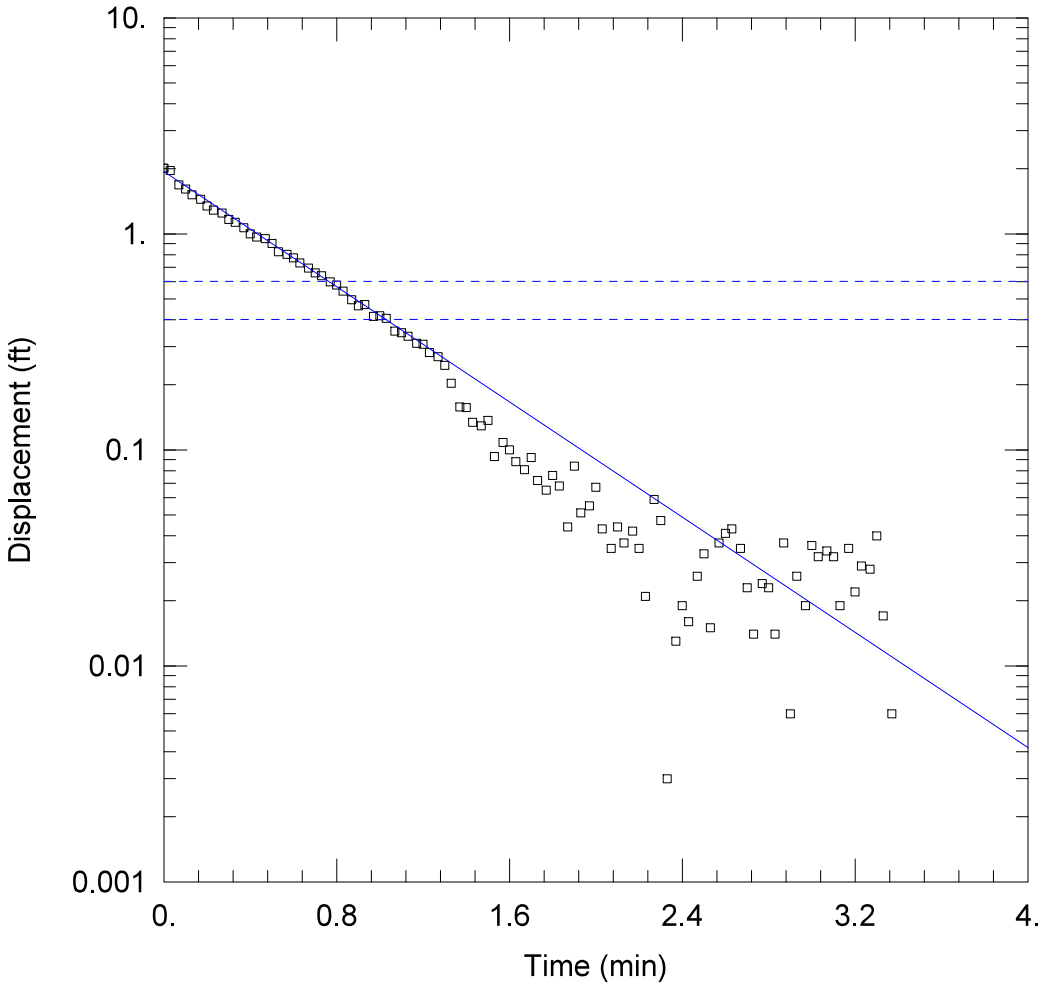
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 2 slug out))

Initial Displacement: 1.956 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001025 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.915 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:38:16

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

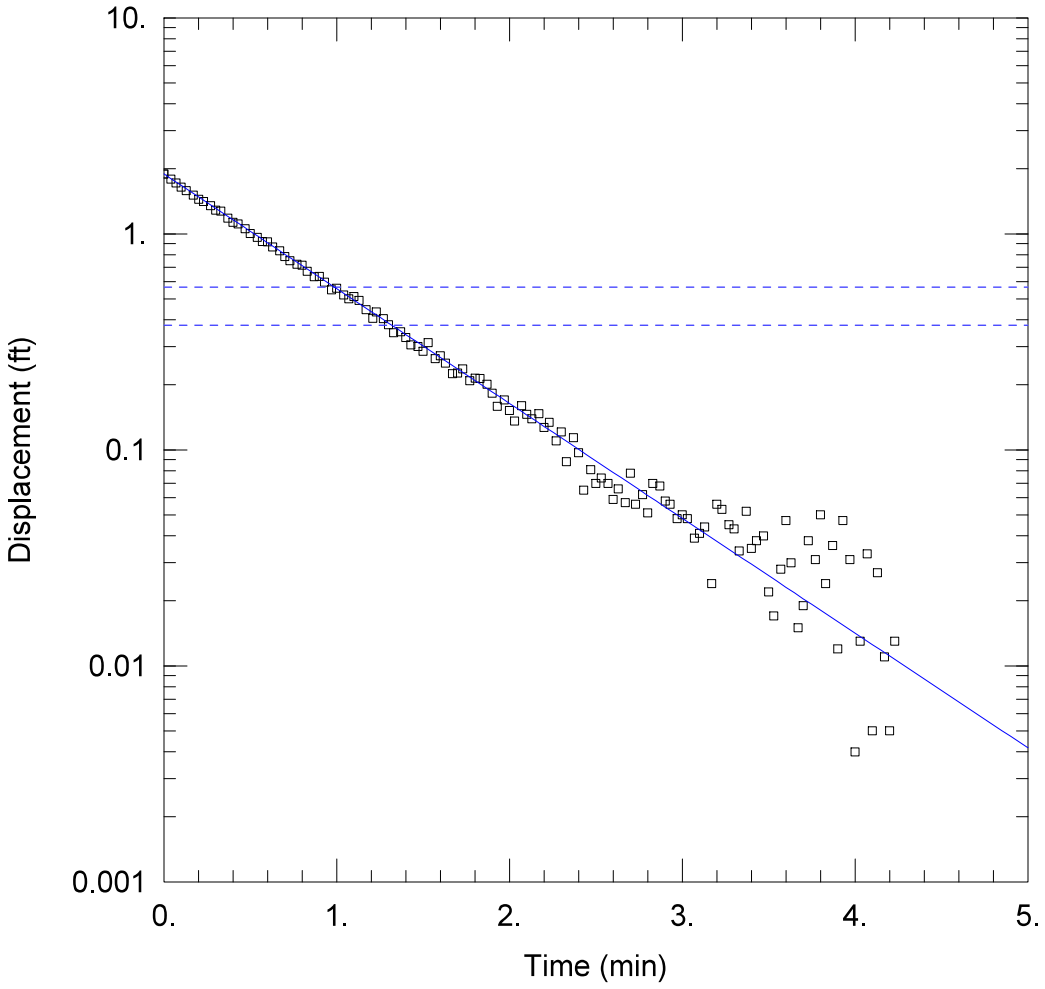
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 3 slug in))

Initial Displacement: 2.01 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.001022 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.941 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-06 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:38:53

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-06

AQUIFER DATA

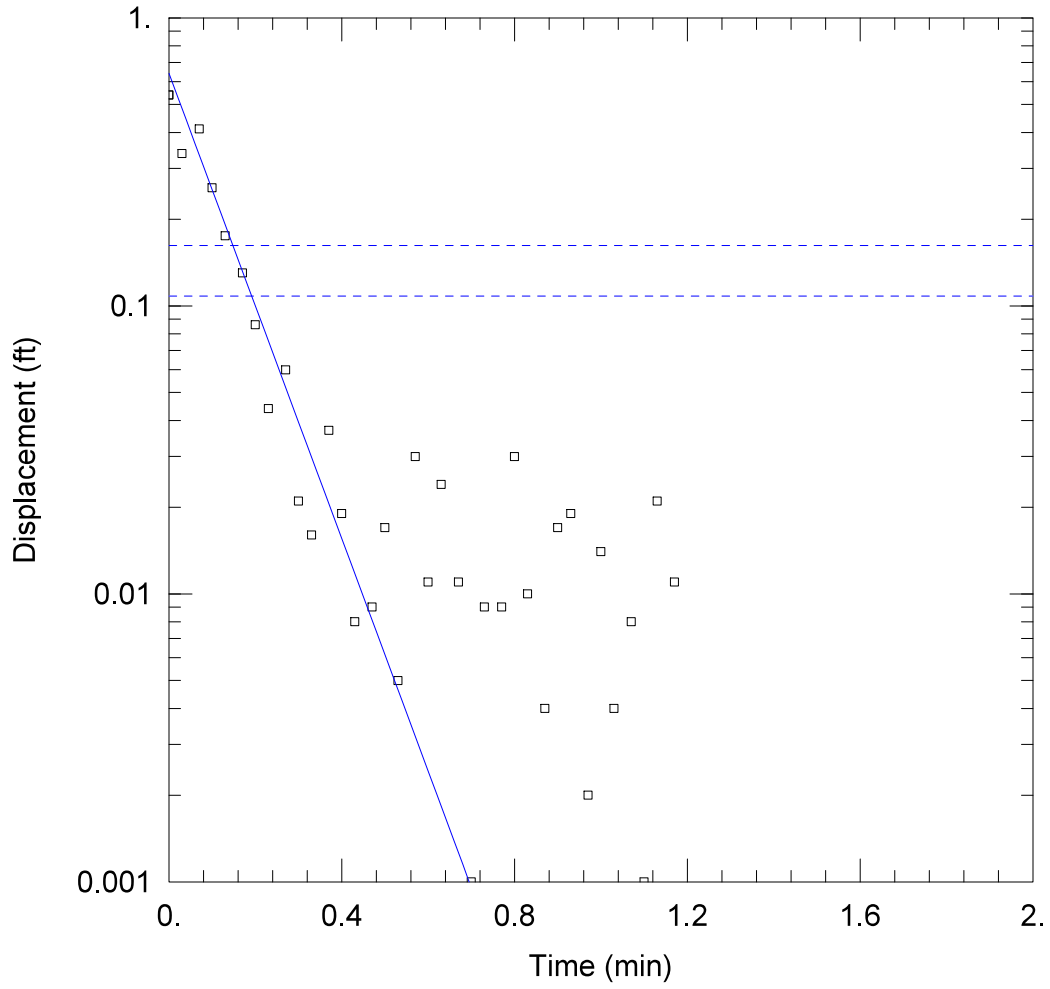
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-06 (test 4 slug out))

Initial Displacement: 1.89 ft
Total Well Penetration Depth: 52.85 ft
Casing Radius: 0.083 ft
Static Water Column Height: 52.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.0008143 cm/sec
Solution Method: Bouwer-Rice
y0 = 1.895 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:41:12

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

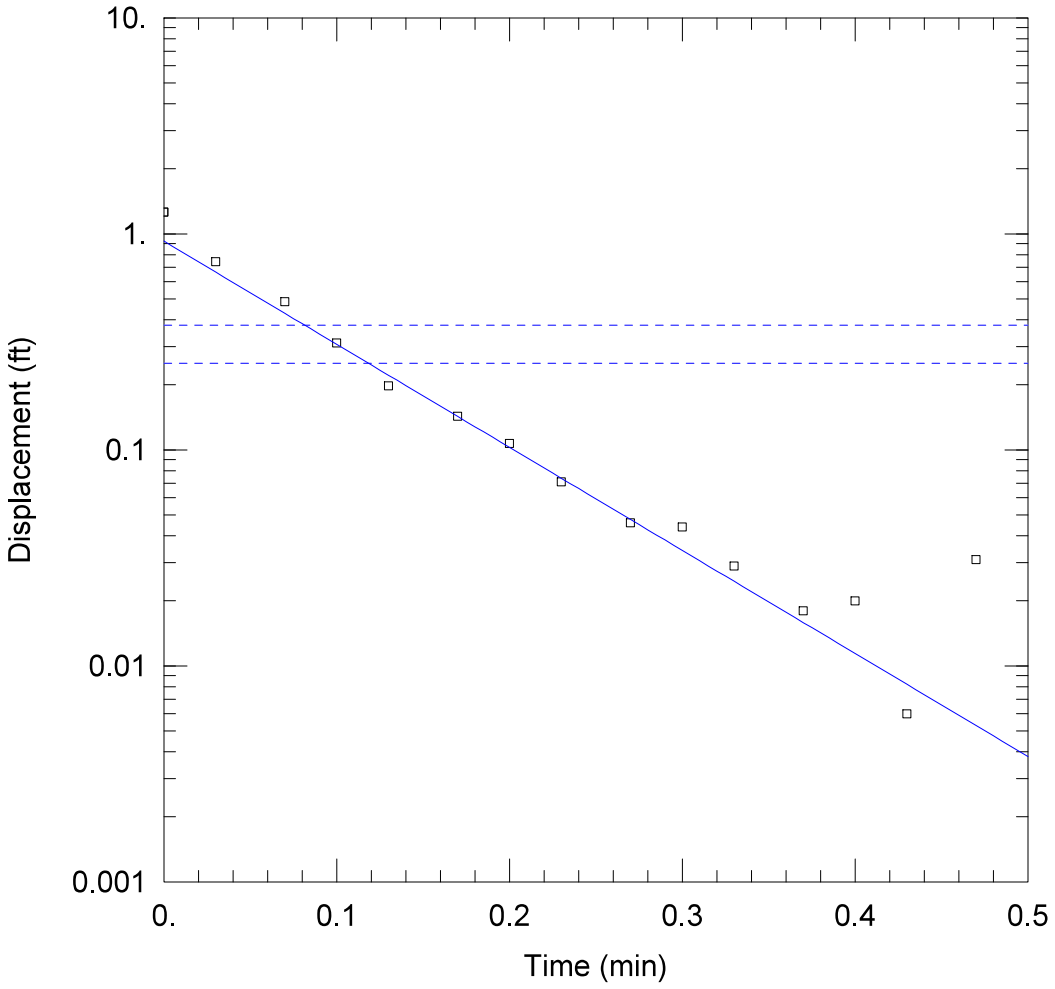
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 1 slug in))

Initial Displacement: 0.54 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006959 cm/sec
y0 = 0.6416 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:41:51

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: G-07

AQUIFER DATA

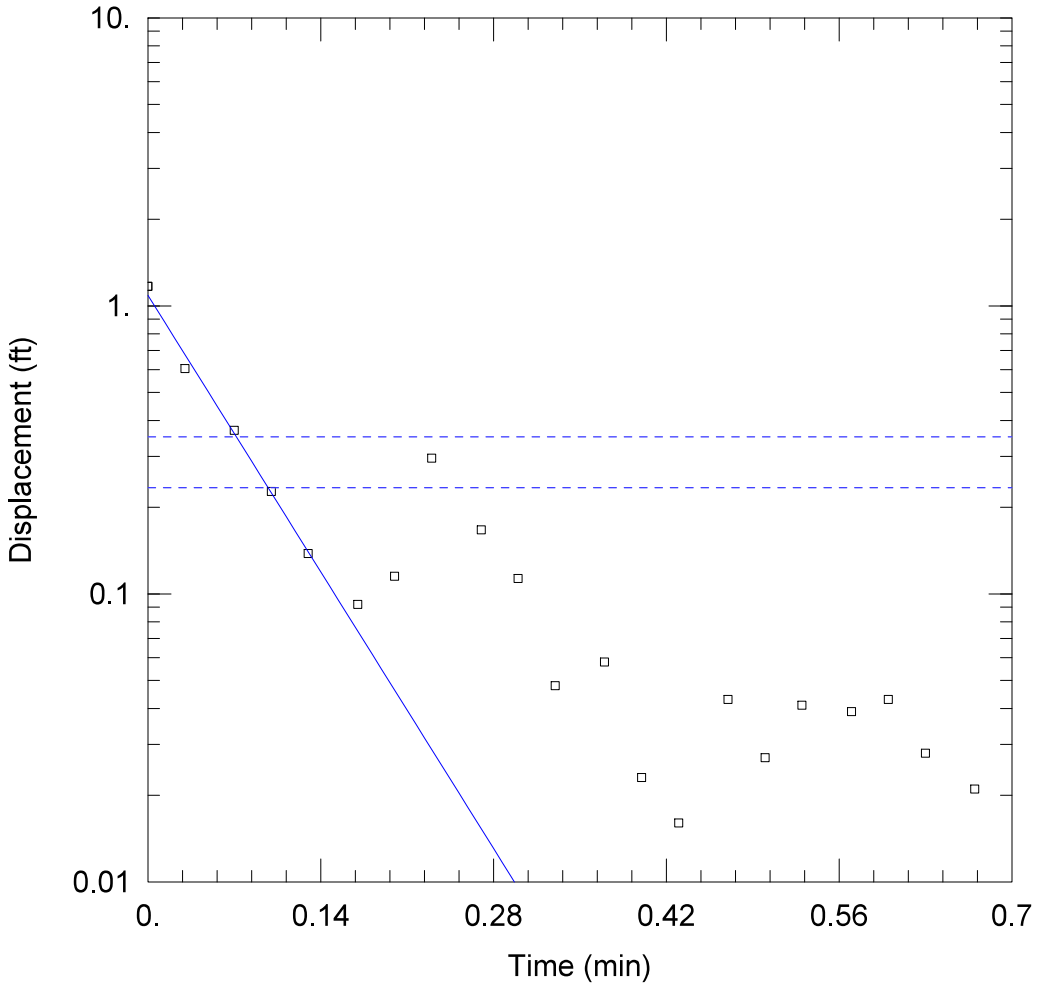
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 2 slug-out))

Initial Displacement: 1.26 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.008223 cm/sec
y0 = 0.9246 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:42:56

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: G-07

AQUIFER DATA

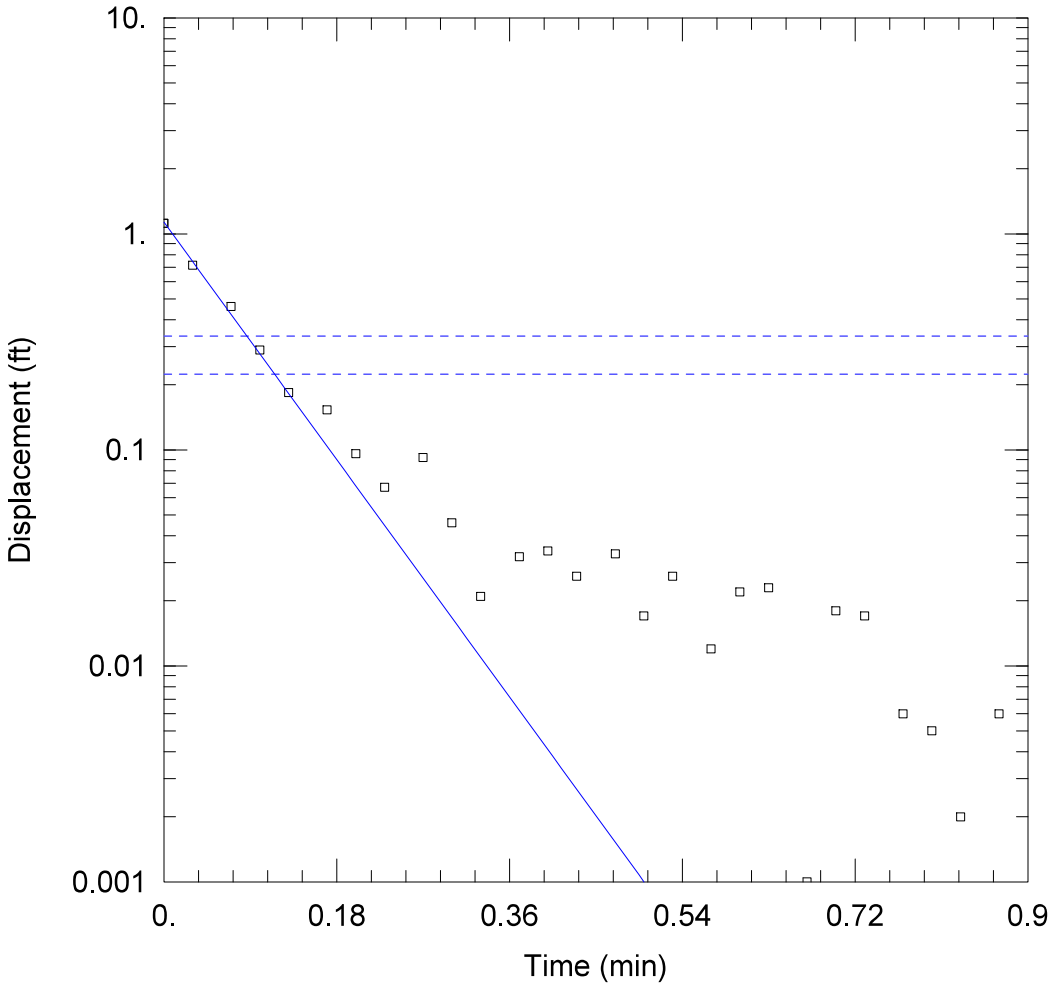
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 3 slug-in))

Initial Displacement: 1.168 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01182 cm/sec
y0 = 1.087 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:43:39

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

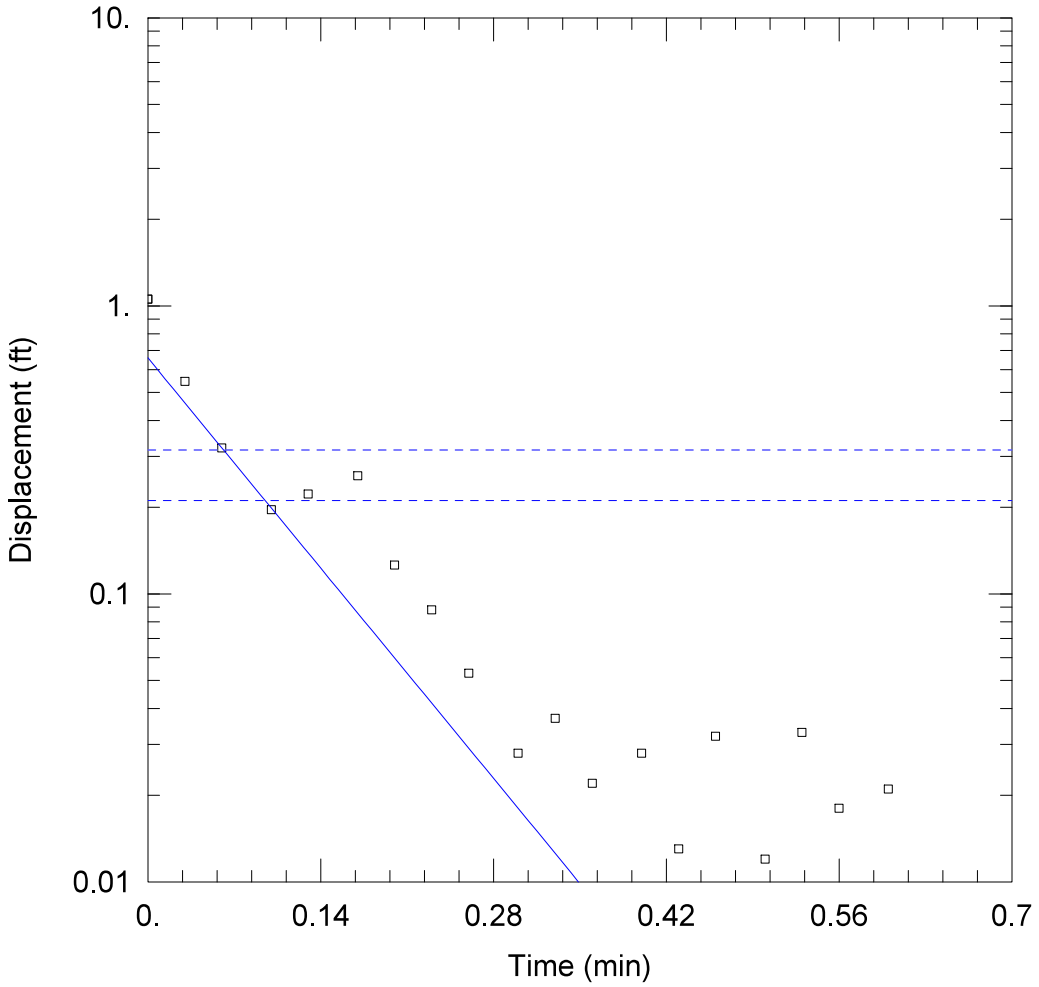
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 4 slug-out))

Initial Displacement: 1.119 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01052 cm/sec
y0 = 1.132 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 5 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:44:38

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

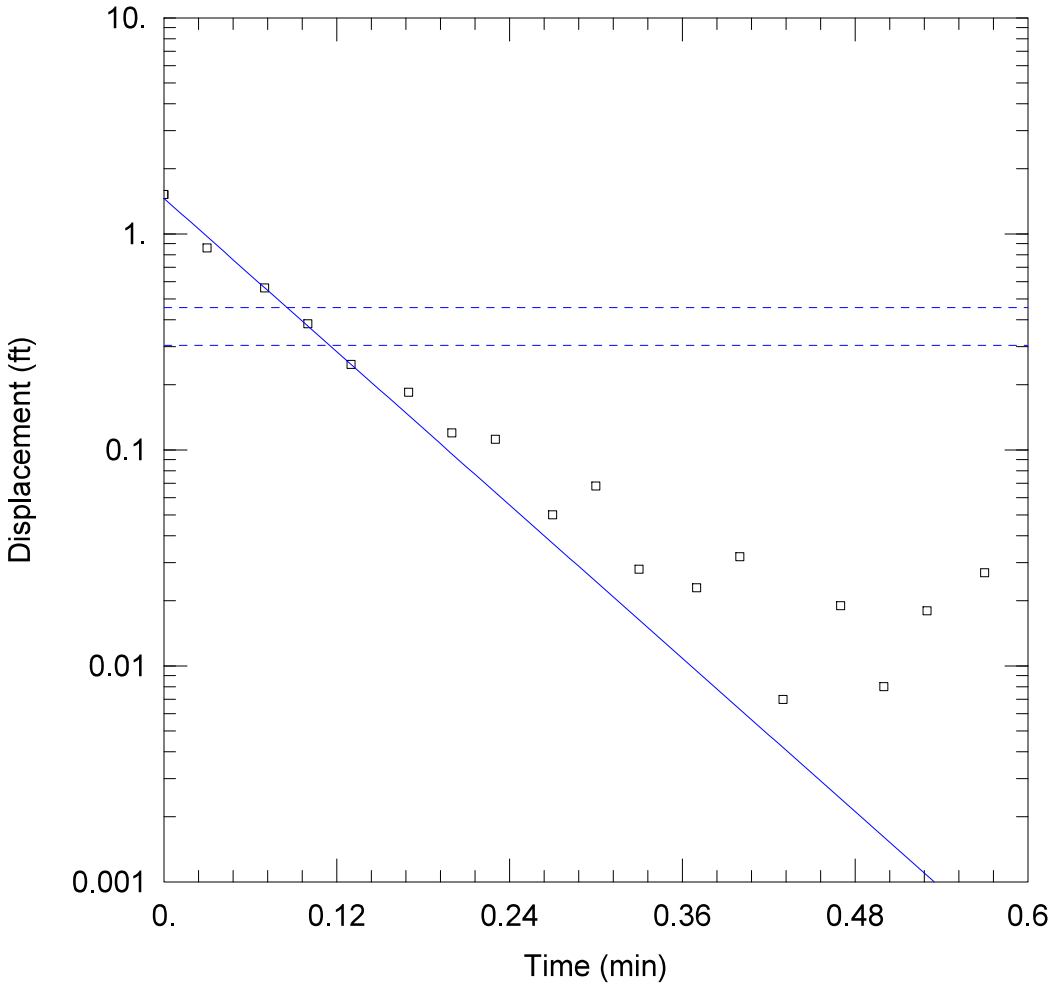
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 5 slug-out))

Initial Displacement: 1.054 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
K = 0.008984 cm/sec
Solution Method: Bouwer-Rice
y0 = 0.6591 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G-07 test 6 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:45:44

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa
Test Well: G-07

AQUIFER DATA

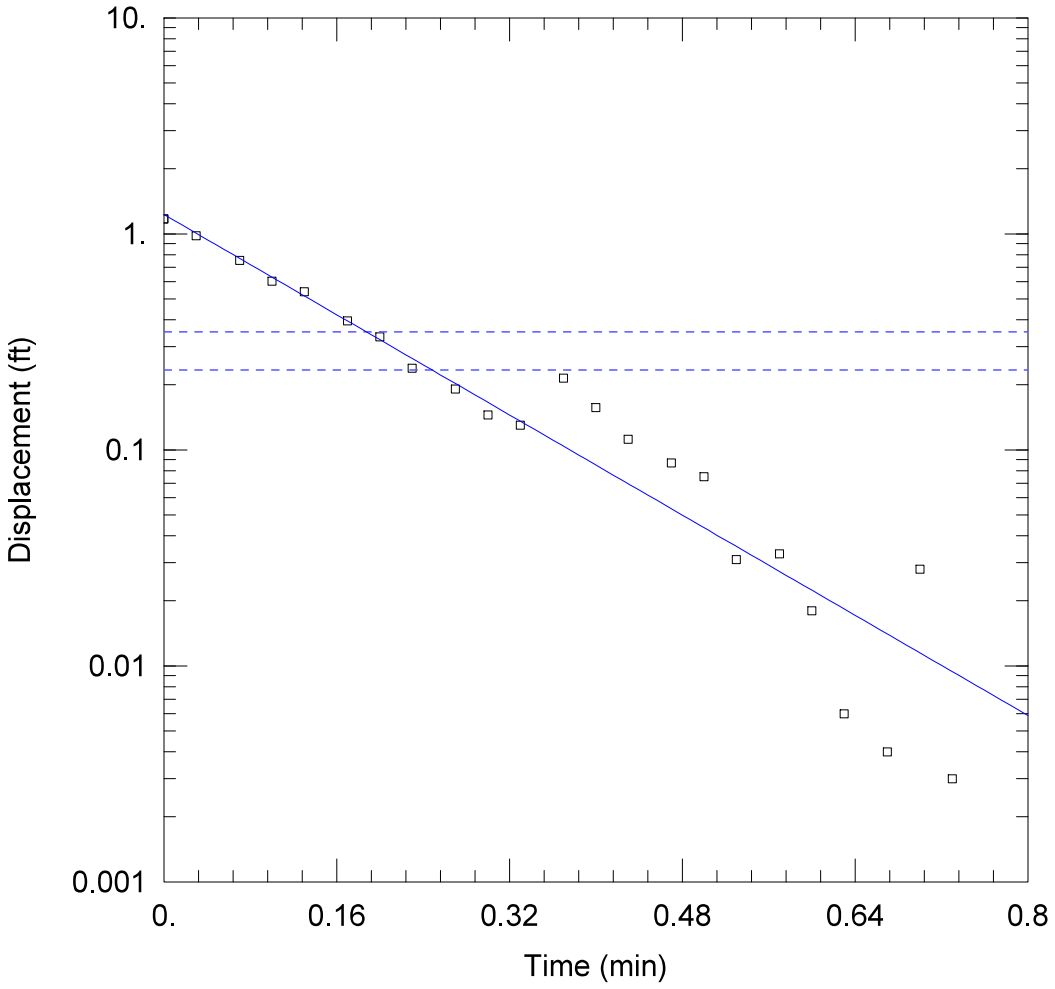
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-07 (test 6 slug-out))

Initial Displacement: 1.521 ft
Total Well Penetration Depth: 23.39 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.39 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.01019 cm/sec
y0 = 1.46 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 16:26:39

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

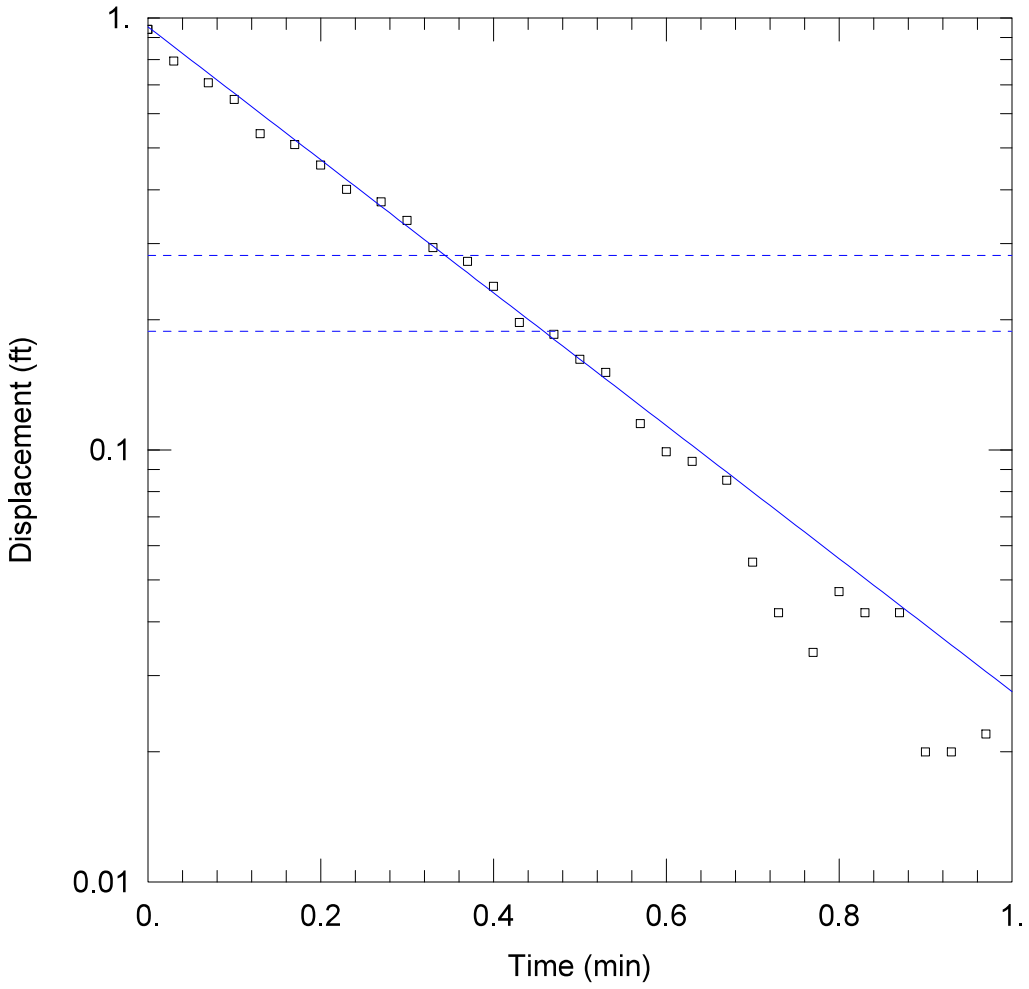
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 1 slug-in))

Initial Displacement: 1.17 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.005507 cm/sec
y0 = 1.229 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 16:29:24

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

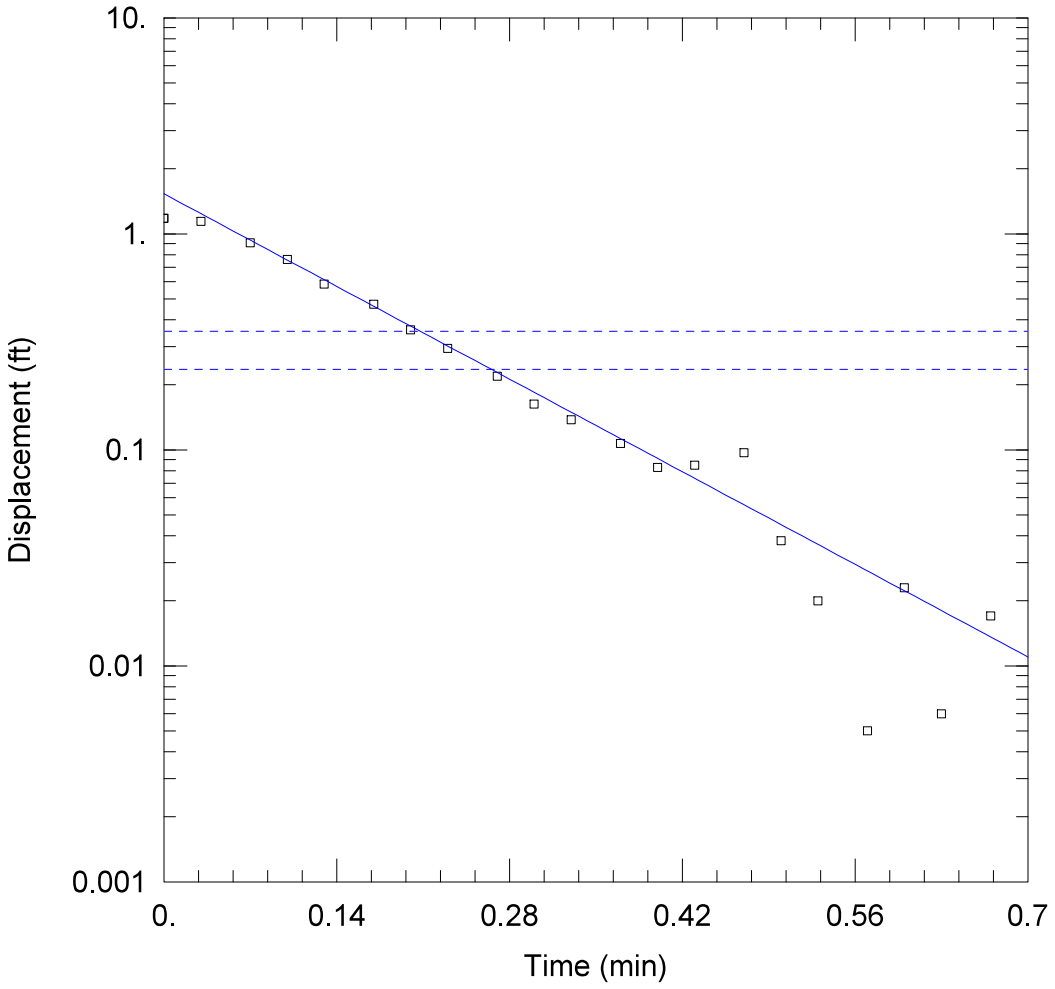
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 2 slug-out))

Initial Displacement: 0.94 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.002923 cm/sec
y0 = 0.953 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 16:31:33

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

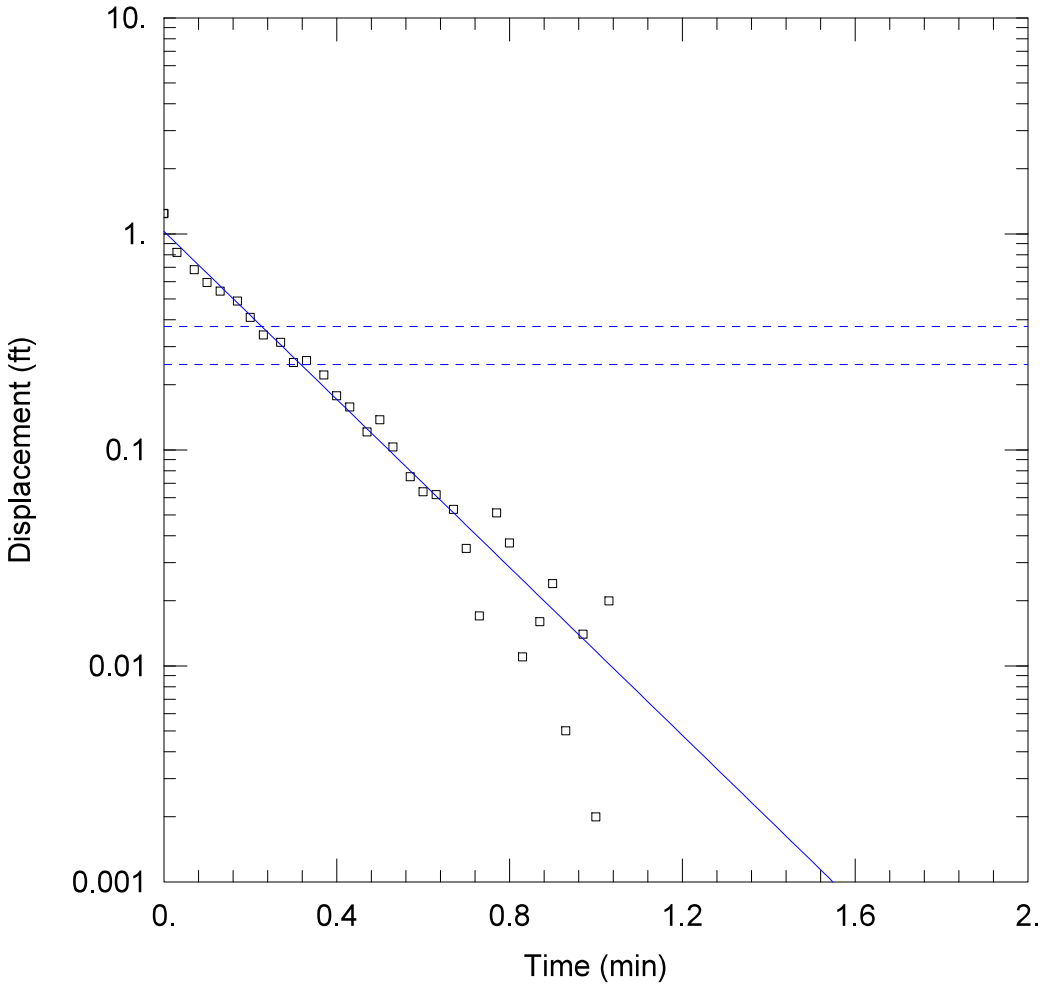
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 2 slug-out))

Initial Displacement: 1.18 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.005818 cm/sec
y0 = 1.532 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-8 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 16:33:50

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-8

AQUIFER DATA

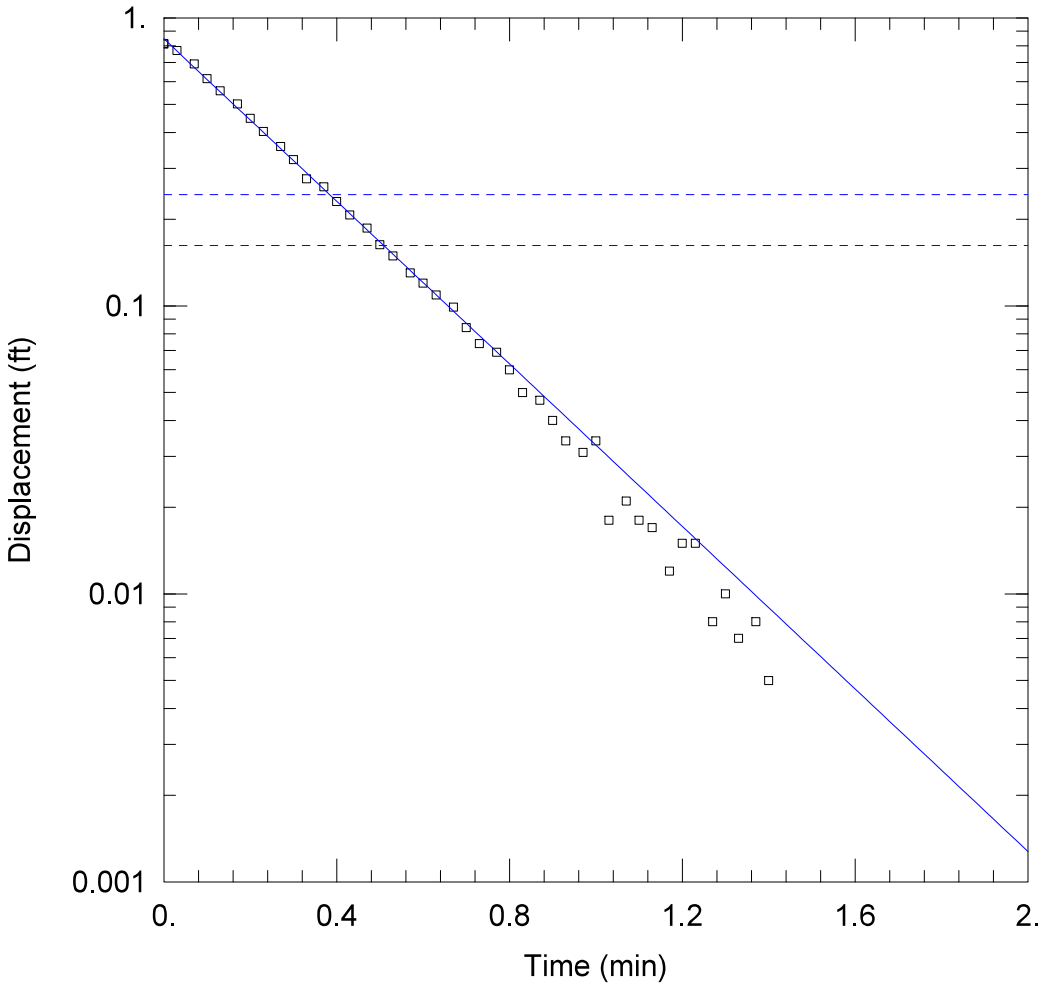
Saturated Thickness: 48. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-8 (test 4 slug-out))

Initial Displacement: 1.24 ft
Total Well Penetration Depth: 48. ft
Casing Radius: 0.083 ft
Static Water Column Height: 60.85 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.003693 cm/sec
y0 = 1.026 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-9 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:43:53

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-9

AQUIFER DATA

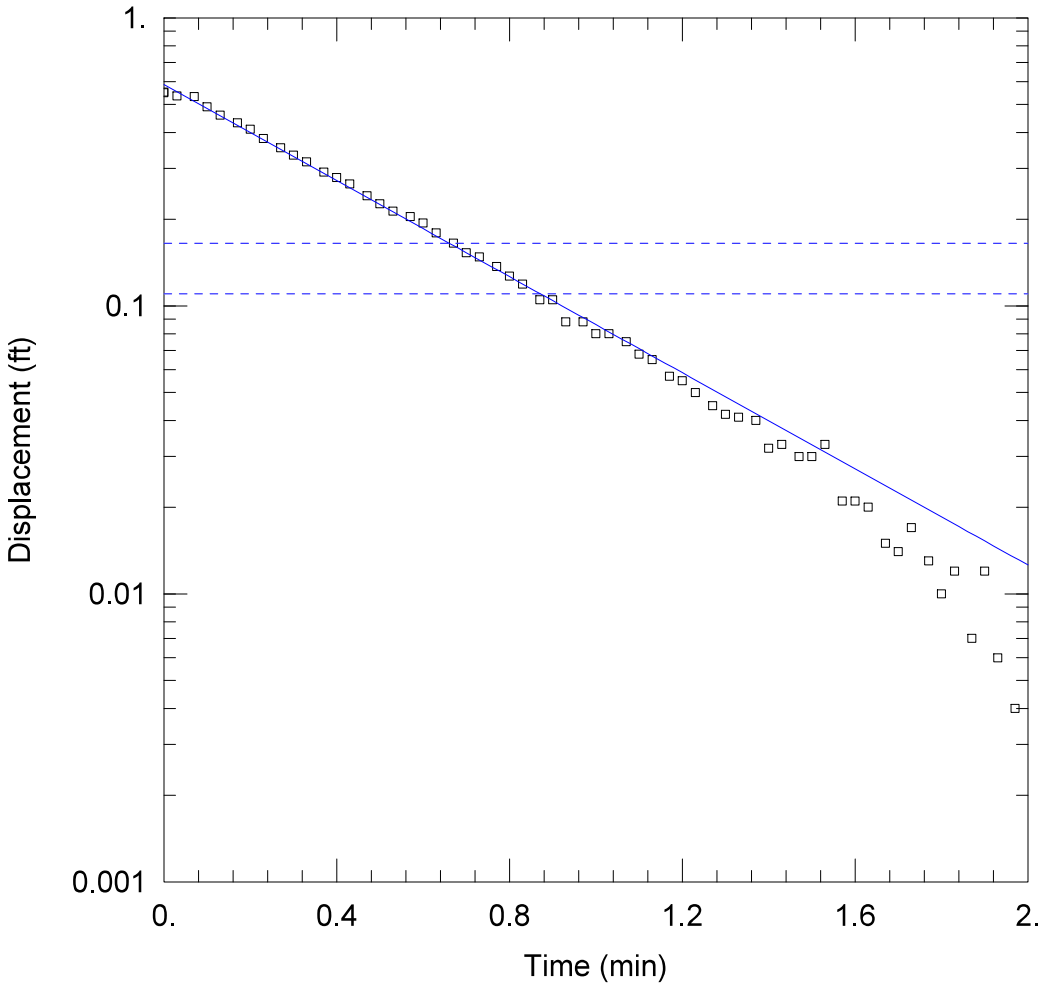
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-9 (test 1 slug-in))

Initial Displacement: 0.81 ft
Total Well Penetration Depth: 40.03 ft
Casing Radius: 0.083 ft
Static Water Column Height: 40.03 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.002618 cm/sec
y0 = 0.8457 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-9 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:46:36

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-9

AQUIFER DATA

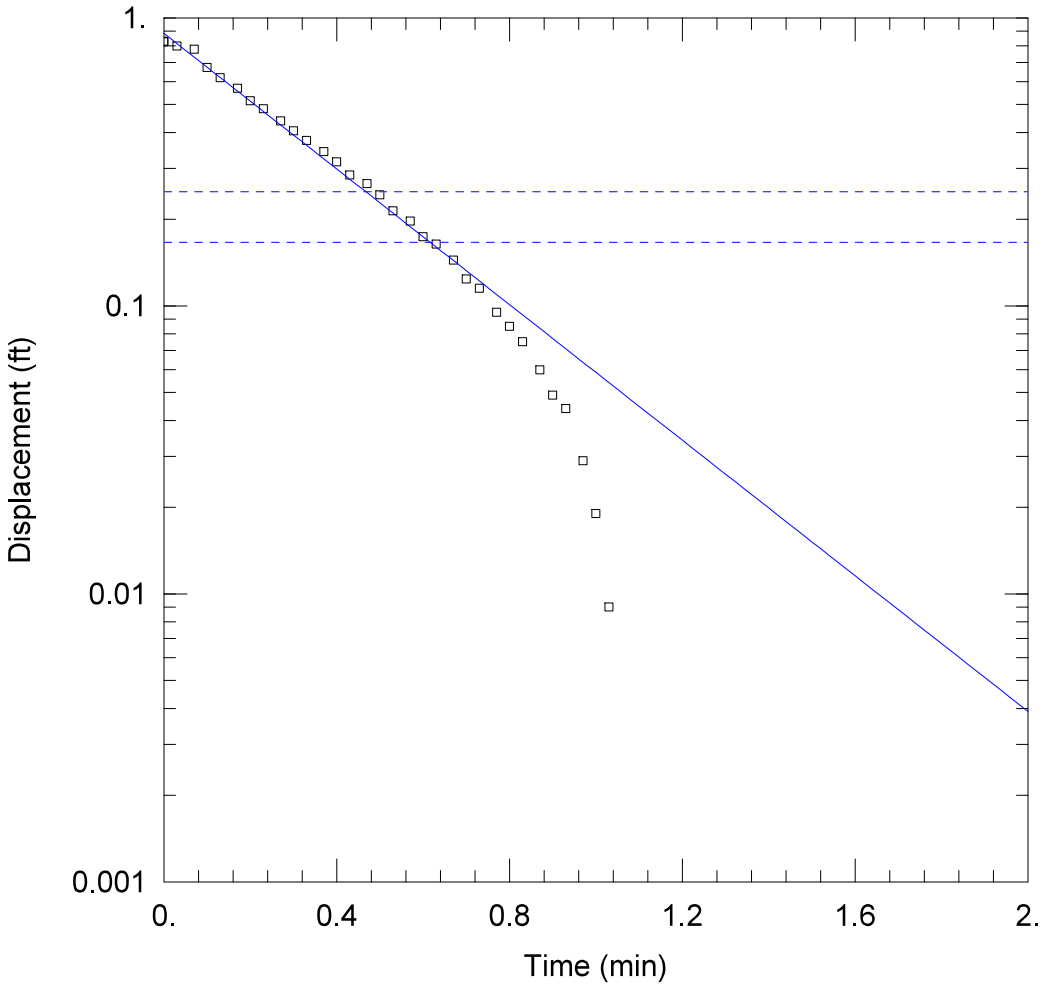
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-9 (test 2 slug-out))

Initial Displacement: 0.55 ft
Total Well Penetration Depth: 40.03 ft
Casing Radius: 0.083 ft
Static Water Column Height: 40.03 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.001548 cm/sec
y0 = 0.5873 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:40:34

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

Saturated Thickness: 10. ft Anisotropy Ratio (Kz/Kr): 0.1

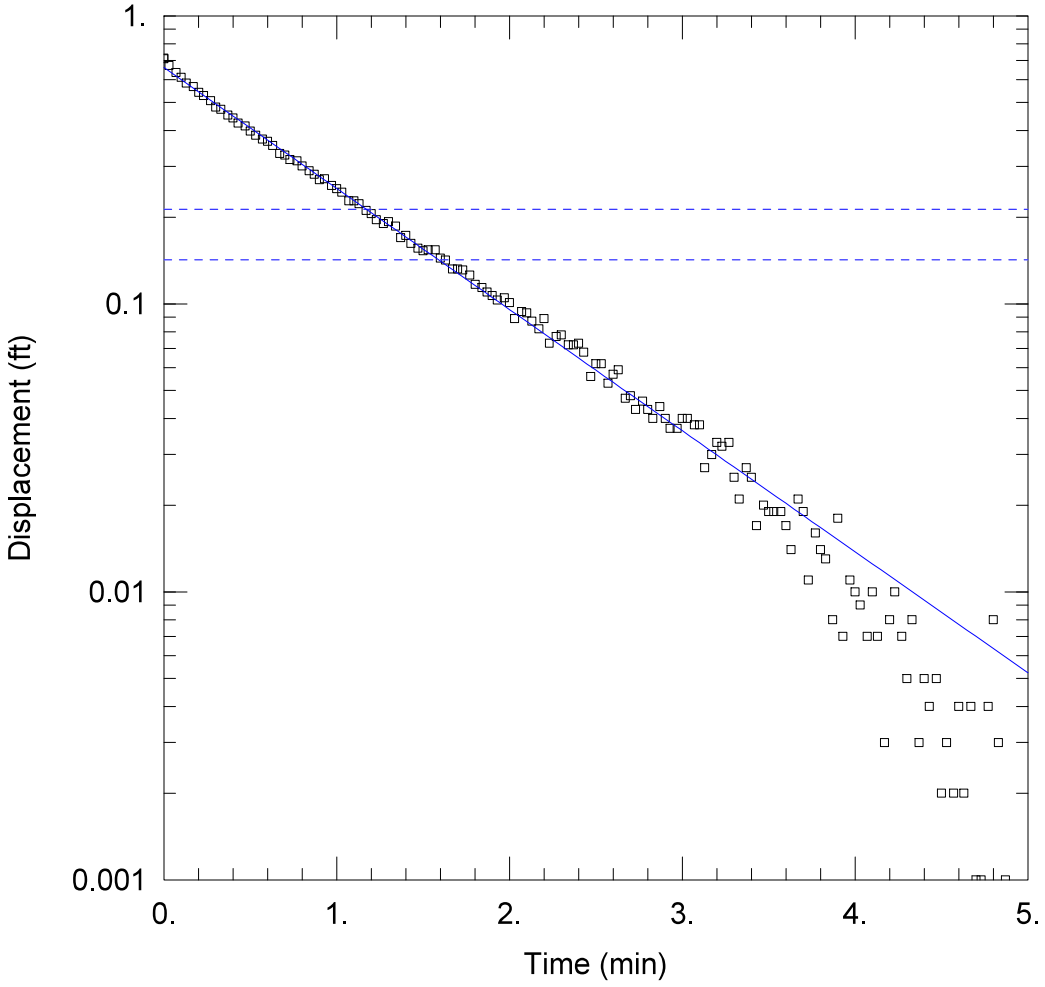
WELL DATA (G-10 (test 1 slug-in))

Initial Displacement: 0.83 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 0.001355 cm/sec y0 = 0.8835 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:42:40

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

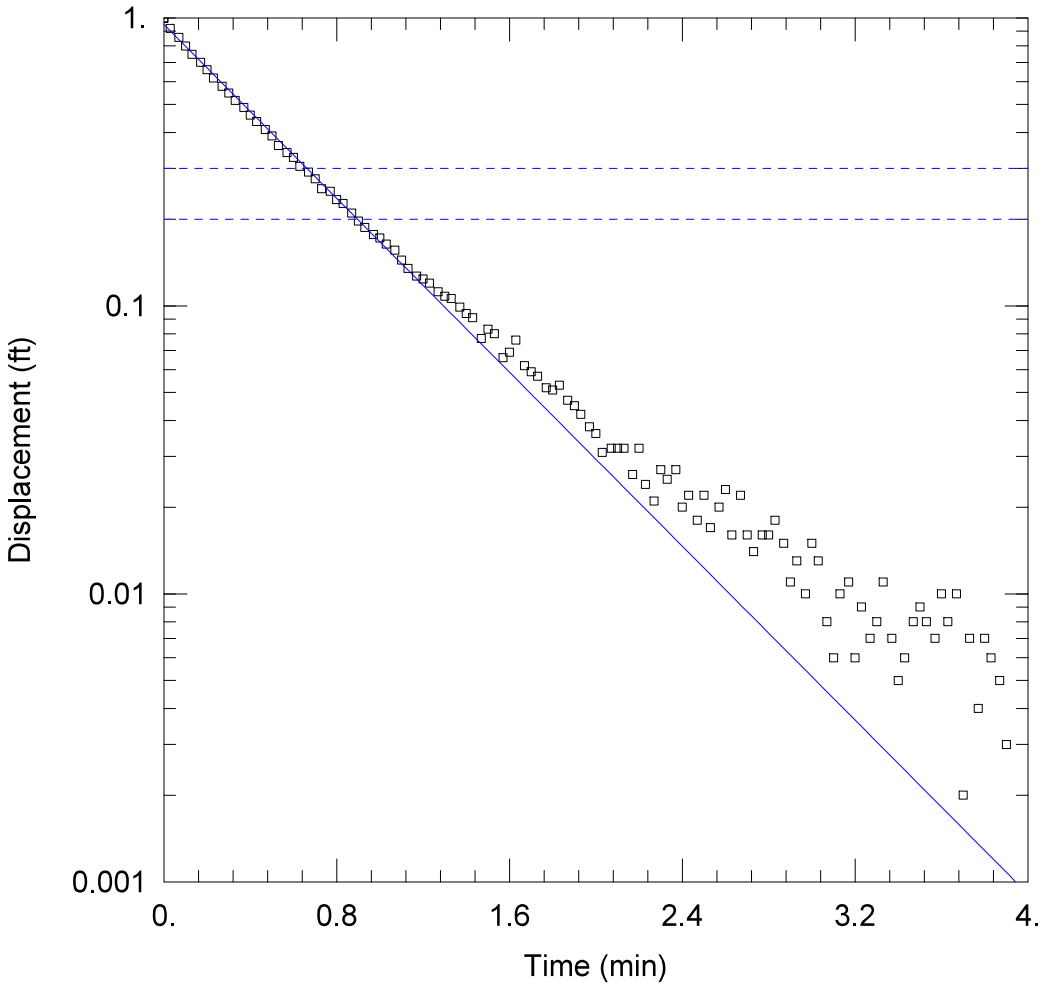
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 2 slug-out))

Initial Displacement: 0.71 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004838 cm/sec
y0 = 0.662 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:44:50

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

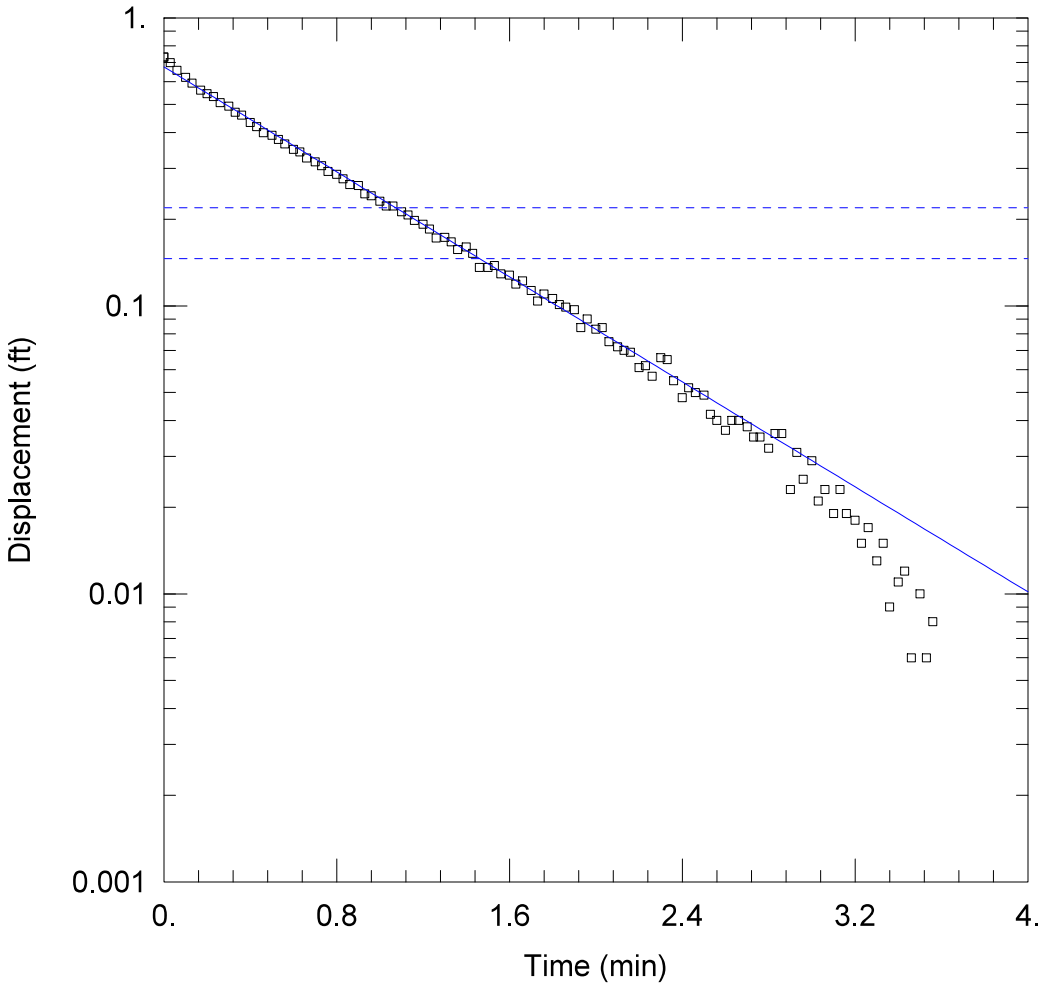
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 3 slug-in))

Initial Displacement: 1. ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0008689 cm/sec
y0 = 0.9483 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-10 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:46:31

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-10

AQUIFER DATA

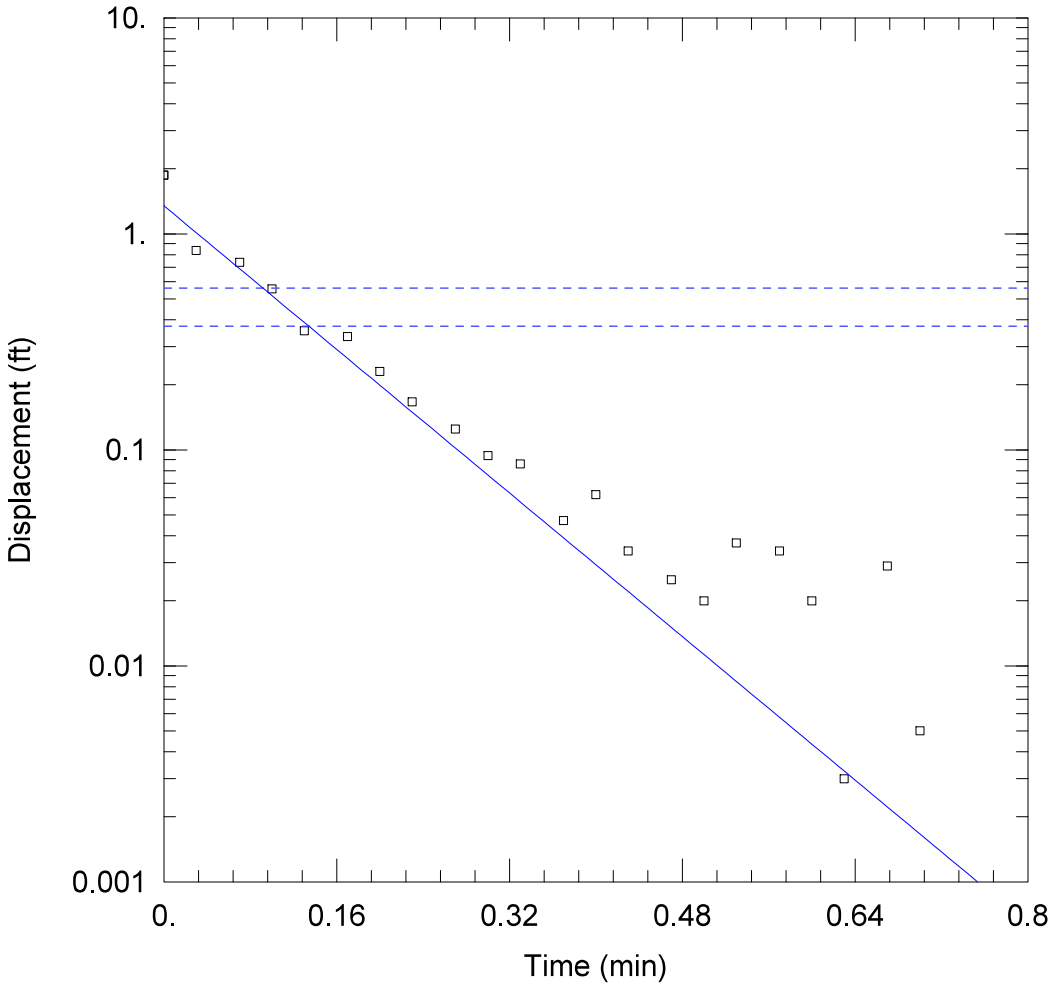
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-10 (test 4 slug-out))

Initial Displacement: 0.73 ft
Total Well Penetration Depth: 10.73 ft
Casing Radius: 0.083 ft
Static Water Column Height: 10.73 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0005246 cm/sec
y0 = 0.6756 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:09:34

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

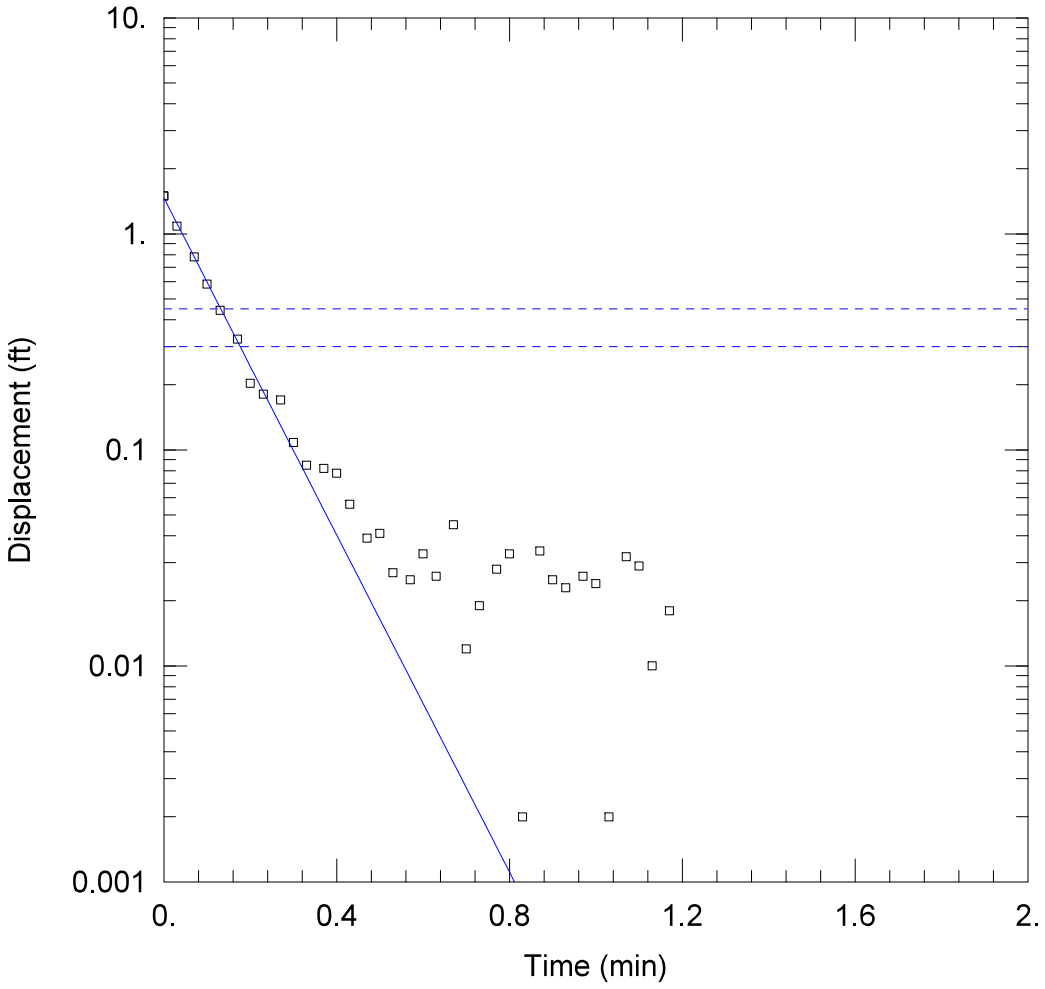
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 1 slug-in))

Initial Displacement: 1.87 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.007151 cm/sec
y0 = 1.348 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:11:32

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

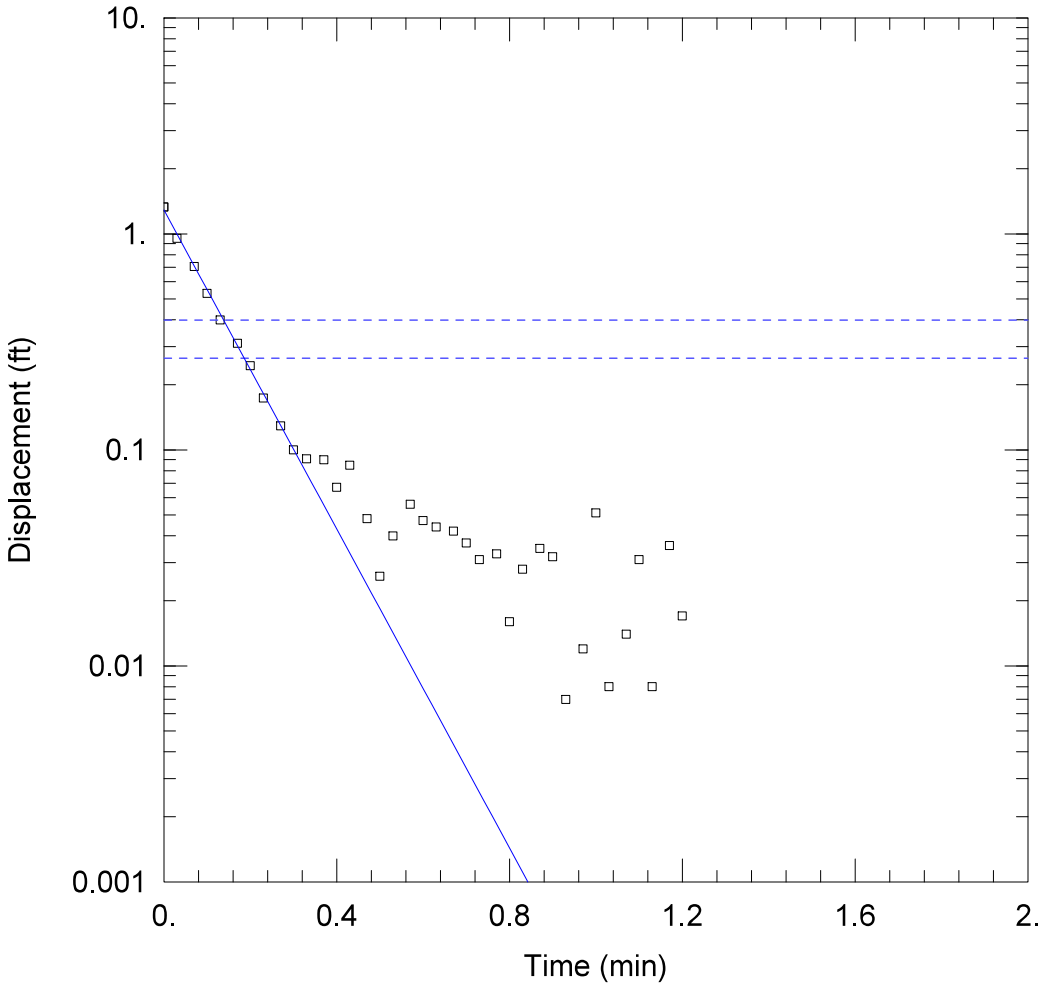
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 2 slug-out))

Initial Displacement: 1.5 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006716 cm/sec
y0 = 1.466 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 15:15:17

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

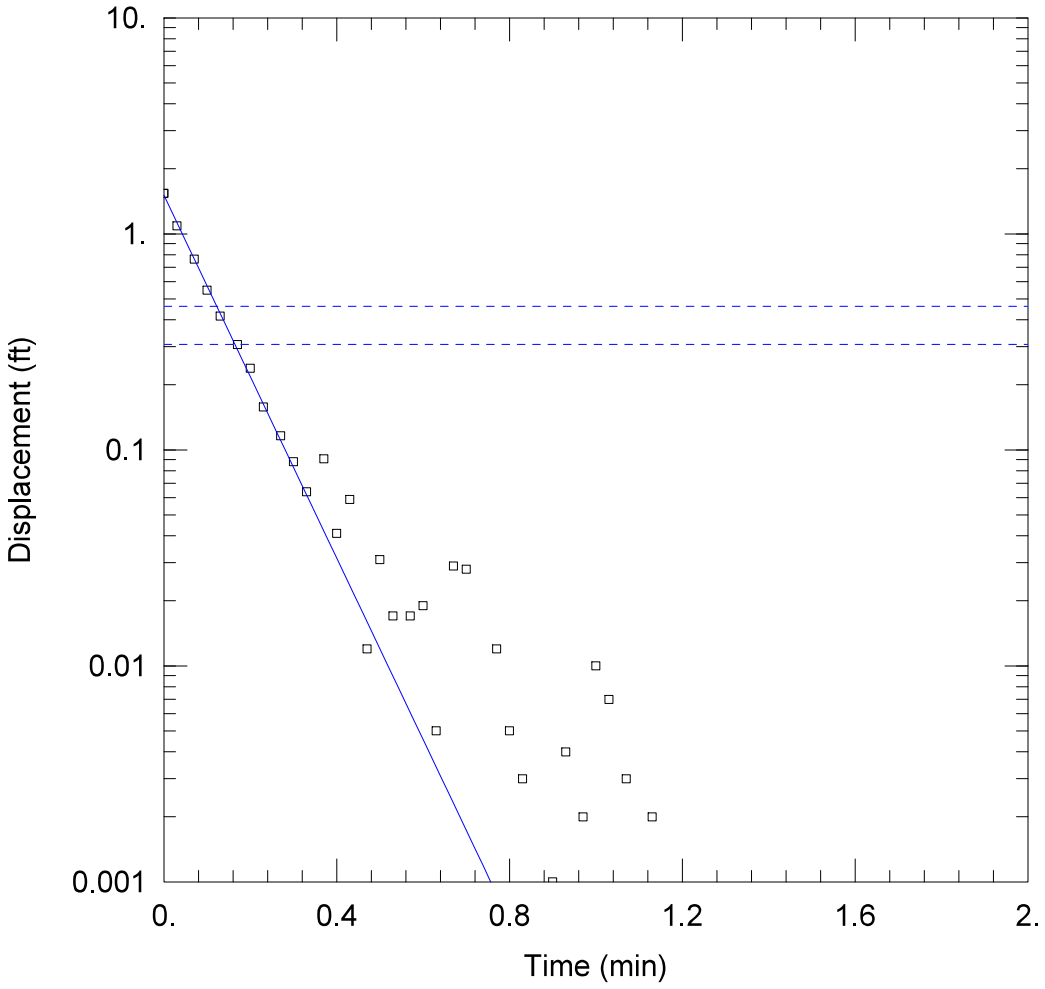
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 3 slug-in))

Initial Displacement: 1.33 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.006355 cm/sec
y0 = 1.288 ft



WELL TEST ANALYSIS

Data Set: P:\...\G-11 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 15:19:03

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: G-11

AQUIFER DATA

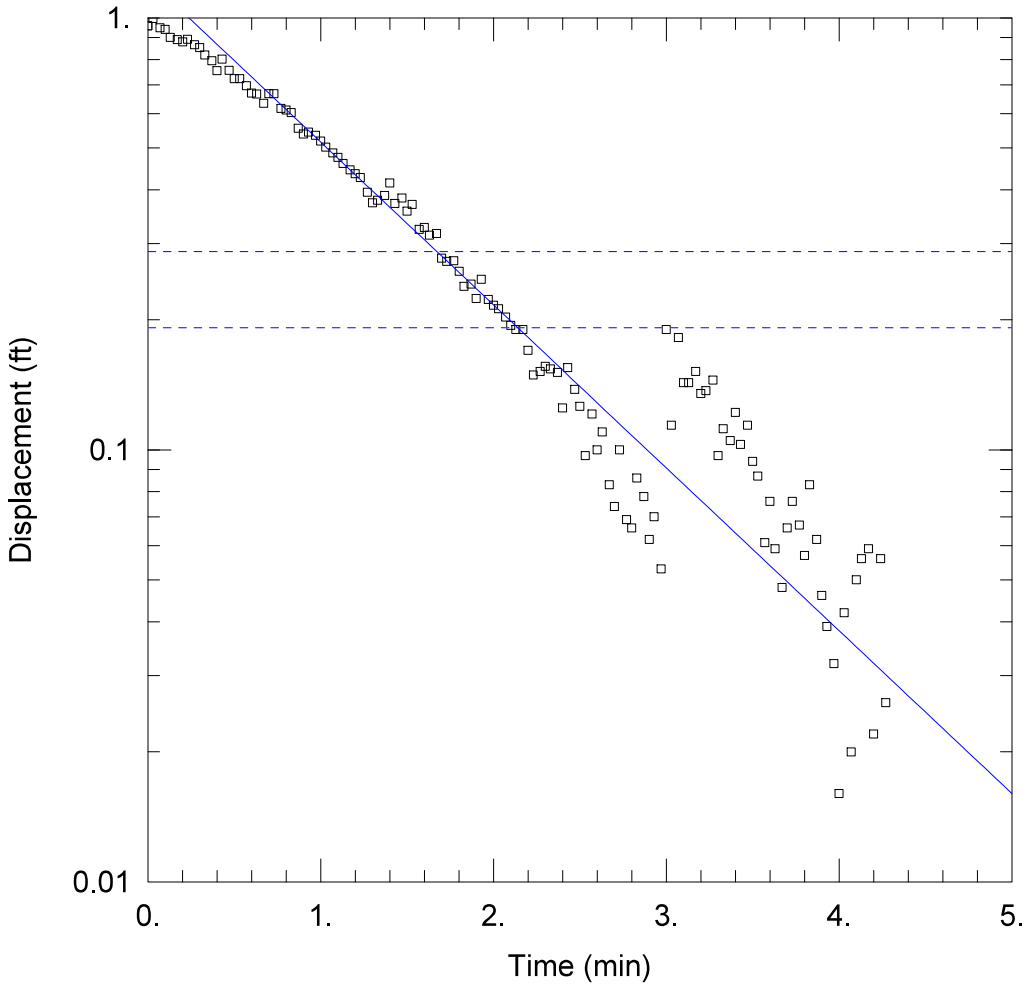
Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (G-11 (test 4 slug-out))

Initial Displacement: 1.54 ft
Total Well Penetration Depth: 23.2 ft
Casing Radius: 0.083 ft
Static Water Column Height: 23.2 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.007229 cm/sec
y0 = 1.506 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 1 (Slug-in).aqt
Date: 03/31/21 Time: 08:32:59

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

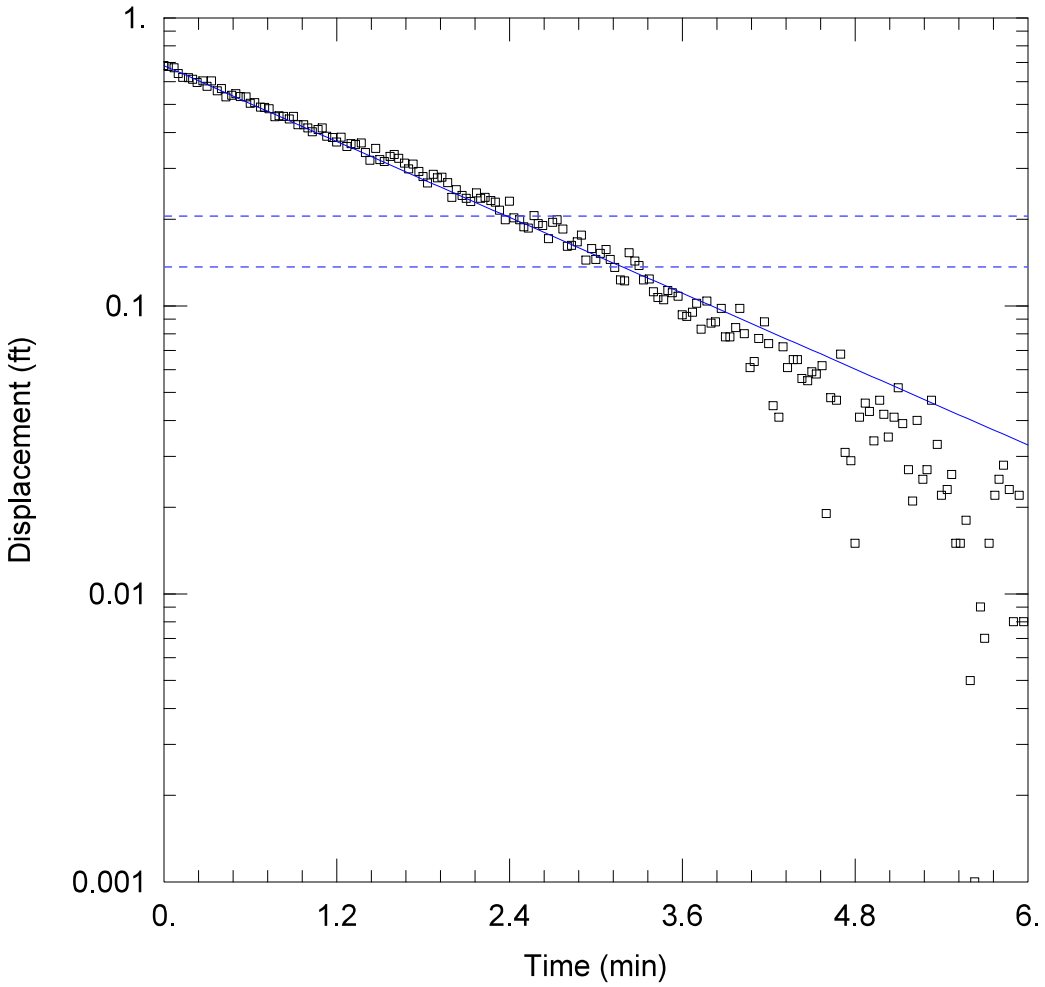
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 1 (Slug in))

Initial Displacement: 0.959 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 1. ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0002725 cm/sec
y0 = 1.228 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 2 (Slug-out).aqt
Date: 03/31/21 Time: 08:41:16

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

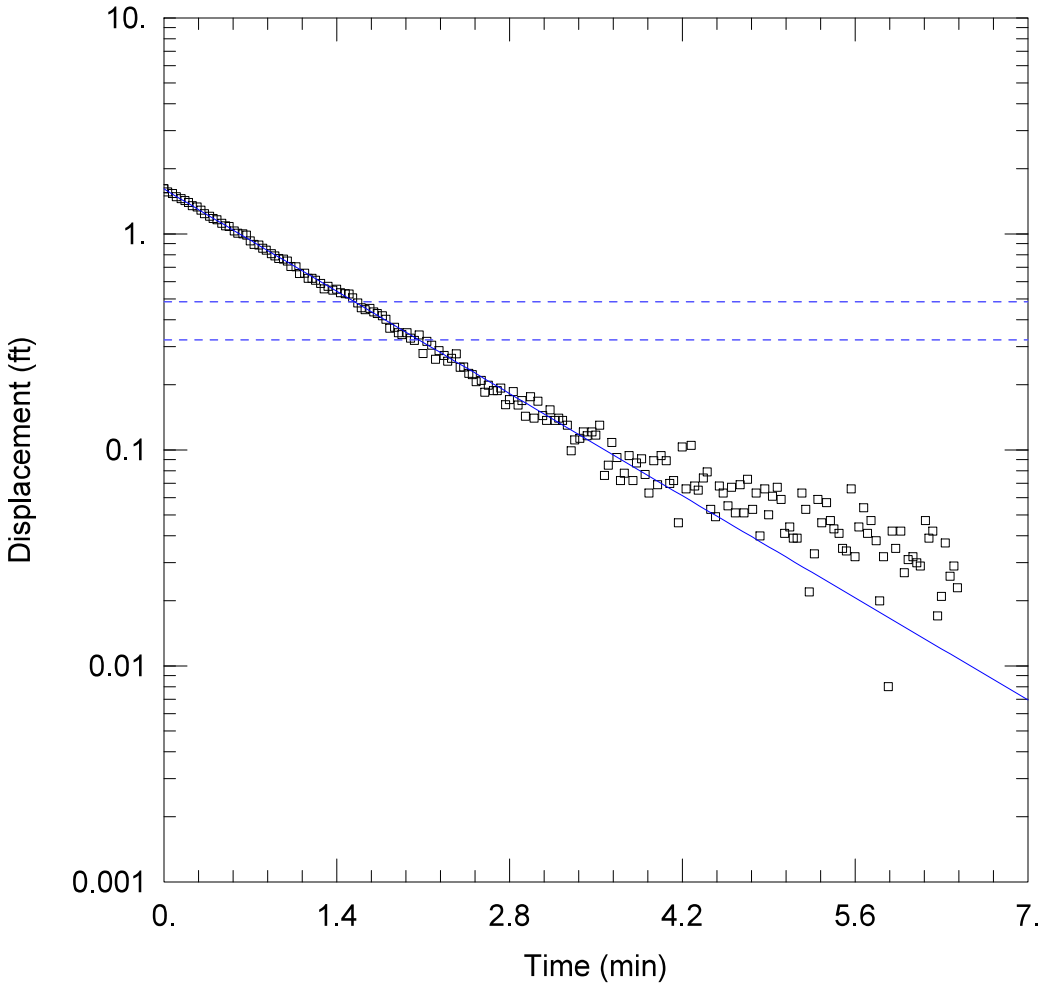
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 2 (Slug out))

Initial Displacement: 0.683 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0003783 cm/sec
y0 = 0.6827 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 3 (Slug-in).aqt
Date: 03/31/21 Time: 08:44:06

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

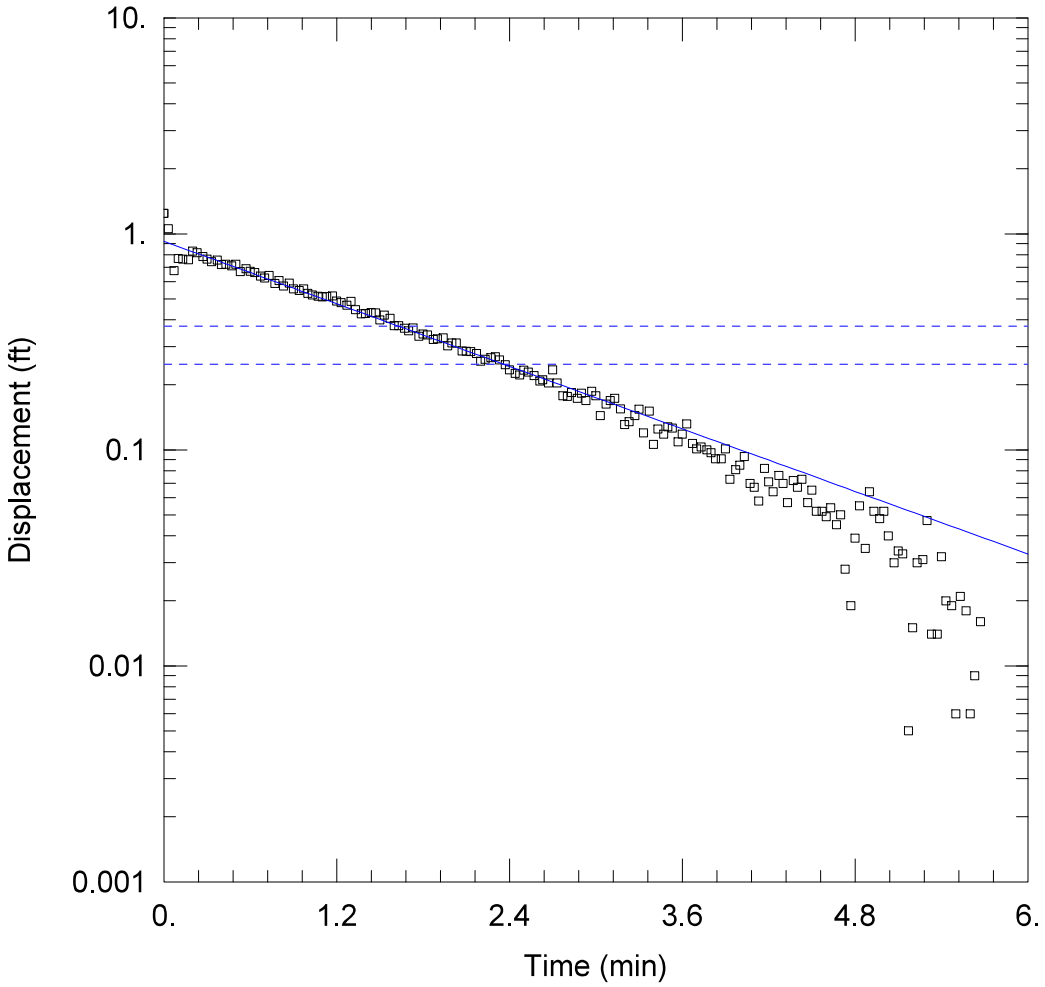
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 3 (Slug in))

Initial Displacement: 1.615 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0005824 cm/sec
y0 = 1.613 ft



TEST 1 SLUG IN

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\G09M test 4 (Slug-out).aqt
Date: 03/31/21 Time: 08:48:06

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa, IL
Test Well: G09M
Test Date: 2/26/2021

AQUIFER DATA

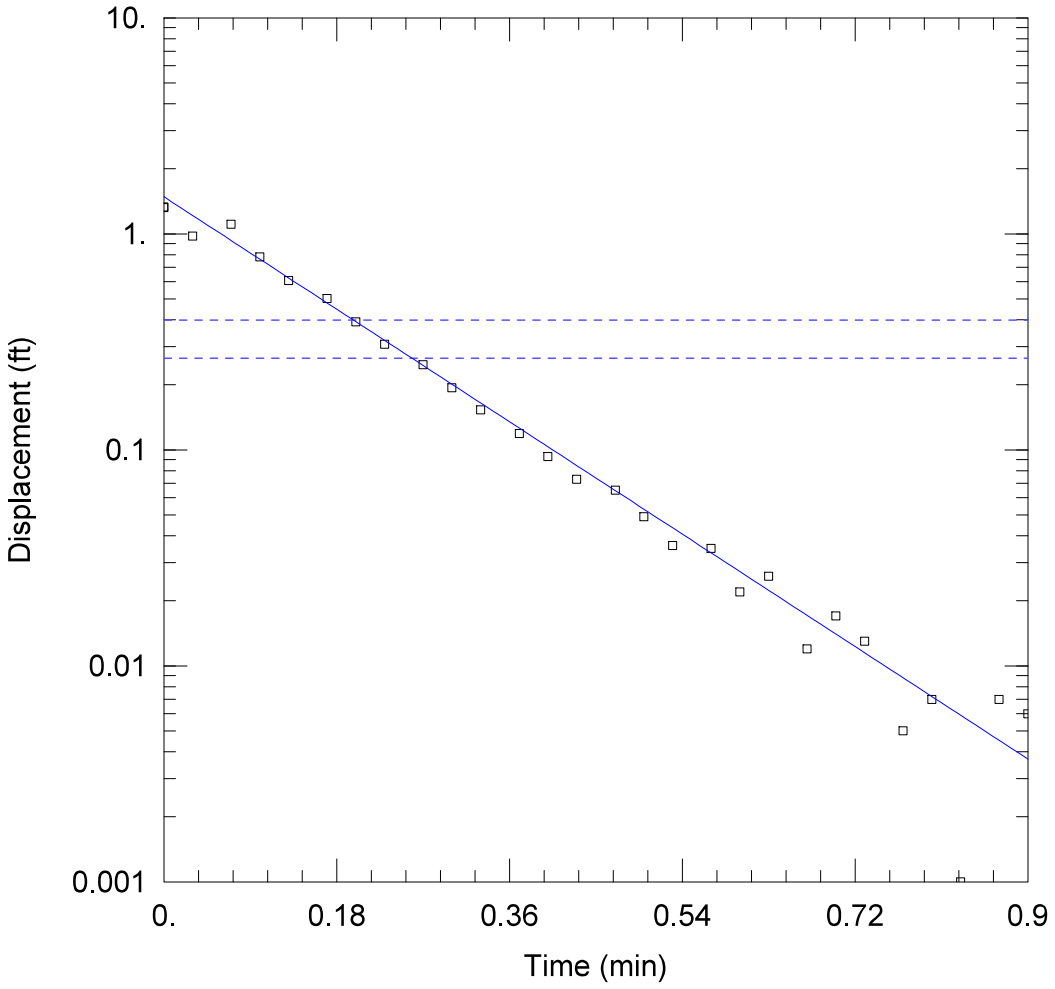
Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G09M test 4 (Slug out))

Initial Displacement: 1.244 ft
Total Well Penetration Depth: 127.8 ft
Casing Radius: 0.083 ft
Static Water Column Height: 127.8 ft
Screen Length: 10. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004155 cm/sec
y0 = 0.9235 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 1 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:03:08

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

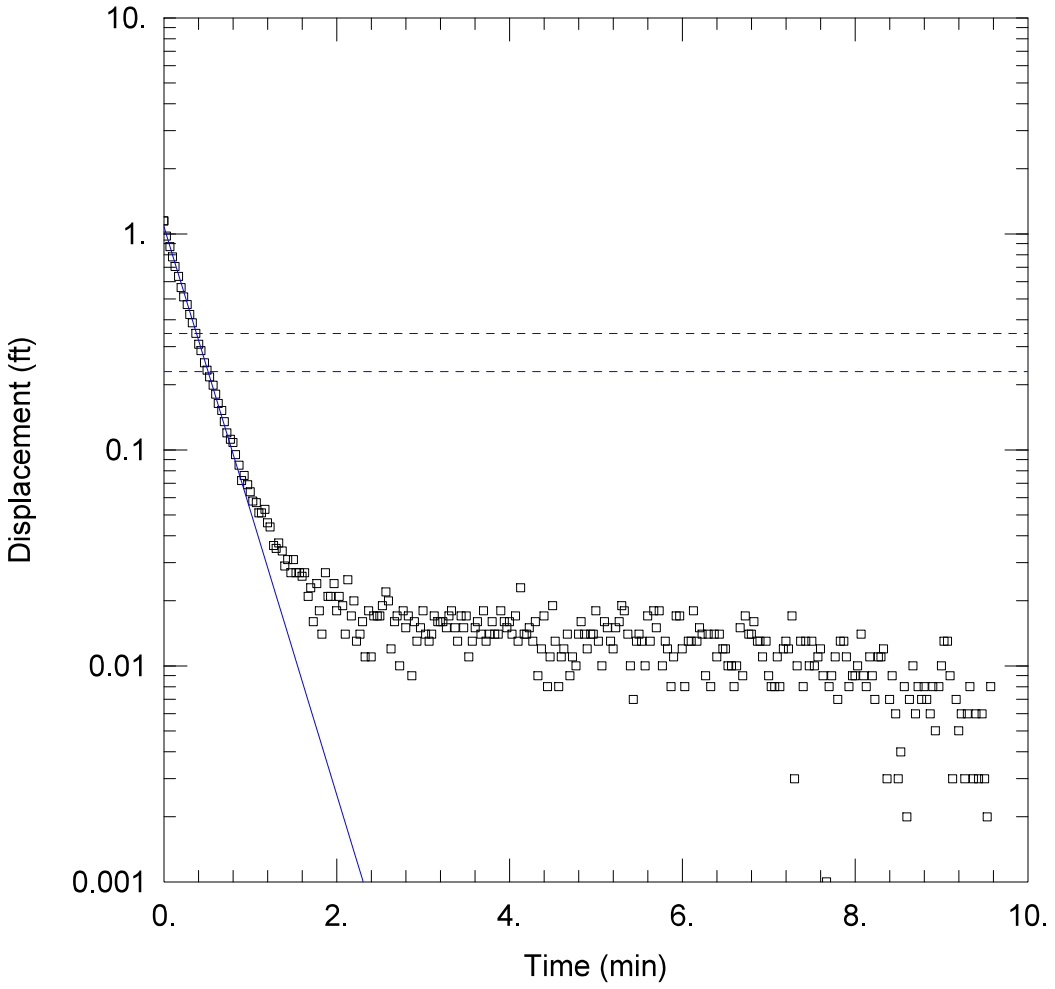
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 1 slug-in))

Initial Displacement: 1.33 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.009817 cm/sec
y0 = 1.486 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 2 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:19:01

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

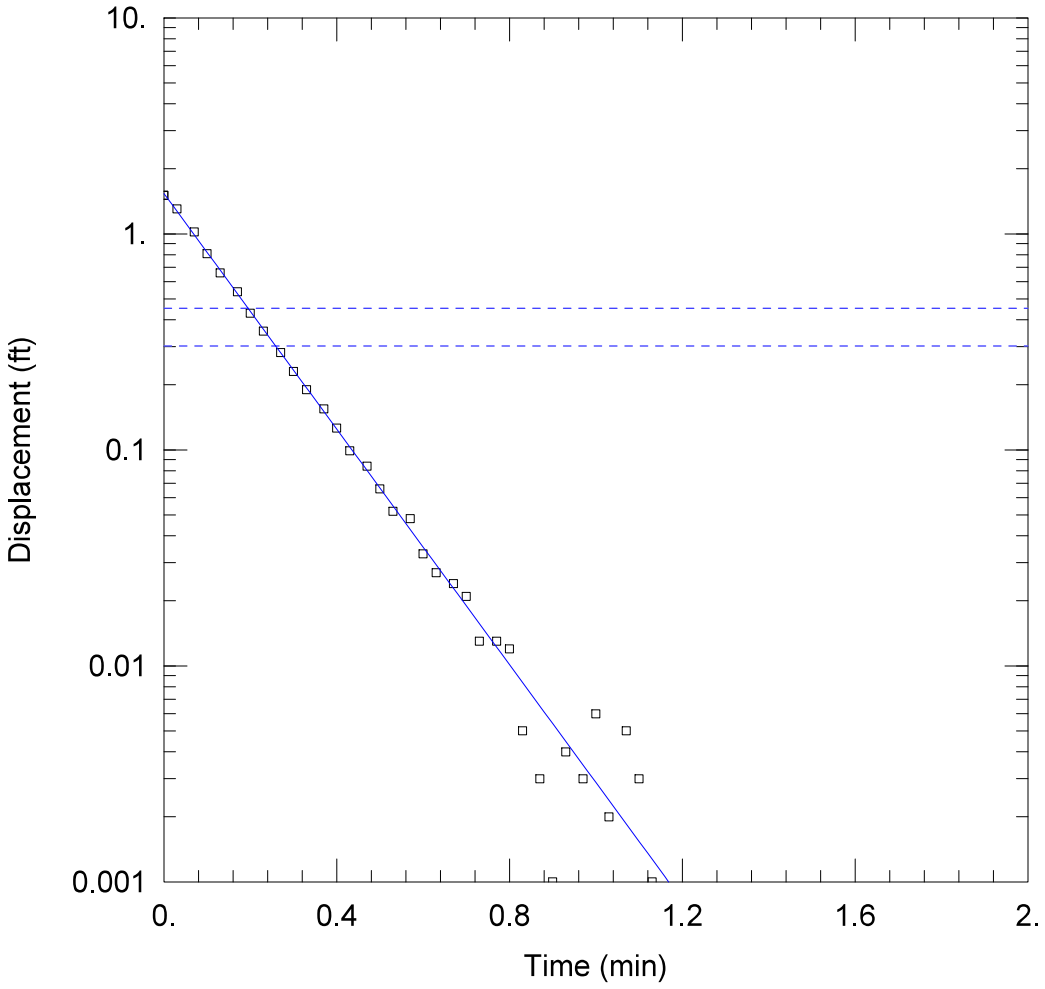
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 2 slug-out))

Initial Displacement: 1.15 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.004464 cm/sec
y0 = 1.079 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 3 (slug-in) BR.aqt
Date: 03/31/21 Time: 11:22:08

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

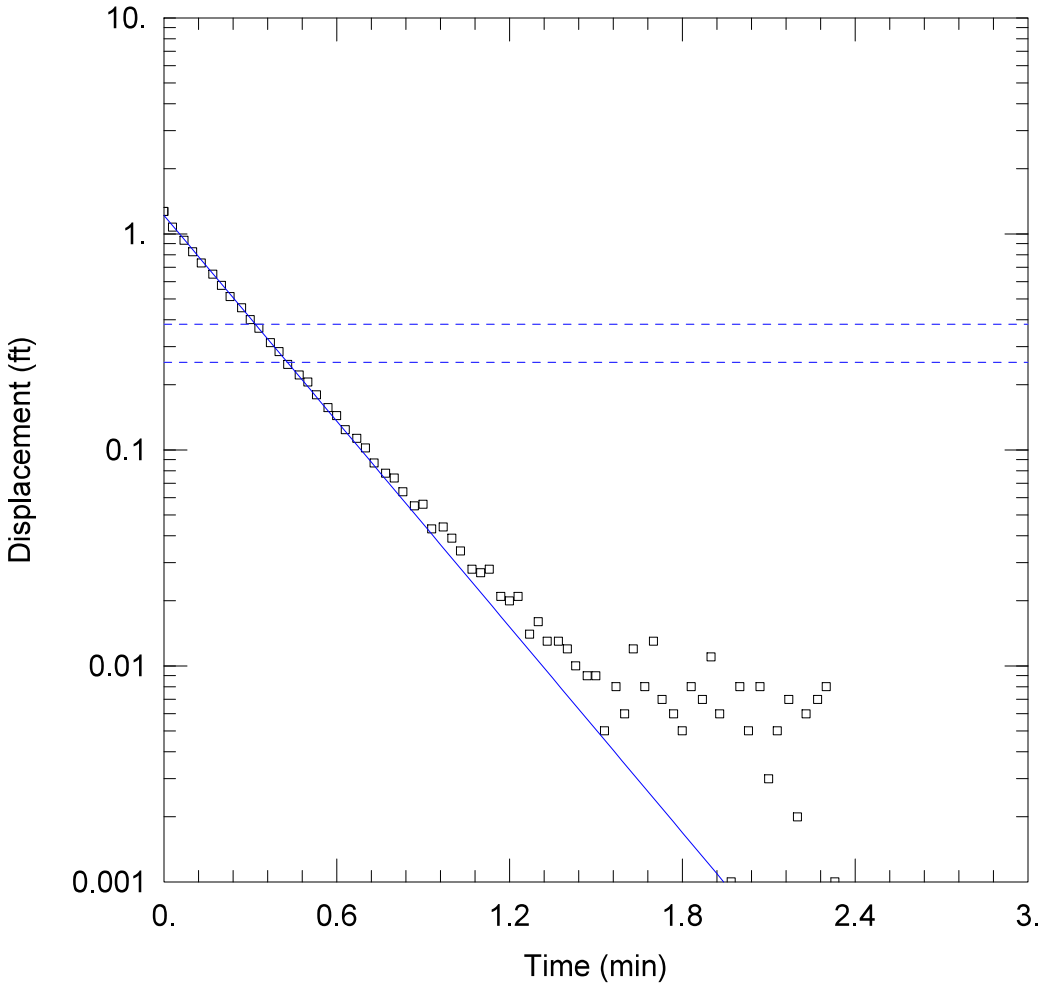
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 3 slug-in))

Initial Displacement: 1.51 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.009254 cm/sec
y0 = 1.537 ft



WELL TEST ANALYSIS

Data Set: C:\Users\kcarlton\Desktop\Joppa Slug Tests\XPW-02 test 4 (slug-out) BR.aqt
Date: 03/31/21 Time: 11:24:39

PROJECT INFORMATION

Company: Geosyntec
Location: Joppa Ash Pond
Test Well: XPW-02

AQUIFER DATA

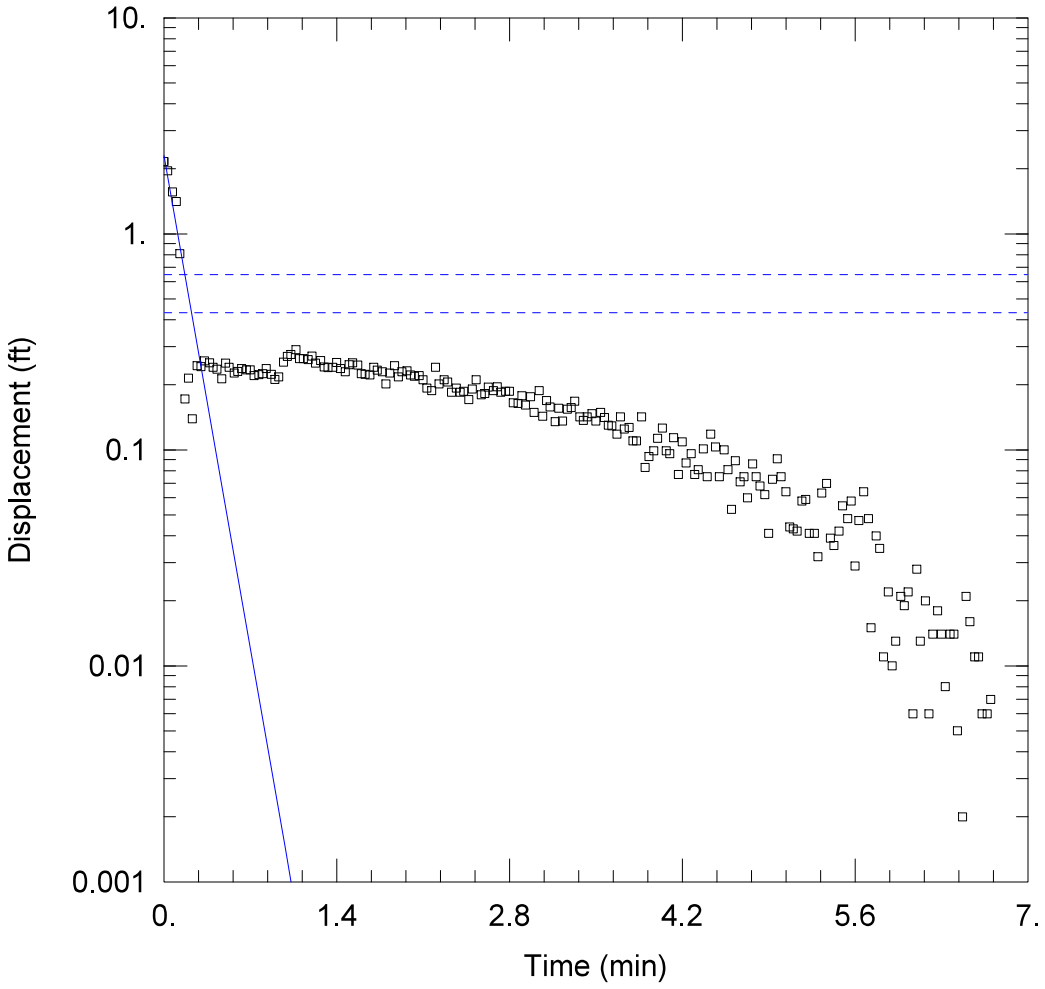
Saturated Thickness: 25. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-02 ((test 4 slug-out))

Initial Displacement: 1.27 ft
Total Well Penetration Depth: 27.13 ft
Casing Radius: 0.083 ft
Static Water Column Height: 27.13 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.005386 cm/sec
y0 = 1.217 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 1 (slug-in) BR.aqt
Date: 04/09/21 Time: 13:57:26

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

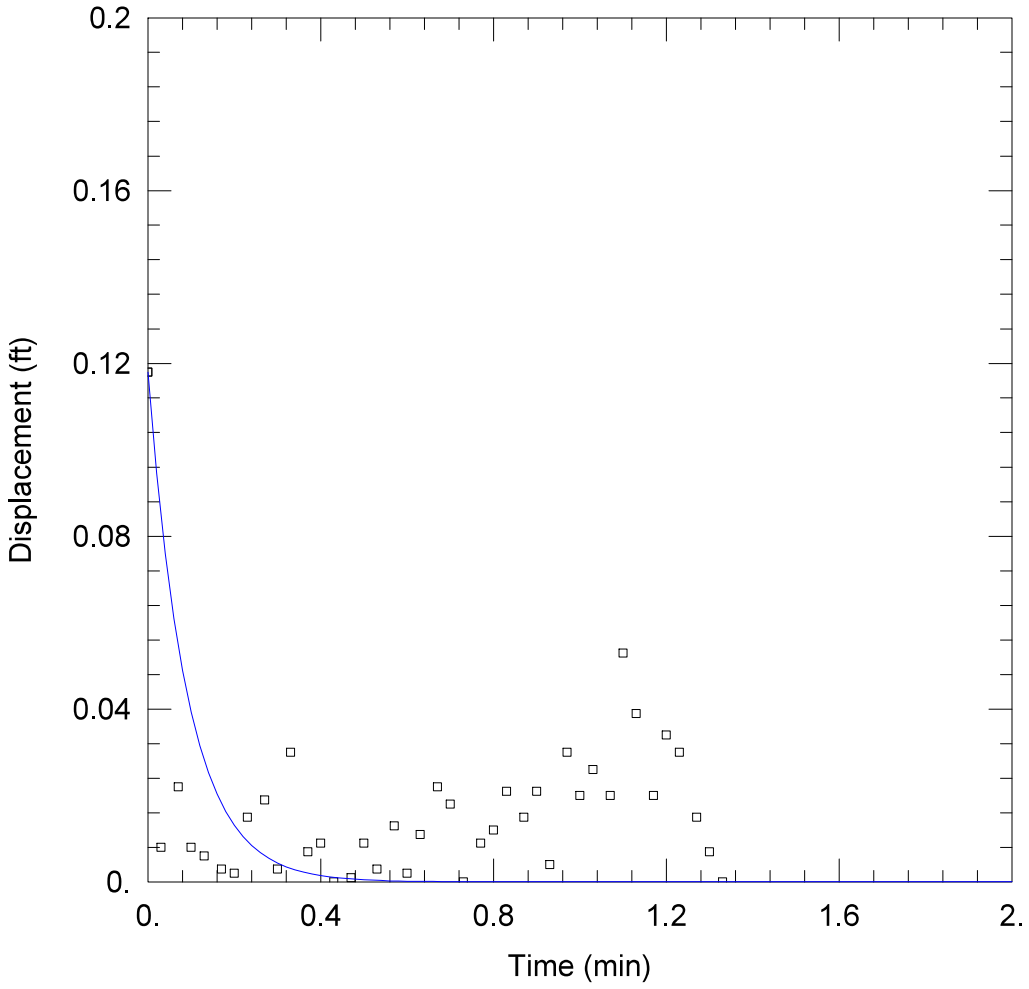
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 1 slug-in))

Initial Displacement: 2.159 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.01129 cm/sec
y0 = 2.303 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 2 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:00:35

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

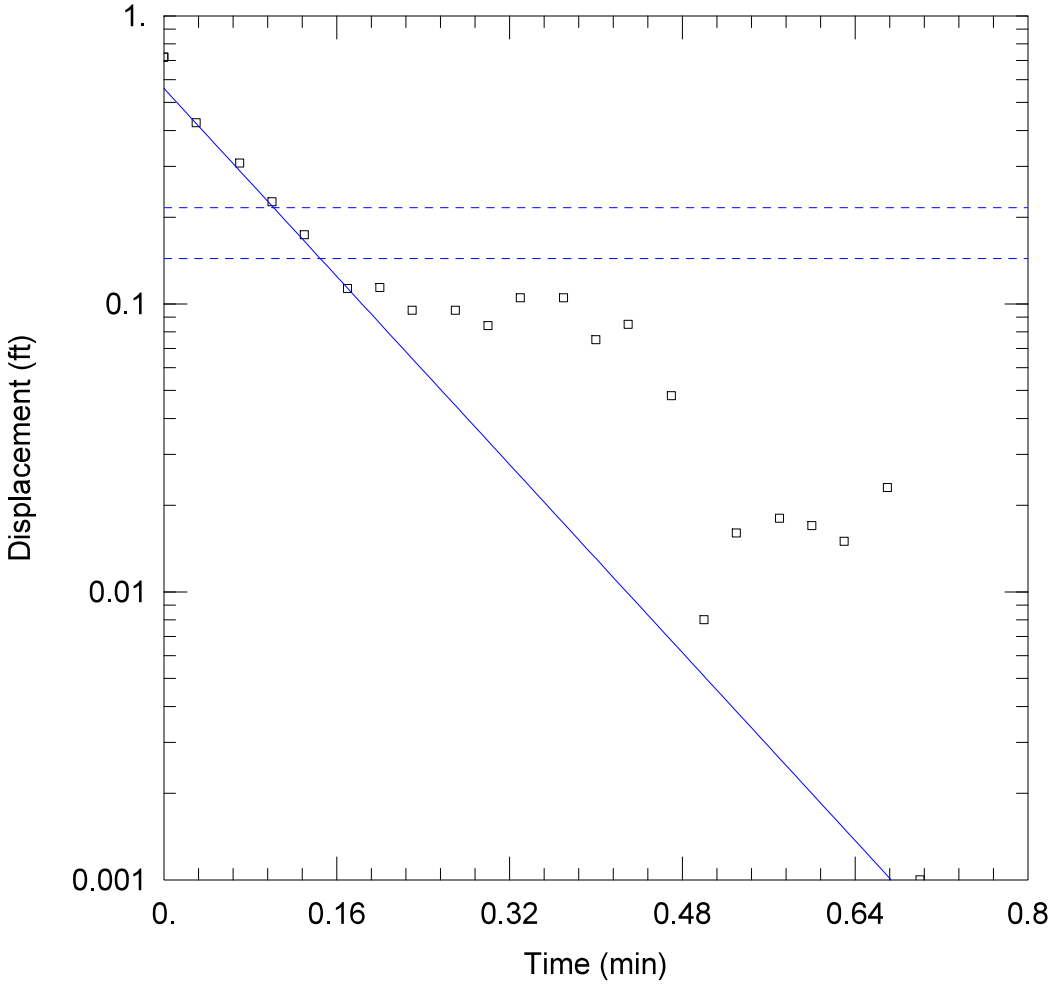
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 1 slug-in))

Initial Displacement: 0.118 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Springer-Gelhar
K = 0.01653 cm/sec
Le = 0.1 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 3 (slug-in) BR.aqt
Date: 04/09/21 Time: 14:04:42

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

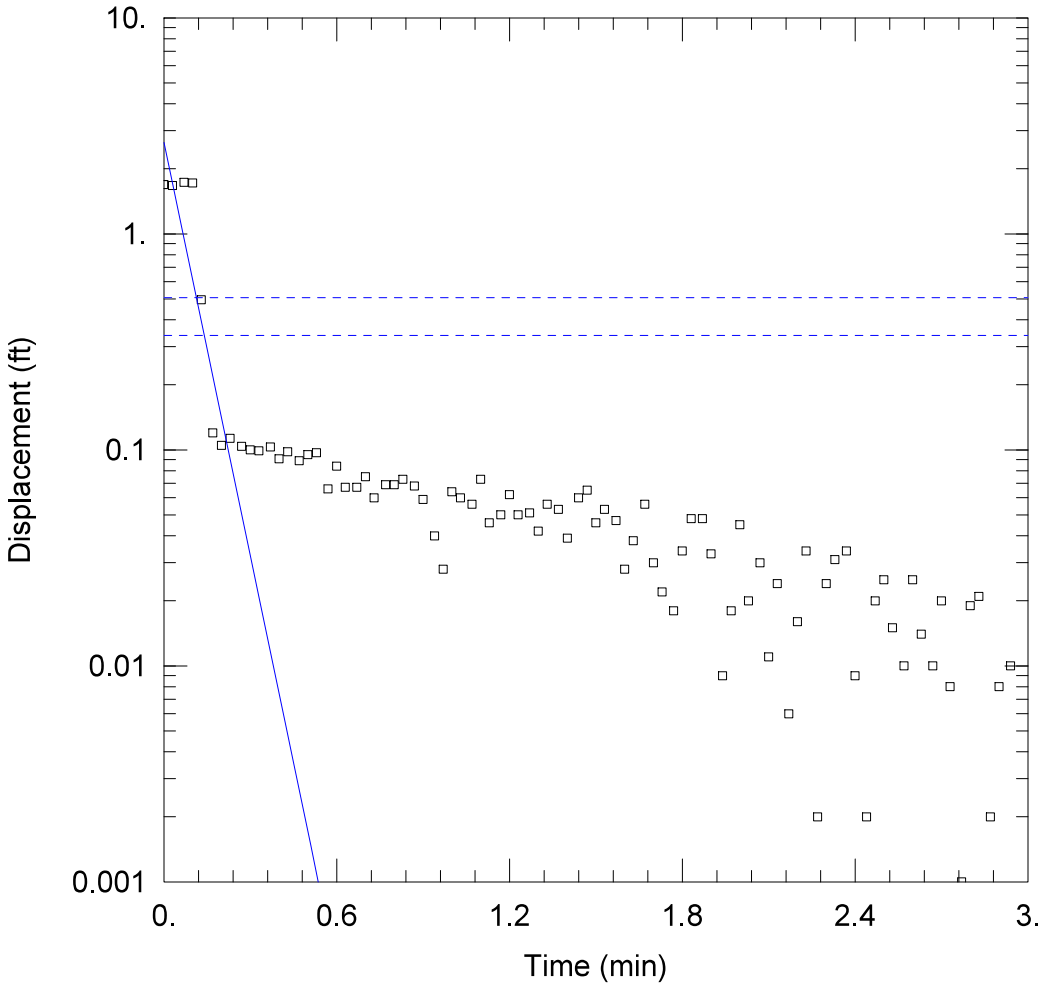
Saturated Thickness: 31. ft
Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 3 slug-out))

Initial Displacement: 0.719 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.01413 cm/sec
y0 = 0.5601 ft



WELL TEST ANALYSIS

Data Set: P:\...\XPW-03 test 4 (slug-out) BR.aqt
Date: 04/09/21 Time: 14:07:51

PROJECT INFORMATION

Company: Geosyntec
Client: Vistra
Project: GLP8021
Location: Joppa Ash Pond
Test Well: XPW-03

AQUIFER DATA

Saturated Thickness: 31. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (XPW-03 (test 4 slug-out))

Initial Displacement: 1.69 ft
Total Well Penetration Depth: 31.43 ft
Casing Radius: 0.083 ft
Static Water Column Height: 31.43 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

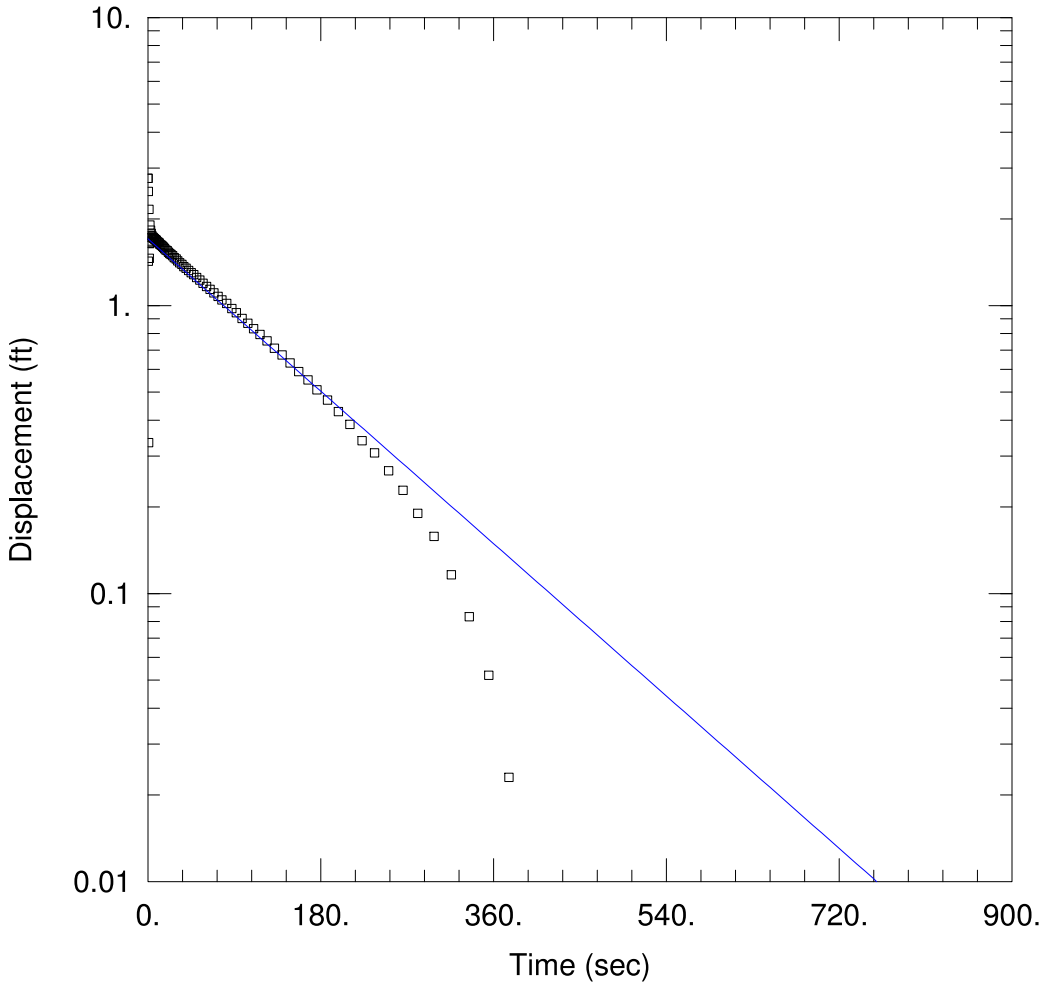
Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.02209 cm/sec y0 = 2.648 ft

Table 1. Falling/Rising Head Test Results Summary
Joppa East Ash Pond
April 2017
Hydrogeologic Monitoring Plan

Location	Test Type	Slug Type	Number	K (cm/sec)
G01D	Falling Head	Slug In	1	1.33E-04
G01D	Rising Head	Slug Out	1	1.40E-04
G01D	Rising Head	Slug Out	2	1.08E-04
G01D	Rising Head	Slug Out	3	1.04E-04
G02D	Falling Head	Slug In	1	6.50E-04
G02D	Falling Head	Slug In	2	2.37E-05
G02D	Rising Head	Slug Out	2	7.23E-04
G02D	Rising Head	Slug Out	3	6.40E-04
G51D	Falling Head	Slug In	1	2.13E-04
G51D	Falling Head	Slug In	2	3.98E-04
G51D	Rising Head	Slug Out	1	2.35E-04
G51D	Rising Head	Slug Out	2	2.12E-04
G51D	Rising Head	Slug Out	3	2.30E-04
G52D	Rising Head	Slug Out	1	7.13E-08
G53D	Falling Head	Slug In	1	7.52E-04
G53D	Falling Head	Slug In	2	6.41E-04
G53D	Rising Head	Slug Out	1	5.17E-04
G53D	Rising Head	Slug Out	2	4.71E-04
G53D	Rising Head	Slug Out	3	4.57E-04
G54D	Falling Head	Slug In	1	9.93E-04
G54D	Falling Head	Slug In	2	9.04E-04
G54D	Rising Head	Slug Out	1	4.18E-04
G54D	Rising Head	Slug Out	2	8.93E-04
G54D	Rising Head	Slug Out	3	6.57E-04

Natural Resource Technology
AN OBG COMPANY



G01D SI1

Data Set: P:\...\G01D Slug In 1.aqt
Date: 09/22/17 Time: 13:52:56

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G01D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G01D SI1)

Initial Displacement: 2.767 ft
Total Well Penetration Depth: 9.55 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.08 ft
Screen Length: 9.55 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0001325 cm/sec
y0 = 1.704 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G01D SI1
Date: 09/22/17
Time: 13:54:26

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G01D

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G01D SI1

X Location: 831716.1 ft
Y Location: 202039.3 ft

Initial Displacement: 2.767 ft
Static Water Column Height: 10.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.55 ft
Total Well Penetration Depth: 9.55 ft

No. of Observations: 102

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.767	47.96	1.279
0.406	2.489	50.96	1.25
0.53	1.426	54.14	1.227
0.75	0.334	57.5	1.195
1.	2.158	61.1	1.164
1.406	1.646	64.7	1.137
1.53	1.457	68.9	1.106
1.75	1.639	73.1	1.075
2.	1.904	77.3	1.045
2.353	1.676	82.1	1.016
2.5	1.653	87.5	0.976
2.75	1.828	92.3	0.943
3.	1.753	98.3	0.902
3.25	1.723	104.3	0.868
3.5	1.782	110.3	0.83
3.86	1.724	116.9	0.794
4.22	1.749	124.1	0.754
4.64	1.728	131.9	0.71
5.06	1.725	139.7	0.674
5.48	1.723	148.1	0.631
5.96	1.713	157.1	0.59
6.5	1.708	166.7	0.551
6.98	1.703	176.3	0.509
7.58	1.694	187.1	0.47
8.18	1.69	198.5	0.428
8.78	1.685	210.5	0.387
9.44	1.669	223.1	0.339
10.16	1.663	236.3	0.308
10.94	1.656	250.7	0.267
11.72	1.649	265.7	0.228

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
12.56	1.631	281.3	0.19
13.46	1.622	298.1	0.158
14.42	1.615	316.1	0.116
15.38	1.602	334.7	0.083
16.46	1.591	355.1	0.052
17.6	1.576	376.1	0.023
18.8	1.559	398.3	0.
20.06	1.549	422.3	-0.026
21.38	1.53	447.5	-0.056
22.82	1.515	473.9	-0.077
24.32	1.505	502.1	-0.092
25.88	1.489	532.1	-0.111
27.56	1.465	563.9	-0.125
29.36	1.451	597.5	-0.138
31.22	1.429	633.5	-0.155
33.26	1.407	669.5	-0.162
35.36	1.389	711.5	-0.178
37.58	1.366	753.5	-0.182
39.98	1.347	795.5	-0.193
42.5	1.324	843.5	-0.195
45.14	1.3	897.5	-0.196

SOLUTION

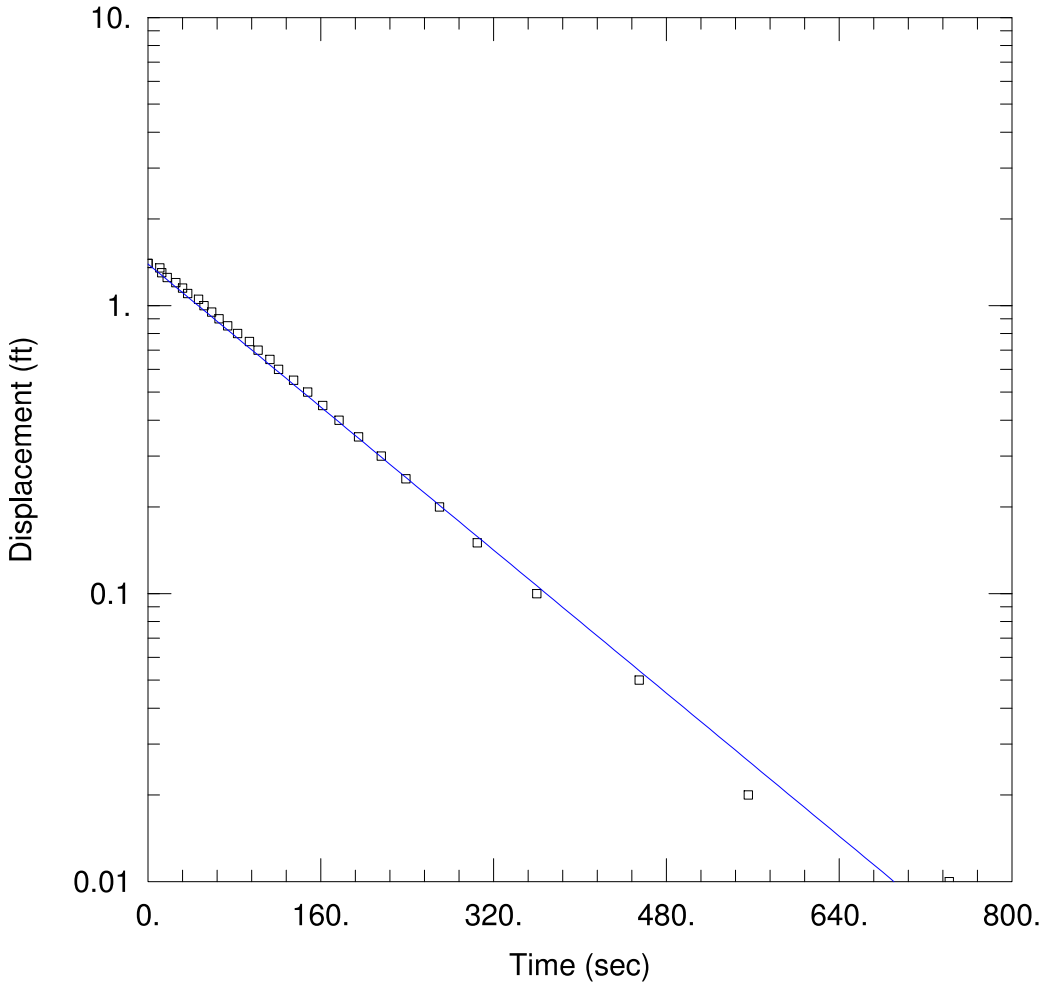
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.03

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0001325	cm/sec
y0	1.704	ft

$T = K*b = 0.3522$ cm²/sec



G01D SO1

Data Set: P:\...\G01D Slug Out 1.aqt
Date: 09/22/17 Time: 13:57:51

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G01D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 87.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G01D SO1)

Initial Displacement: 1.4 ft
Total Well Penetration Depth: 9.55 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.08 ft
Screen Length: 9.55 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0001399 cm/sec
y0 = 1.394 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G01D SO1
Date: 09/22/17
Time: 13:58:33

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G01D

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G01D SO1

X Location: 831716.1 ft
Y Location: 202039.3 ft

Initial Displacement: 1.4 ft
Static Water Column Height: 10.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.55 ft
Total Well Penetration Depth: 9.55 ft

No. of Observations: 31

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.4	121.	0.6
11.	1.35	135.	0.55
13.	1.3	148.	0.5
18.	1.25	162.	0.45
26.	1.2	177.	0.4
32.	1.15	195.	0.35
37.	1.1	216.	0.3
47.	1.05	239.	0.25
52.	1.	270.	0.2
59.	0.95	305.	0.15
66.	0.9	360.	0.1
74.	0.85	455.	0.05
83.	0.8	556.	0.02
94.	0.75	742.	0.01
102.	0.7	796.	0.
113.	0.65		

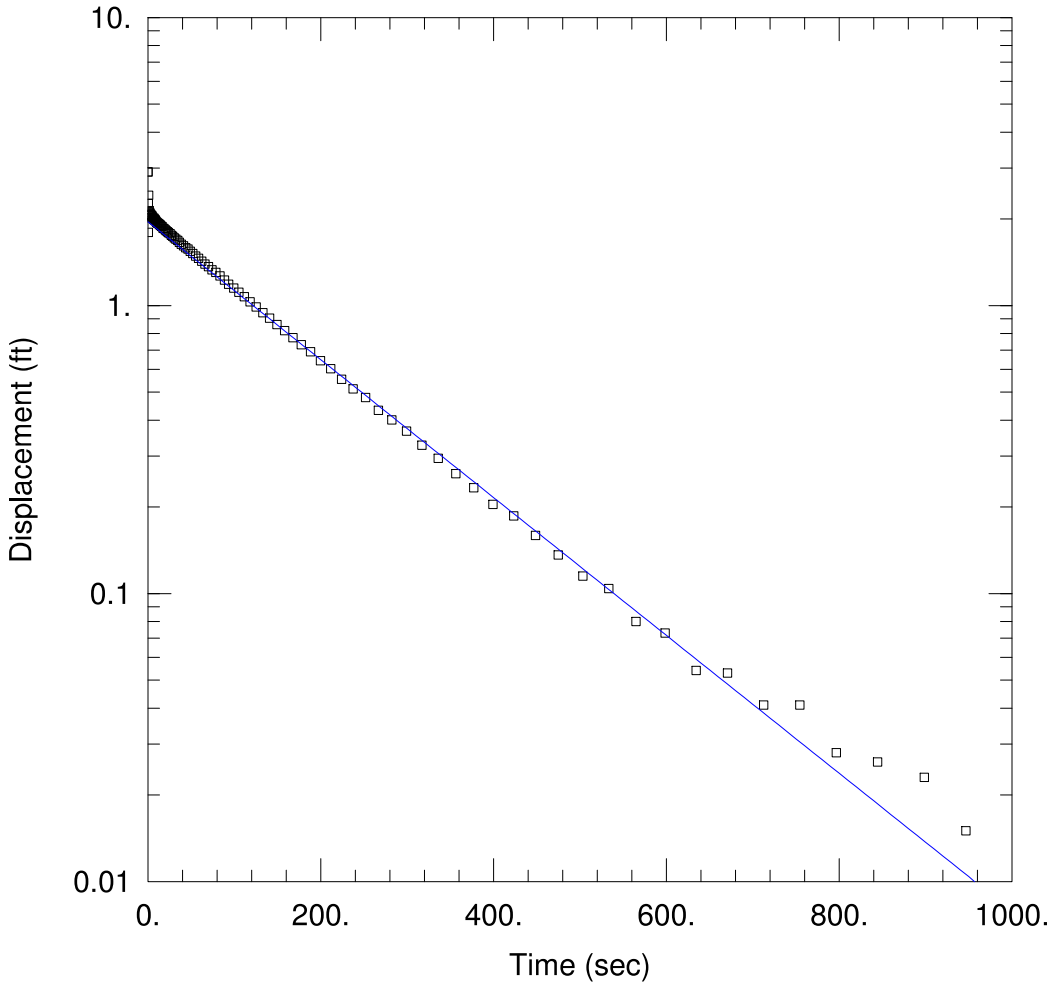
SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.03

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0001399	cm/sec



G01D SO2

Data Set: P:\...\G01D Slug Out 2.aqt
Date: 09/22/17 Time: 14:02:09

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G01D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G01D SO2)

Initial Displacement: 2.908 ft
Total Well Penetration Depth: 9.55 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.08 ft
Screen Length: 9.55 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0001079 cm/sec
y0 = 1.953 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G01D SO2
Date: 09/22/17
Time: 14:02:37

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G01D

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G01D SO2

X Location: 831716.1 ft
Y Location: 202039.3 ft

Initial Displacement: 2.908 ft
Static Water Column Height: 10.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.55 ft
Total Well Penetration Depth: 9.55 ft

No. of Observations: 108

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.908	43.75	1.588
0.408	1.793	46.39	1.57
0.531	2.266	49.21	1.541
0.75	2.416	52.21	1.515
1.	2.053	55.39	1.486
1.405	2.106	58.75	1.459
1.528	2.079	62.35	1.427
1.75	2.137	65.95	1.394
2.	2.073	70.15	1.366
2.405	2.1	74.35	1.329
2.528	2.071	78.55	1.303
2.75	2.073	83.35	1.267
3.	2.062	88.75	1.225
3.25	2.075	93.55	1.185
3.5	2.037	99.55	1.149
3.75	2.05	105.6	1.111
4.	2.058	111.6	1.072
4.25	2.051	118.2	1.03
4.5	2.012	125.3	0.989
4.75	2.048	133.2	0.943
5.11	2.017	140.9	0.904
5.471	2.027	149.3	0.859
5.89	2.025	158.3	0.818
6.31	2.	167.9	0.773
6.73	1.991	177.6	0.731
7.21	2.008	188.3	0.691
7.75	1.985	199.8	0.643
8.23	1.988	211.8	0.603
8.83	1.973	224.3	0.555
9.43	1.964	237.6	0.514

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.03	1.949	251.9	0.479
10.69	1.941	266.9	0.433
11.41	1.933	282.6	0.401
12.19	1.929	299.4	0.366
12.97	1.919	317.4	0.327
13.81	1.908	335.9	0.295
14.71	1.9	356.4	0.261
15.67	1.883	377.4	0.233
16.63	1.879	399.6	0.204
17.71	1.856	423.6	0.186
18.85	1.851	448.8	0.159
20.05	1.832	475.1	0.136
21.31	1.817	503.4	0.115
22.63	1.803	533.4	0.104
24.07	1.79	565.1	0.08
25.57	1.774	598.8	0.073
27.13	1.755	634.8	0.054
28.81	1.742	670.8	0.053
30.61	1.72	712.8	0.041
32.47	1.7	754.8	0.041
34.51	1.682	796.8	0.028
36.61	1.656	844.8	0.026
38.83	1.631	898.8	0.023
41.23	1.61	946.8	0.015

SOLUTION

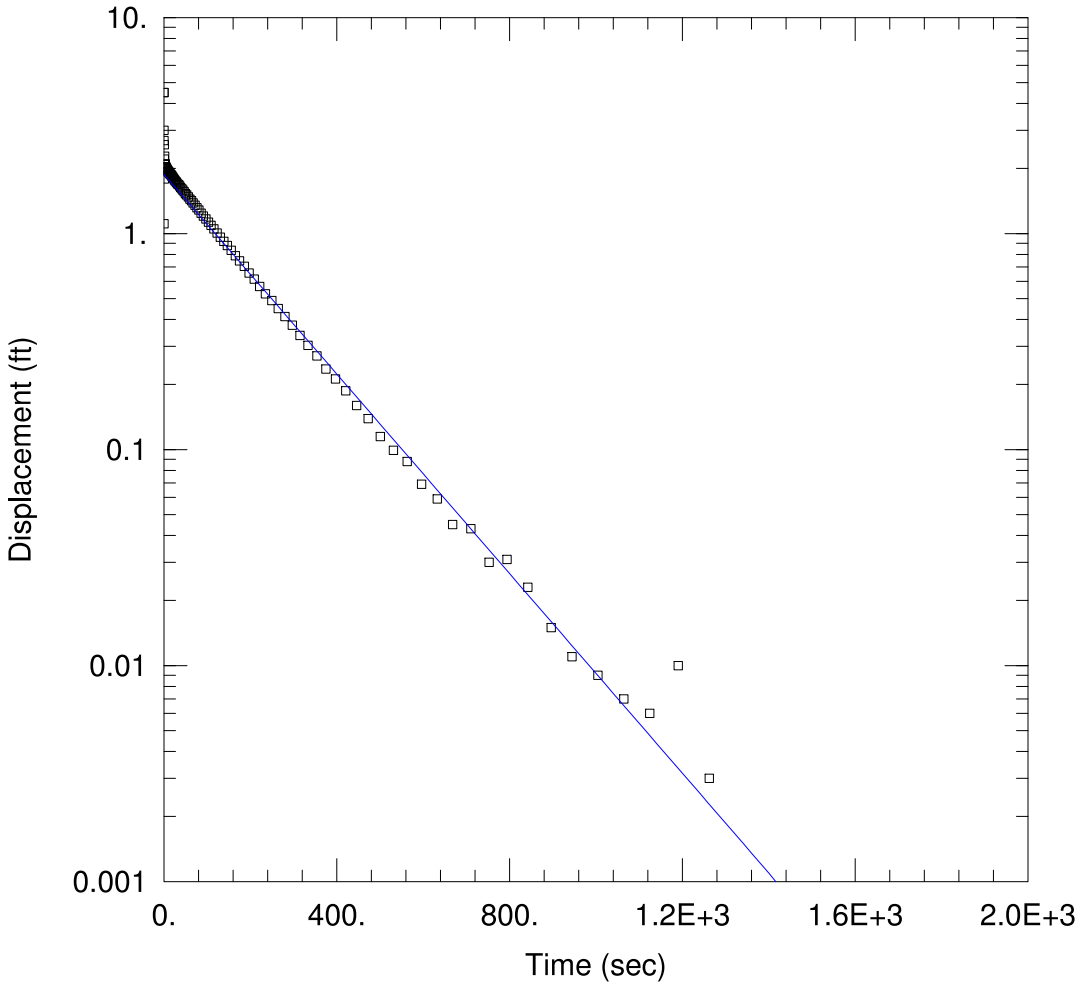
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.03

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0001079	cm/sec
y0	1.953	ft

$T = K*b = 0.2868$ cm²/sec



G01D SO3

Data Set: P:\...\G01D Slug Out 3.aqt
Date: 09/22/17 Time: 14:04:38

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G01D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 87.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G01D SO3)

Initial Displacement: 4.498 ft
Total Well Penetration Depth: 9.55 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.08 ft
Screen Length: 9.55 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0001041 cm/sec
y0 = 1.877 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G01D SO3
Date: 09/22/17
Time: 14:05:00

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G01D

AQUIFER DATA

Saturated Thickness: 87.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G01D SO3

X Location: 831716.1 ft
Y Location: 202039.3 ft

Initial Displacement: 4.498 ft
Static Water Column Height: 10.08 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.55 ft
Total Well Penetration Depth: 9.55 ft

No. of Observations: 105

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.498	63.8	1.417
0.124	2.694	68.	1.387
0.345	1.11	72.19	1.351
0.595	3.005	76.39	1.316
0.993	2.208	81.19	1.283
1.117	2.576	86.59	1.242
1.345	1.786	91.39	1.205
1.595	2.278	97.39	1.166
1.845	2.	103.4	1.128
2.095	2.092	109.4	1.091
2.345	2.094	116.	1.049
2.595	2.039	123.2	1.005
2.955	2.019	131.	0.962
3.315	2.1	138.8	0.92
3.735	2.034	147.2	0.879
4.155	2.034	156.2	0.836
4.575	2.017	165.8	0.79
5.055	2.033	175.4	0.748
5.595	2.012	186.2	0.704
6.075	2.005	197.6	0.657
6.675	1.983	209.6	0.616
7.275	1.991	222.2	0.568
7.875	1.969	235.4	0.525
8.535	1.962	249.8	0.49
9.255	1.946	264.8	0.45
10.04	1.944	280.4	0.412
10.82	1.944	297.2	0.376
11.65	1.916	315.2	0.337
12.56	1.924	333.8	0.304
13.52	1.902	354.2	0.271

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
14.48	1.892	375.2	0.236
15.56	1.879	397.4	0.212
16.7	1.872	421.4	0.187
17.9	1.856	446.6	0.16
19.16	1.84	473.	0.139
20.48	1.823	501.2	0.115
21.91	1.805	531.2	0.099
23.41	1.789	563.	0.088
24.98	1.772	596.6	0.069
26.66	1.754	632.6	0.059
28.45	1.735	668.6	0.045
30.32	1.718	710.6	0.043
32.35	1.696	752.6	0.03
34.45	1.681	794.6	0.031
36.67	1.66	842.6	0.023
39.08	1.633	896.6	0.015
41.59	1.611	944.6	0.011
44.23	1.589	1004.6	0.009
47.06	1.559	1064.6	0.007
50.06	1.527	1124.6	0.006
53.23	1.506	1190.6	0.01
56.59	1.476	1262.6	0.003
60.2	1.445		

SOLUTION

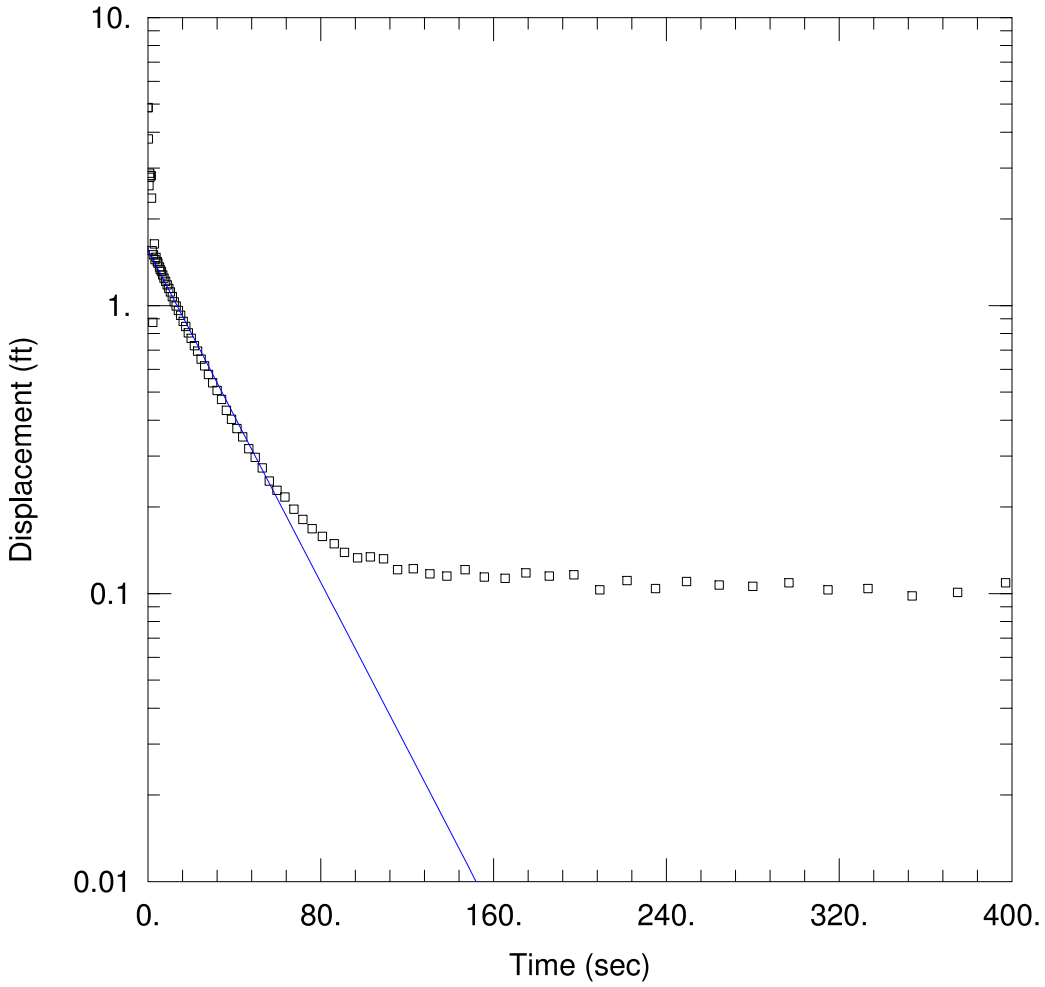
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.03

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0001041	cm/sec
y0	1.877	ft

T = K*b = 0.2768 cm²/sec



SLUG IN 1

Data Set: P:\...\G02D Slug In 1.aqt
Date: 09/22/17 Time: 14:07:01

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G02D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 78.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G02D SI1)

Initial Displacement: 4.872 ft
Total Well Penetration Depth: 9.63 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.34 ft
Screen Length: 9.63 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0006495 cm/sec
y0 = 1.561 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 1
Date: 09/22/17
Time: 14:07:30

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G02D

AQUIFER DATA

Saturated Thickness: 78.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G02D SI1

X Location: 832843. ft
Y Location: 202137.1 ft

Initial Displacement: 4.872 ft
Static Water Column Height: 10.34 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.63 ft
Total Well Penetration Depth: 9.63 ft

No. of Observations: 83

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.872	36.33	0.433
0.25	3.788	38.73	0.403
0.5	2.61	41.25	0.374
0.75	2.883	43.89	0.35
1.	2.787	46.71	0.318
1.25	2.828	49.71	0.297
1.5	2.819	52.89	0.273
1.75	2.36	56.25	0.246
2.	1.55	59.85	0.228
2.25	0.874	63.45	0.216
2.609	1.501	67.65	0.196
2.97	1.638	71.85	0.181
3.39	1.445	76.05	0.168
3.809	1.468	80.85	0.158
4.408	1.42	86.25	0.149
4.71	1.403	91.05	0.139
5.339	1.362	97.05	0.133
5.729	1.332	103.	0.134
6.329	1.312	109.	0.132
6.93	1.278	115.6	0.121
7.529	1.245	122.8	0.122
8.189	1.213	130.6	0.117
8.91	1.179	138.4	0.115
9.689	1.147	146.8	0.121
10.47	1.114	155.8	0.114
11.31	1.074	165.4	0.113
12.21	1.03	175.	0.118
13.17	0.995	185.8	0.115
14.13	0.961	197.2	0.116
15.21	0.925	209.2	0.103

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
16.35	0.881	221.8	0.111
17.55	0.846	235.	0.104
18.81	0.804	249.4	0.11
20.13	0.769	264.4	0.107
21.57	0.726	280.	0.106
23.07	0.694	296.8	0.109
24.63	0.651	314.8	0.103
26.31	0.618	333.4	0.104
28.11	0.576	353.8	0.098
29.97	0.539	374.8	0.101
32.01	0.507	397.	0.109
34.11	0.472		

SOLUTION

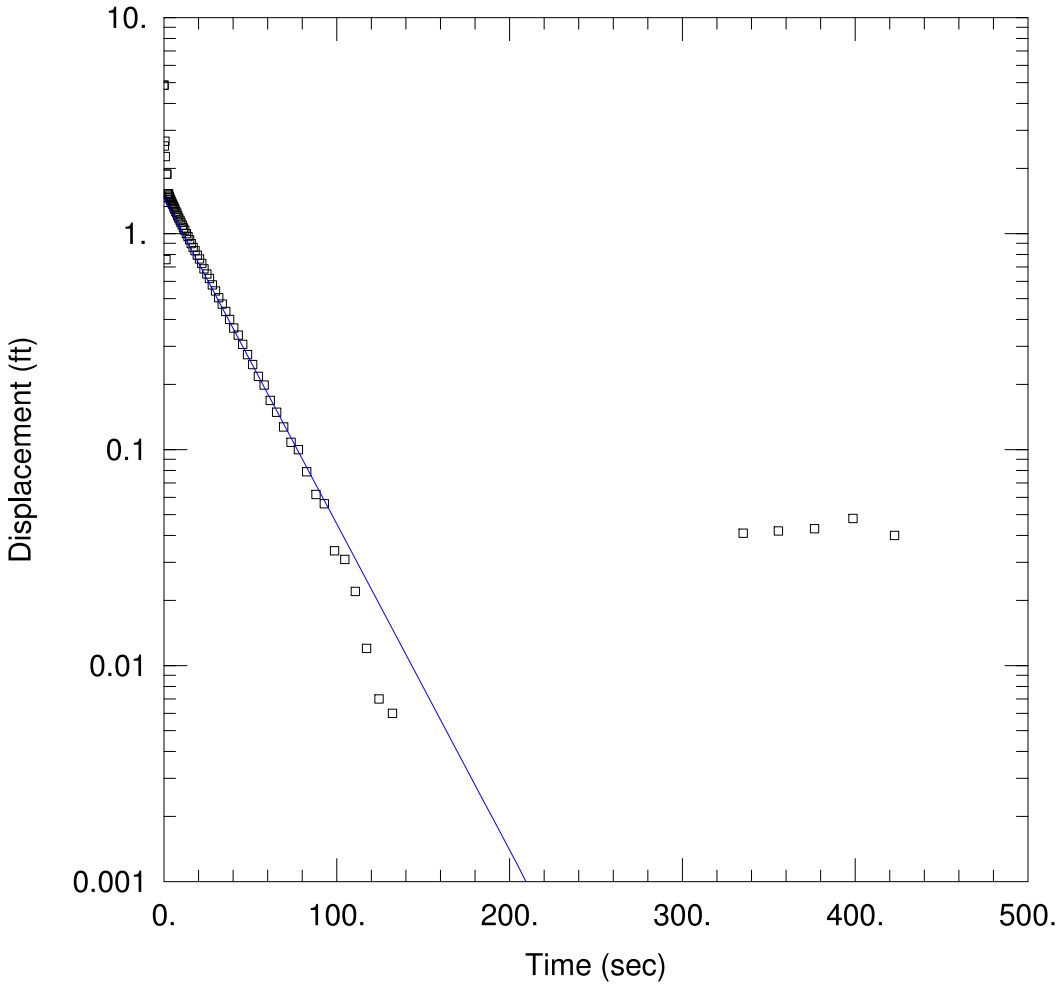
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.043

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0006495	cm/sec
y0	1.561	ft

$T = K*b = 1.56$ cm²/sec



SLUG IN 2

Data Set: P:\...\G02D Slug In 2.aqt
Date: 09/22/17 Time: 14:09:13

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G02D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 78.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G02D SI2)

Initial Displacement: 4.864 ft
Total Well Penetration Depth: 9.63 ft
Casing Radius: 0.03333 ft
Static Water Column Height: 10.34 ft
Screen Length: 9.63 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 2.373E-5 cm/sec
y0 = 1.461 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 2
Date: 09/22/17
Time: 14:09:43

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G02D

AQUIFER DATA

Saturated Thickness: 78.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G02D SI2

X Location: 832843. ft
Y Location: 202137.1 ft

Initial Displacement: 4.864 ft
Static Water Column Height: 10.34 ft
Casing Radius: 0.03333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.63 ft
Total Well Penetration Depth: 9.63 ft

No. of Observations: 91

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.864	31.72	0.505
0.25	2.543	33.76	0.472
0.629	2.675	35.86	0.436
0.752	2.268	38.08	0.4
1.	1.396	40.48	0.365
1.25	0.756	43.	0.338
1.643	1.884	45.64	0.307
1.766	1.881	48.46	0.275
2.	1.526	51.46	0.247
2.25	1.469	54.64	0.218
2.639	1.529	58.	0.199
2.762	1.51	61.6	0.169
3.	1.488	65.2	0.149
3.251	1.468	69.41	0.127
3.5	1.46	73.6	0.108
3.75	1.435	77.8	0.1
4.	1.426	82.6	0.079
4.36	1.402	88.	0.062
4.72	1.383	92.8	0.056
5.14	1.361	98.8	0.034
5.56	1.337	104.8	0.031
5.979	1.313	110.8	0.022
6.46	1.292	117.4	0.012
7.	1.264	124.6	0.007
7.48	1.243	132.4	0.006
8.08	1.208	140.2	0.
8.68	1.18	148.6	-0.006
9.28	1.153	157.6	-0.012
9.939	1.124	167.2	-0.011
10.66	1.093	176.8	-0.011

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
11.44	1.062	187.6	-0.013
12.22	1.036	199.	-0.016
13.06	0.999	211.	-0.019
13.96	0.968	223.6	-0.023
14.92	0.937	236.8	-0.025
15.88	0.897	251.2	-0.027
16.96	0.863	266.2	-0.029
18.1	0.832	281.8	-0.029
19.3	0.795	298.6	-0.031
20.56	0.763	316.6	-0.025
21.88	0.728	335.2	0.041
23.32	0.687	355.6	0.042
24.82	0.65	376.6	0.043
26.38	0.619	398.8	0.048
28.06	0.578	422.8	0.04
29.86	0.542		

SOLUTION

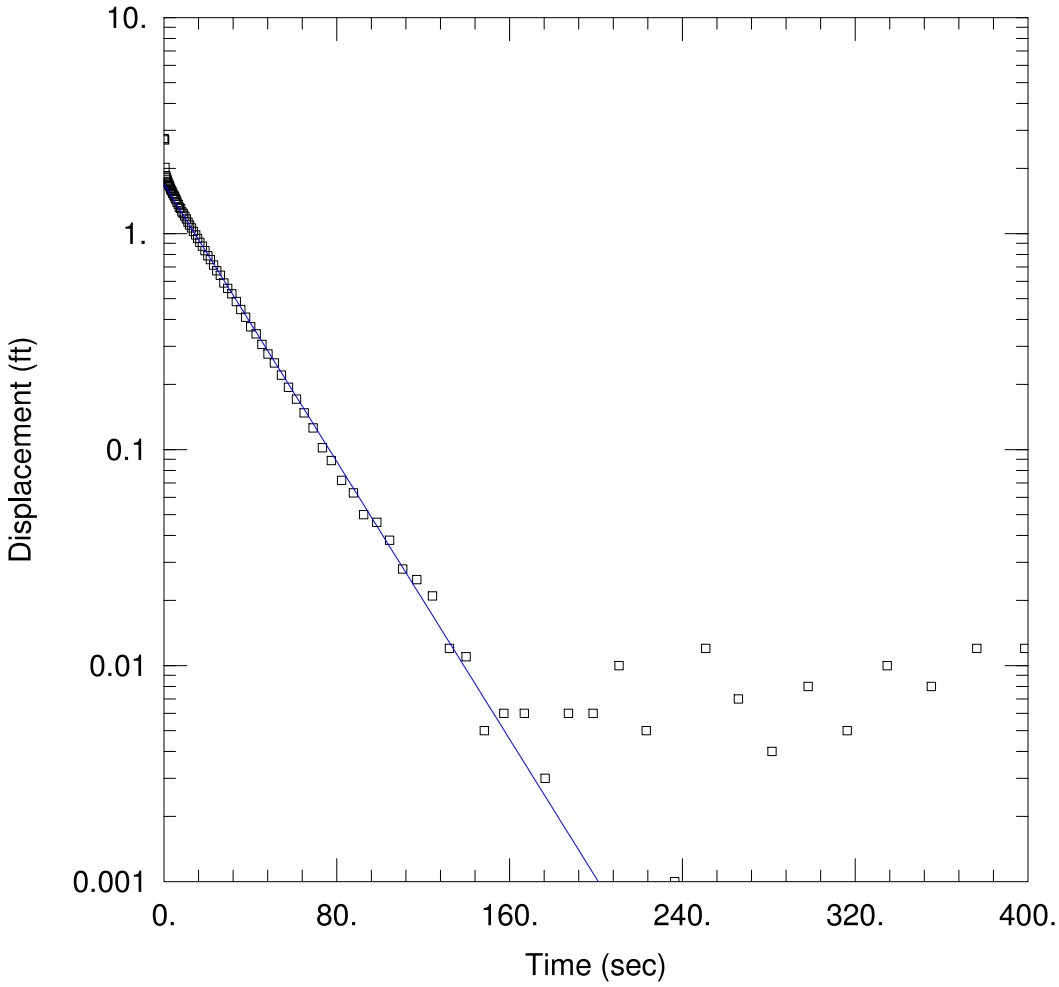
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.043

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	2.373E-5	cm/sec
y0	1.461	ft

$T = K*b = 0.05699$ cm²/sec



SLUG OUT 2

Data Set: P:\...\G02D Slug Out 2.aqt
Date: 09/22/17 Time: 14:12:11

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G02D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 78.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G02D SO1)

Initial Displacement: 2.749 ft
Total Well Penetration Depth: 9.63 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.34 ft
Screen Length: 9.63 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0007228 cm/sec
y0 = 1.693 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 2
Date: 09/22/17
Time: 14:12:31

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G02D

AQUIFER DATA

Saturated Thickness: 78.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G02D SO1

X Location: 832843. ft
Y Location: 202137.1 ft

Initial Displacement: 2.749 ft
Static Water Column Height: 10.34 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.63 ft
Total Well Penetration Depth: 9.63 ft

No. of Observations: 89

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.749	31.47	0.525
0.336	2.709	33.51	0.485
0.5	2.02	35.61	0.445
0.75	1.827	37.83	0.41
1.	1.851	40.23	0.37
1.25	1.805	42.75	0.343
1.5	1.773	45.39	0.307
1.75	1.732	48.21	0.277
2.	1.717	51.21	0.252
2.25	1.691	54.39	0.221
2.5	1.669	57.75	0.194
2.75	1.648	61.35	0.171
3.	1.618	64.95	0.148
3.25	1.598	69.15	0.126
3.5	1.581	73.35	0.102
3.75	1.567	77.55	0.089
4.109	1.532	82.35	0.072
4.469	1.508	87.75	0.063
4.889	1.49	92.55	0.05
5.309	1.455	98.55	0.046
5.729	1.432	104.5	0.038
6.209	1.395	110.5	0.028
6.749	1.361	117.1	0.025
7.229	1.322	124.3	0.021
7.829	1.306	132.1	0.012
8.429	1.261	139.9	0.011
9.029	1.238	148.3	0.005
9.689	1.203	157.3	0.006
10.41	1.167	166.9	0.006
11.19	1.129	176.5	0.003

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
11.97	1.094	187.3	0.006
12.81	1.062	198.7	0.006
13.71	1.022	210.7	0.01
14.67	0.986	223.3	0.005
15.63	0.95	236.5	0.001
16.71	0.911	250.9	0.012
17.85	0.875	265.9	0.007
19.05	0.833	281.5	0.004
20.31	0.79	298.3	0.008
21.63	0.756	316.3	0.005
23.07	0.715	334.9	0.01
24.57	0.672	355.3	0.008
26.13	0.64	376.3	0.012
27.81	0.591	398.5	0.012
29.61	0.558		

SOLUTION

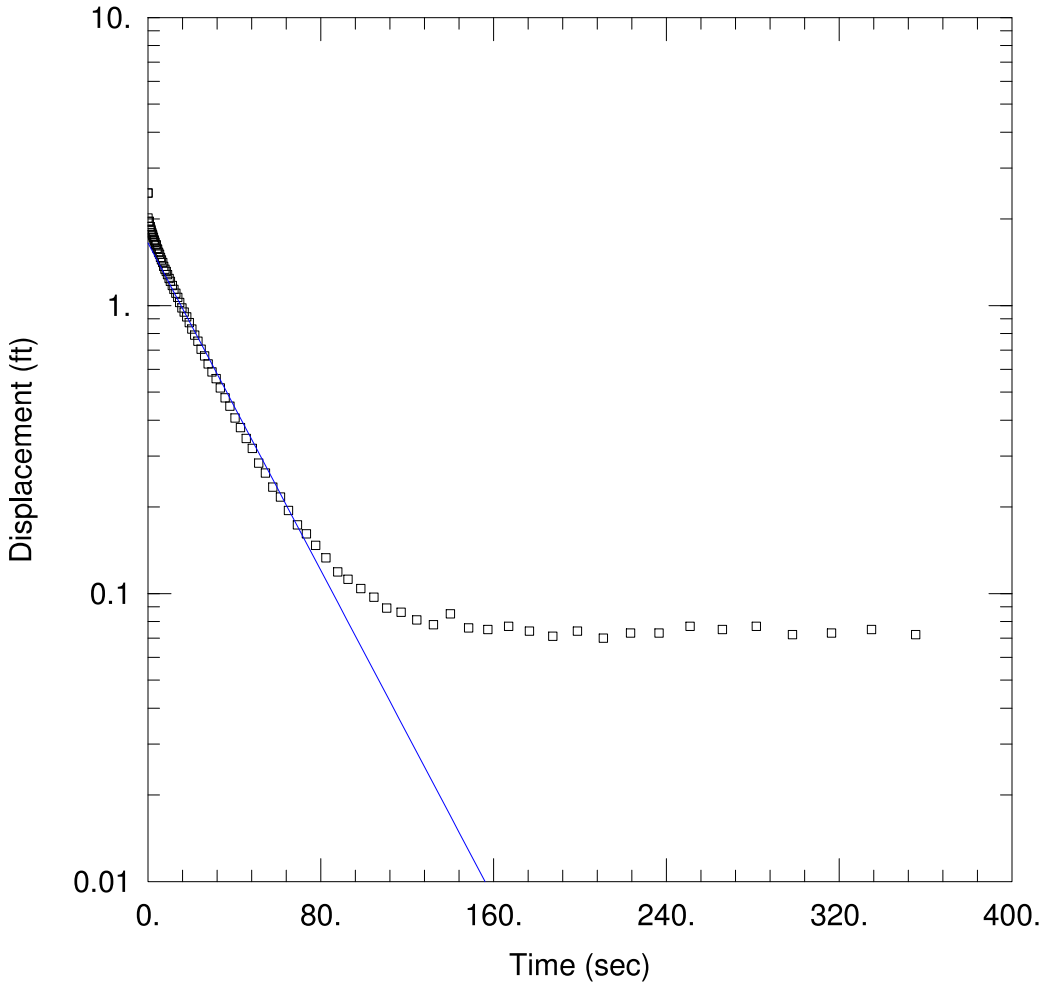
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.043

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0007228	cm/sec
y0	1.693	ft

T = K*b = 1.736 cm²/sec



SLUG OUT 3

Data Set: P:\...\G02D Slug Out 3.aqt
Date: 09/22/17 Time: 14:13:36

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G02D
Test Date: 4/4/2017

AQUIFER DATA

Saturated Thickness: 78.8 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G02D SO3)

Initial Displacement: 2.457 ft
Total Well Penetration Depth: 9.63 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.34 ft
Screen Length: 9.63 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0006395 cm/sec
y0 = 1.649 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 3
Date: 09/22/17
Time: 14:13:57

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/4/2017
Test Well: G02D

AQUIFER DATA

Saturated Thickness: 78.8 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G02D SO3

X Location: 832843. ft
Y Location: 202137.1 ft

Initial Displacement: 2.457 ft
Static Water Column Height: 10.34 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.63 ft
Total Well Penetration Depth: 9.63 ft

No. of Observations: 88

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.457	27.92	0.627
0.123	2.015	29.72	0.588
0.358	1.954	31.58	0.558
0.608	1.964	33.62	0.518
1.015	1.878	35.72	0.478
1.138	1.878	37.94	0.447
1.358	1.841	40.34	0.407
1.608	1.816	42.86	0.377
1.858	1.791	45.5	0.345
2.108	1.766	48.32	0.319
2.358	1.744	51.32	0.284
2.608	1.721	54.5	0.262
2.858	1.691	57.86	0.234
3.108	1.678	61.46	0.216
3.358	1.657	65.06	0.194
3.608	1.627	69.26	0.173
3.858	1.624	73.46	0.161
4.218	1.578	77.66	0.147
4.578	1.565	82.46	0.133
4.998	1.53	87.86	0.119
5.418	1.509	92.66	0.112
5.838	1.469	98.66	0.104
6.318	1.439	104.7	0.097
6.858	1.41	110.7	0.089
7.338	1.367	117.3	0.086
7.938	1.338	124.5	0.081
8.538	1.313	132.3	0.078
9.138	1.281	140.1	0.085
9.798	1.24	148.5	0.076
10.52	1.214	157.5	0.075

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
11.3	1.172	167.1	0.077
12.08	1.137	176.7	0.074
12.92	1.103	187.5	0.071
13.82	1.067	198.9	0.074
14.78	1.024	210.9	0.07
15.74	0.982	223.5	0.073
16.82	0.95	236.7	0.073
17.96	0.913	251.1	0.077
19.16	0.871	266.1	0.075
20.42	0.829	281.7	0.077
21.74	0.789	298.5	0.072
23.18	0.751	316.5	0.073
24.68	0.706	335.1	0.075
26.24	0.668	355.5	0.072

SOLUTION

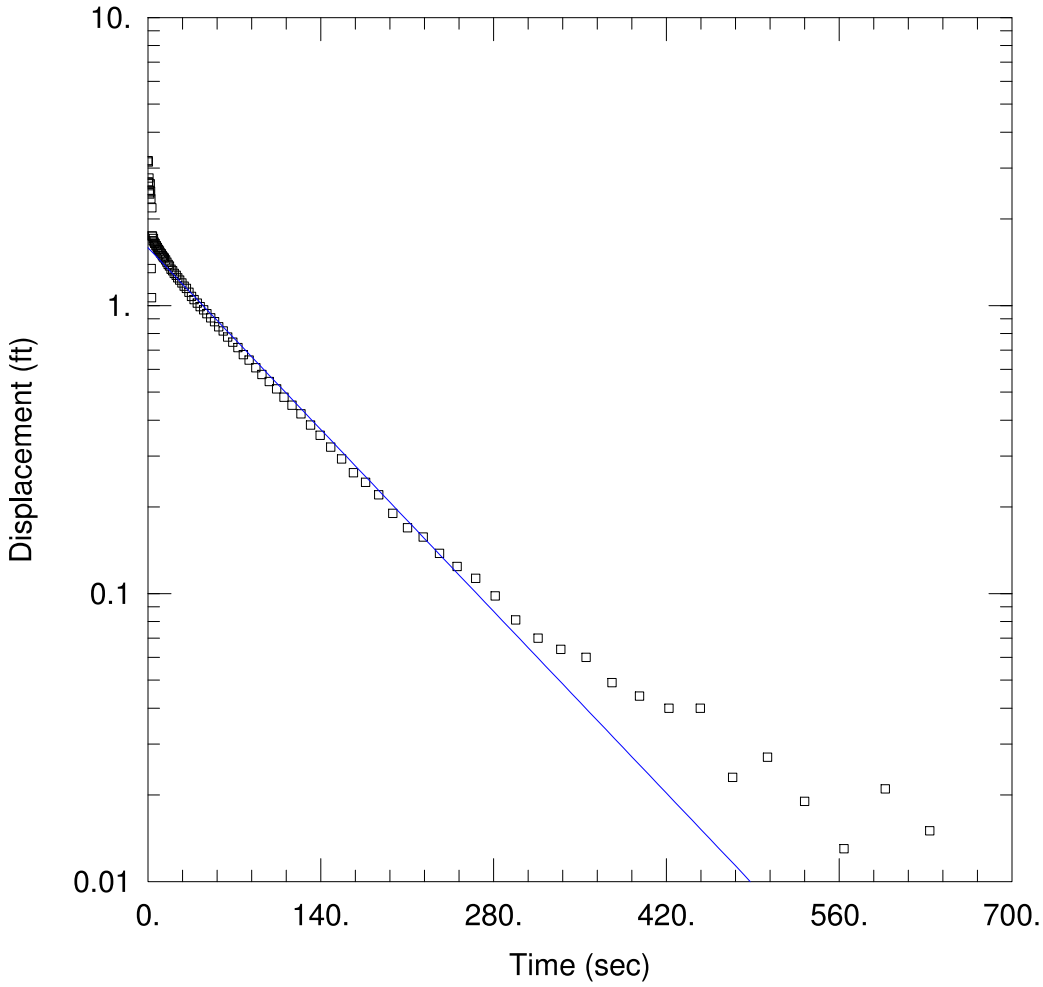
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.043

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0006395	cm/sec
y0	1.649	ft

$T = K*b = 1.536$ cm²/sec



SLUG IN 1

Data Set: P:\...\G51D Slug In 1.aqt
Date: 09/22/17 Time: 14:16:56

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G51D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 96.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G51D SI1)

Initial Displacement: 3.183 ft Static Water Column Height: 15.7 ft
Total Well Penetration Depth: 12.97 ft Screen Length: 9.66 ft
Casing Radius: 0.08333 ft Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice
K = 0.0002131 cm/sec y0 = 1.587 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 1
Date: 09/22/17
Time: 14:17:27

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G51D

AQUIFER DATA

Saturated Thickness: 96.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G51D SI1

X Location: 832151.5 ft
Y Location: 200430.1 ft

Initial Displacement: 3.183 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.66 ft
Total Well Penetration Depth: 12.97 ft

No. of Observations: 96

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	3.183	39.98	1.019
0.352	2.689	42.5	0.99
0.5	3.148	45.14	0.967
0.75	2.67	47.96	0.936
1.	2.77	50.96	0.907
1.25	2.512	54.14	0.878
1.5	2.462	57.5	0.843
1.75	2.437	61.1	0.817
2.	2.645	64.7	0.778
2.25	2.499	68.9	0.746
2.5	2.349	73.1	0.715
2.75	1.343	77.3	0.676
3.	1.065	82.1	0.646
3.25	2.187	87.5	0.608
3.5	1.743	92.3	0.576
3.86	1.741	98.3	0.544
4.22	1.678	104.3	0.514
4.64	1.708	110.3	0.48
5.059	1.66	116.9	0.451
5.479	1.643	124.1	0.421
5.96	1.64	131.9	0.385
6.499	1.616	139.7	0.354
6.979	1.613	148.1	0.322
7.579	1.59	157.1	0.293
8.18	1.572	166.7	0.263
8.779	1.562	176.3	0.243
9.439	1.545	187.1	0.22
10.16	1.525	198.5	0.19
10.94	1.51	210.5	0.169
11.72	1.488	223.1	0.157

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
12.56	1.475	236.3	0.138
13.46	1.461	250.7	0.124
14.42	1.439	265.7	0.113
15.38	1.413	281.3	0.098
16.46	1.388	298.1	0.081
17.6	1.372	316.1	0.07
18.8	1.338	334.7	0.064
20.06	1.32	355.1	0.06
21.38	1.294	376.1	0.049
22.82	1.273	398.3	0.044
24.32	1.247	422.3	0.04
25.88	1.225	447.5	0.04
27.56	1.197	473.9	0.023
29.36	1.168	502.1	0.027
31.22	1.147	532.1	0.019
33.26	1.112	563.9	0.013
35.36	1.076	597.5	0.021
37.58	1.048	633.5	0.015

SOLUTION

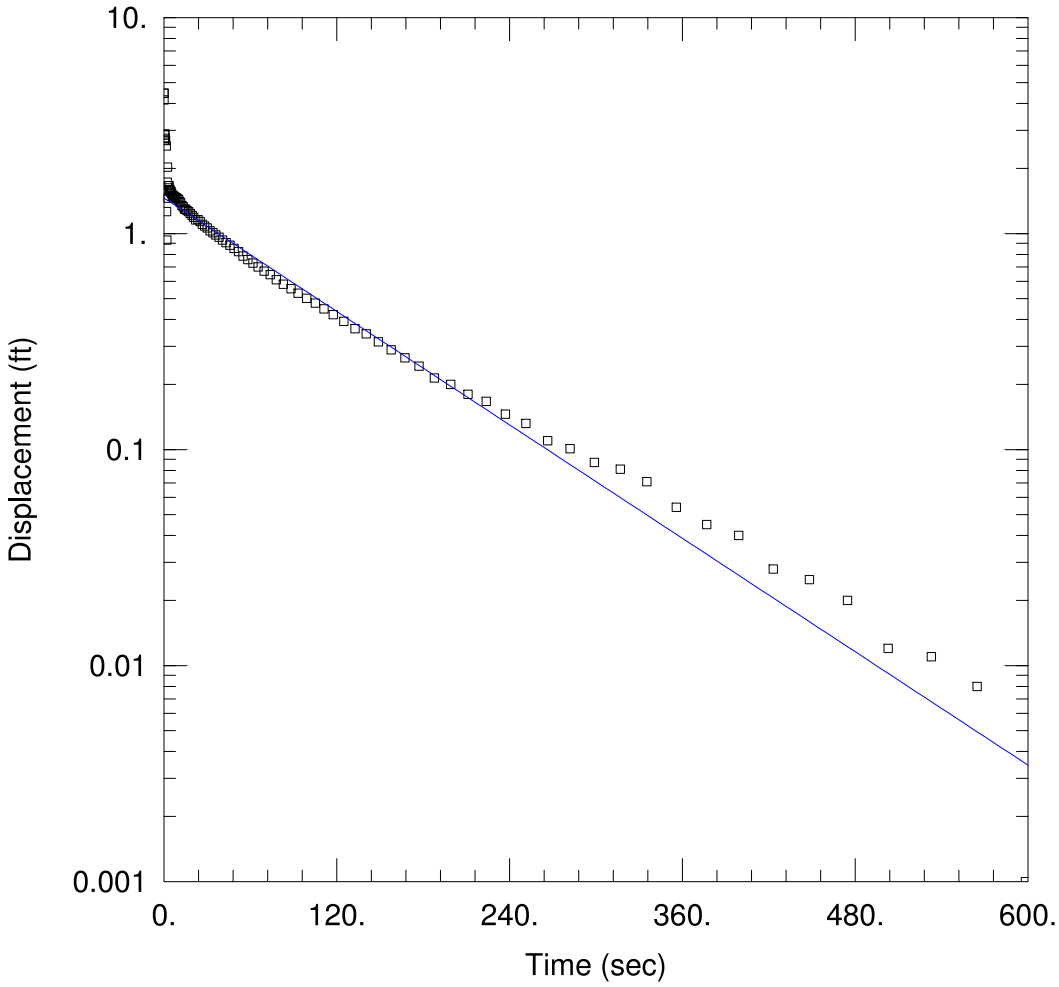
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.152

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0002131	cm/sec
y0	1.587	ft

$T = K*b = 0.6293$ cm²/sec



SLUG IN 2

Data Set: P:\...\G51D Slug In 2.aqt
Date: 09/22/17 Time: 14:18:51

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G51D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 96.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G51D SI2)

Initial Displacement: 4.465 ft
Total Well Penetration Depth: 12.97 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 15.7 ft
Screen Length: 9.66 ft
Well Radius: 0.03458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0003975 cm/sec
y0 = 1.459 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 2
Date: 09/22/17
Time: 14:19:09

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G51D

AQUIFER DATA

Saturated Thickness: 96.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G51D SI2

X Location: 832151.5 ft
Y Location: 200430.1 ft

Initial Displacement: 4.465 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.03458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.66 ft
Total Well Penetration Depth: 12.97 ft

No. of Observations: 99

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.465	36.18	0.985
0.123	4.153	38.4	0.962
0.322	2.709	40.8	0.931
0.572	2.891	43.32	0.908
0.822	2.85	45.96	0.884
1.072	2.76	48.78	0.852
1.322	2.695	51.78	0.824
1.572	2.54	54.96	0.786
1.822	1.262	58.32	0.758
2.072	0.931	61.92	0.73
2.322	1.731	65.52	0.701
2.572	2.03	69.72	0.669
2.822	1.625	73.92	0.645
3.072	1.46	78.12	0.611
3.322	1.668	82.92	0.583
3.572	1.663	88.32	0.555
3.822	1.569	93.12	0.529
4.072	1.594	99.12	0.502
4.322	1.594	105.1	0.476
4.682	1.549	111.1	0.448
5.042	1.567	117.7	0.421
5.462	1.535	124.9	0.392
5.881	1.49	132.7	0.363
6.301	1.501	140.5	0.343
6.782	1.491	148.9	0.315
7.321	1.476	157.9	0.289
7.801	1.473	167.5	0.266
8.401	1.467	177.1	0.243
9.002	1.457	187.9	0.214
9.601	1.446	199.3	0.2

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.26	1.431	211.3	0.18
10.98	1.403	223.9	0.167
11.76	1.388	237.1	0.146
12.54	1.347	251.5	0.132
13.38	1.329	266.5	0.11
14.28	1.298	282.1	0.101
15.24	1.293	298.9	0.087
16.2	1.278	316.9	0.081
17.28	1.263	335.5	0.071
18.42	1.236	355.9	0.054
19.62	1.214	376.9	0.045
20.88	1.186	399.1	0.04
22.2	1.156	423.1	0.028
23.65	1.159	448.3	0.025
25.14	1.135	474.7	0.02
26.7	1.102	502.9	0.012
28.38	1.082	532.9	0.011
30.18	1.062	564.7	0.008
32.04	1.029	598.3	0.001
34.08	1.009		

SOLUTION

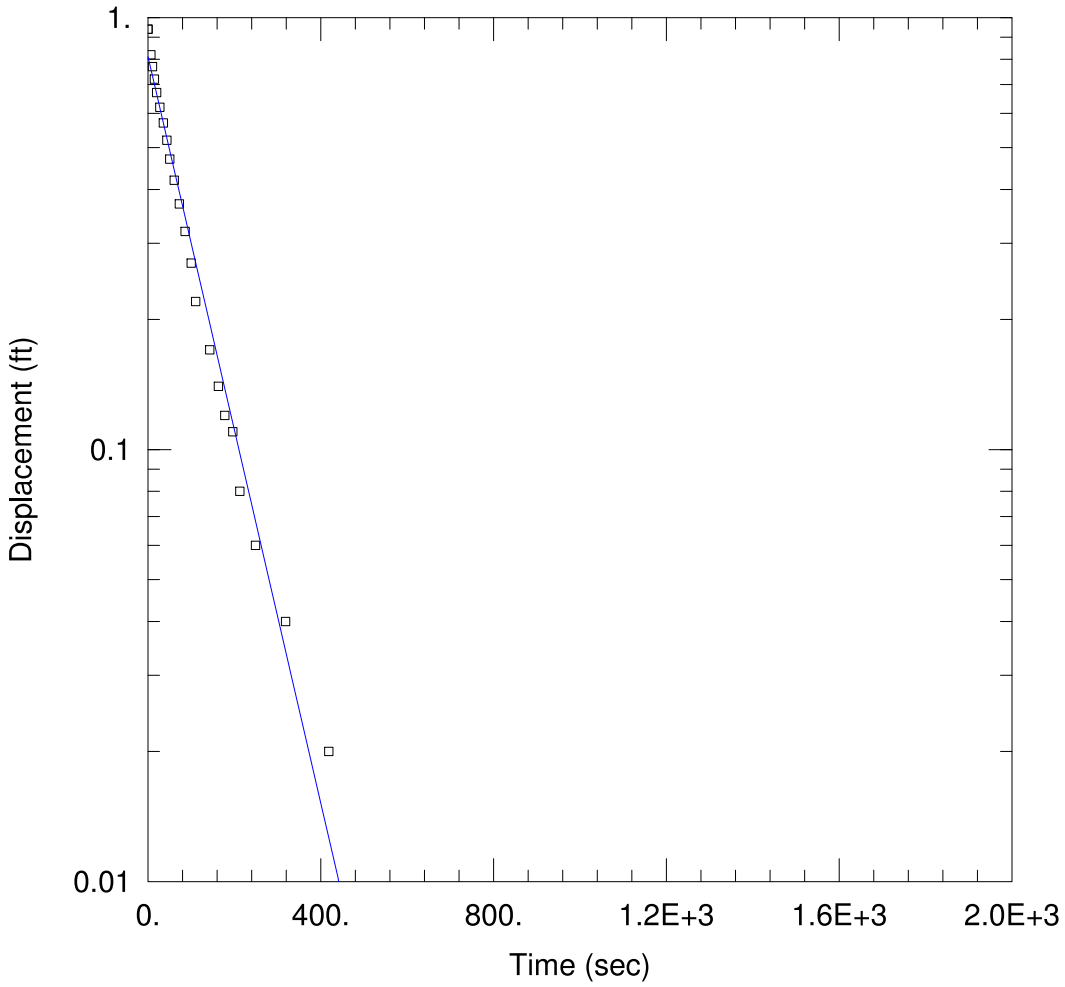
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 4.137

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0003975	cm/sec
y0	1.459	ft

$T = K*b = 1.174$ cm²/sec



SLUG OUT 1

Data Set: P:\...\G51D Slug Out 1.aqt
Date: 09/22/17 Time: 14:20:23

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G51D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 96.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G51D SO1)

Initial Displacement: 0.94 ft
Total Well Penetration Depth: 12.97 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 15.7 ft
Screen Length: 9.66 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0002346 cm/sec
y0 = 0.8117 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 1
Date: 09/22/17
Time: 14:20:38

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G51D

AQUIFER DATA

Saturated Thickness: 96.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G51D SO1

X Location: 832151.5 ft
Y Location: 200430.1 ft

Initial Displacement: 0.94 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.66 ft
Total Well Penetration Depth: 12.97 ft

No. of Observations: 23

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	0.94	100.	0.27
7.	0.82	111.	0.22
11.	0.77	143.	0.17
15.	0.72	163.	0.14
20.	0.67	178.	0.12
28.	0.62	197.	0.11
36.	0.57	213.	0.08
44.	0.52	249.	0.06
51.	0.47	319.	0.04
61.	0.42	419.	0.02
73.	0.37	1166.	-0.01
86.	0.32		

SOLUTION

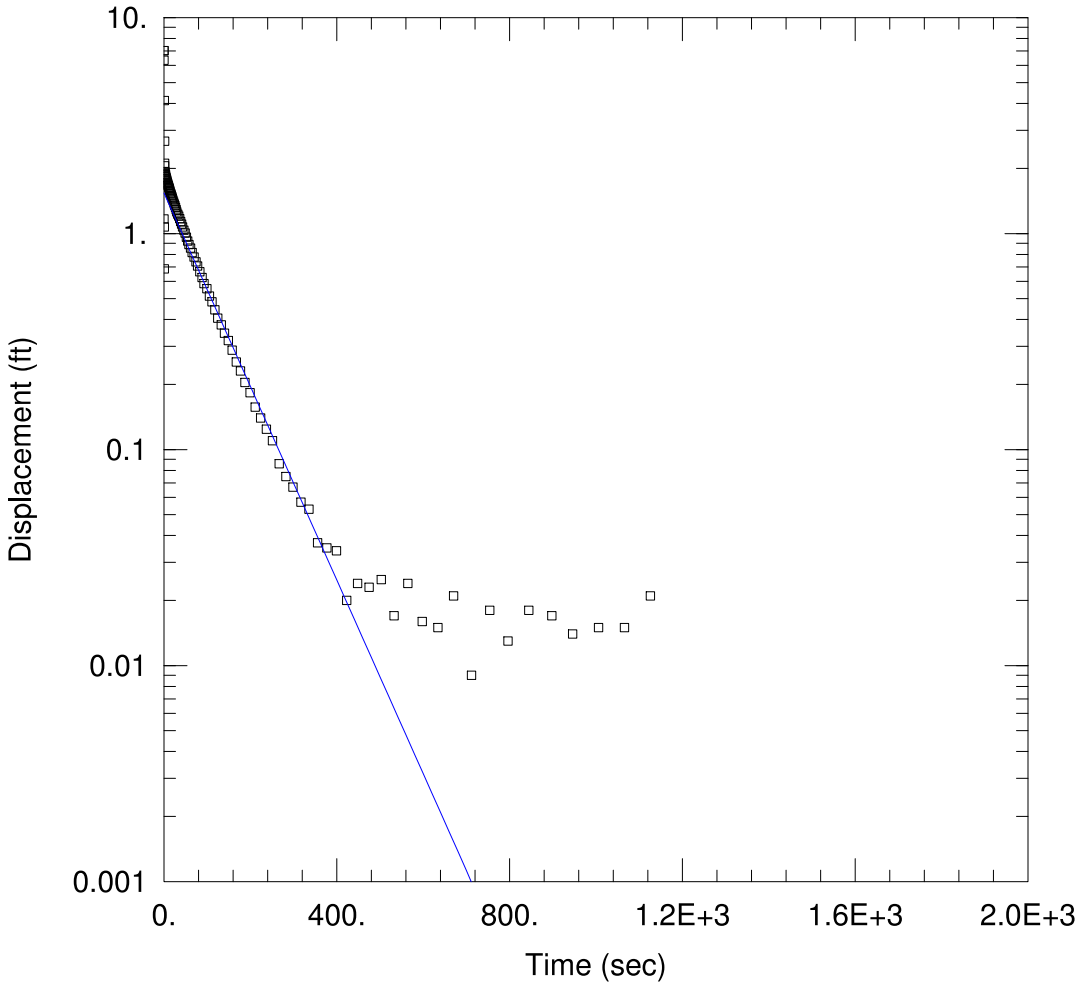
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.152

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0002346	cm/sec
y0	0.8117	ft

T = K*b = 0.6928 cm²/sec



SLUG OUT 2

Data Set: P:\...\G51D Slug Out 2.aqt
Date: 09/22/17 Time: 14:21:57

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G51D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 96.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G51D SO2)

Initial Displacement: 7.037 ft
Total Well Penetration Depth: 12.97 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 15.7 ft
Screen Length: 9.66 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0002118 cm/sec
y0 = 1.542 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 2
Date: 09/22/17
Time: 14:22:17

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G51D

AQUIFER DATA

Saturated Thickness: 96.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G51D SO2

X Location: 832151.5 ft
Y Location: 200430.1 ft

Initial Displacement: 7.037 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.66 ft
Total Well Penetration Depth: 12.97 ft

No. of Observations: 110

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	7.037	48.96	1.004
0.25	1.167	51.96	0.963
0.5	6.352	55.14	0.924
0.879	1.073	58.5	0.888
1.001	4.125	62.1	0.855
1.25	0.687	65.7	0.817
1.5	2.675	69.9	0.777
1.873	2.117	74.1	0.74
1.997	2.059	78.3	0.708
2.25	1.865	83.1	0.665
2.5	1.88	88.5	0.626
2.75	1.937	93.3	0.586
3.	1.835	99.3	0.555
3.25	1.891	105.3	0.513
3.5	1.851	111.3	0.482
3.75	1.868	117.9	0.443
4.	1.831	125.1	0.405
4.25	1.823	132.9	0.377
4.5	1.82	140.7	0.345
4.86	1.797	149.1	0.319
5.22	1.791	158.1	0.288
5.64	1.792	167.7	0.254
6.06	1.784	177.3	0.231
6.48	1.76	188.1	0.204
6.96	1.754	199.5	0.183
7.5	1.73	211.5	0.157
7.98	1.718	224.1	0.14
8.58	1.713	237.3	0.124
9.18	1.692	251.7	0.11
9.78	1.672	266.7	0.086

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.44	1.662	282.3	0.075
11.16	1.637	299.1	0.067
11.94	1.623	317.1	0.057
12.72	1.602	335.7	0.053
13.56	1.582	356.1	0.037
14.46	1.563	377.1	0.035
15.42	1.54	399.3	0.034
16.38	1.525	423.3	0.02
17.46	1.497	448.5	0.024
18.6	1.479	474.9	0.023
19.8	1.452	503.1	0.025
21.06	1.428	533.1	0.017
22.38	1.398	564.9	0.024
23.82	1.371	598.5	0.016
25.32	1.35	634.5	0.015
26.88	1.319	670.5	0.021
28.56	1.29	712.5	0.009
30.36	1.258	754.5	0.018
32.22	1.231	796.5	0.013
34.26	1.203	844.5	0.018
36.36	1.17	898.5	0.017
38.58	1.136	946.5	0.014
40.98	1.106	1006.5	0.015
43.5	1.072	1066.5	0.015
46.14	1.036	1126.5	0.021

SOLUTION

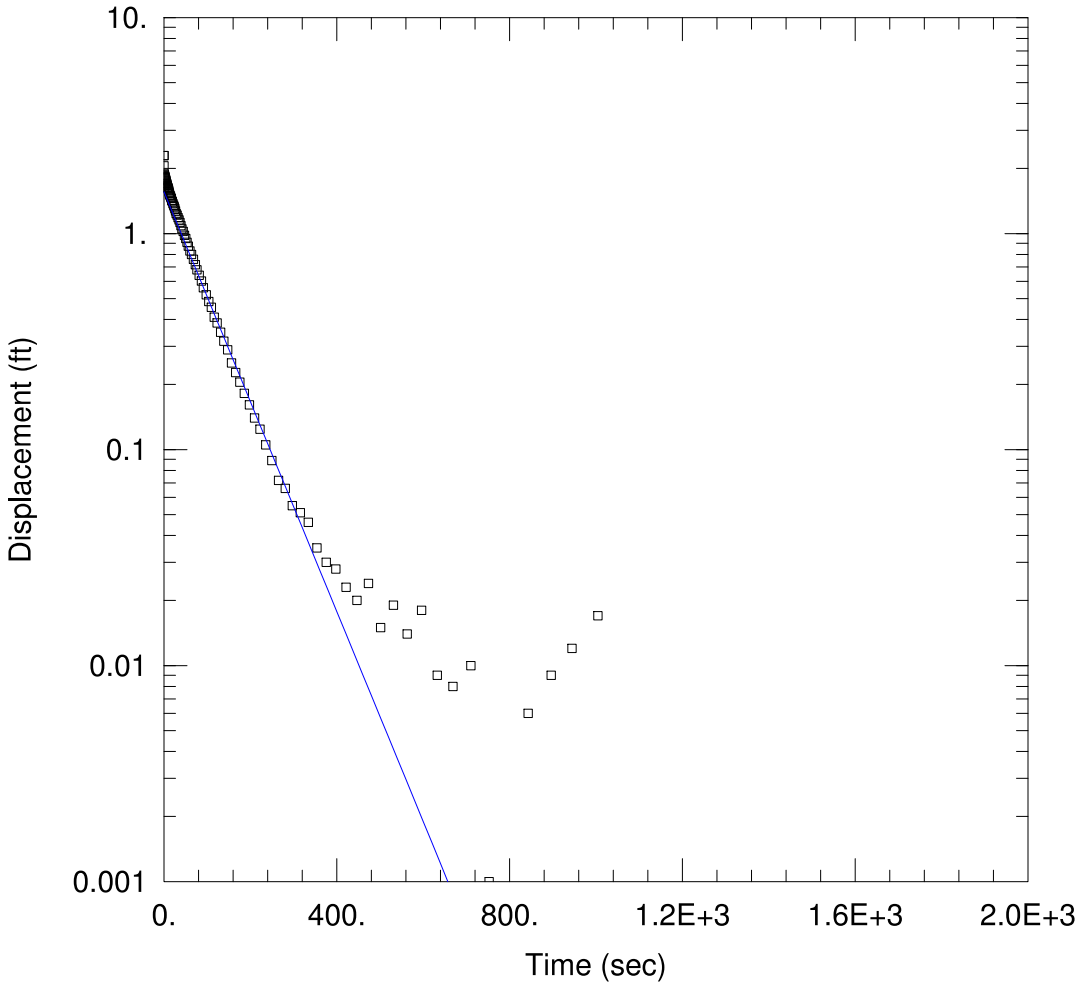
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.152

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0002118	cm/sec
y0	1.542	ft

$T = K*b = 0.6255$ cm²/sec



SLUG OUT 3

Data Set: P:\...\G51D Slug Out 3.aqt
Date: 09/22/17 Time: 14:23:14

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G51D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 96.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G51D SO3)

Initial Displacement: 2.298 ft
Total Well Penetration Depth: 12.97 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 15.7 ft
Screen Length: 9.66 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0002296 cm/sec
y0 = 1.56 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 3
Date: 09/22/17
Time: 14:23:30

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G51D

AQUIFER DATA

Saturated Thickness: 96.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G51D SO3

X Location: 832151.5 ft
Y Location: 200430.1 ft

Initial Displacement: 2.298 ft
Static Water Column Height: 15.7 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.66 ft
Total Well Penetration Depth: 12.97 ft

No. of Observations: 102

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.298	53.64	0.912
0.25	1.633	57.	0.875
0.5	2.056	60.6	0.83
0.75	1.808	64.2	0.8
1.	1.884	68.4	0.759
1.25	1.861	72.6	0.717
1.5	1.825	76.8	0.679
1.75	1.848	81.6	0.64
2.	1.827	87.	0.602
2.25	1.834	91.8	0.561
2.5	1.815	97.8	0.521
2.75	1.8	103.8	0.484
3.	1.799	109.8	0.455
3.36	1.785	116.4	0.41
3.72	1.78	123.6	0.385
4.14	1.767	131.4	0.349
4.56	1.756	139.2	0.317
4.979	1.741	147.6	0.289
5.46	1.731	156.6	0.252
5.999	1.708	166.2	0.227
6.479	1.703	175.8	0.205
7.08	1.686	186.6	0.182
7.68	1.672	198.	0.161
8.279	1.64	210.	0.14
8.939	1.629	222.6	0.124
9.659	1.62	235.8	0.105
10.44	1.597	250.2	0.089
11.22	1.575	265.2	0.072
12.06	1.555	280.8	0.066
12.96	1.531	297.6	0.055

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
13.92	1.507	315.6	0.051
14.88	1.492	334.2	0.046
15.96	1.474	354.6	0.035
17.1	1.452	375.6	0.03
18.3	1.423	397.8	0.028
19.56	1.403	421.8	0.023
20.88	1.375	447.	0.02
22.32	1.352	473.4	0.024
23.82	1.329	501.6	0.015
25.38	1.301	531.6	0.019
27.06	1.274	563.4	0.014
28.86	1.239	597.	0.018
30.72	1.216	633.	0.009
32.76	1.182	669.	0.008
34.86	1.155	711.	0.01
37.08	1.126	753.	0.001
39.48	1.089	795.	0.
42.	1.051	843.	0.006
44.64	1.021	897.	0.009
47.46	0.983	945.	0.012
50.46	0.947	1005.	0.017

SOLUTION

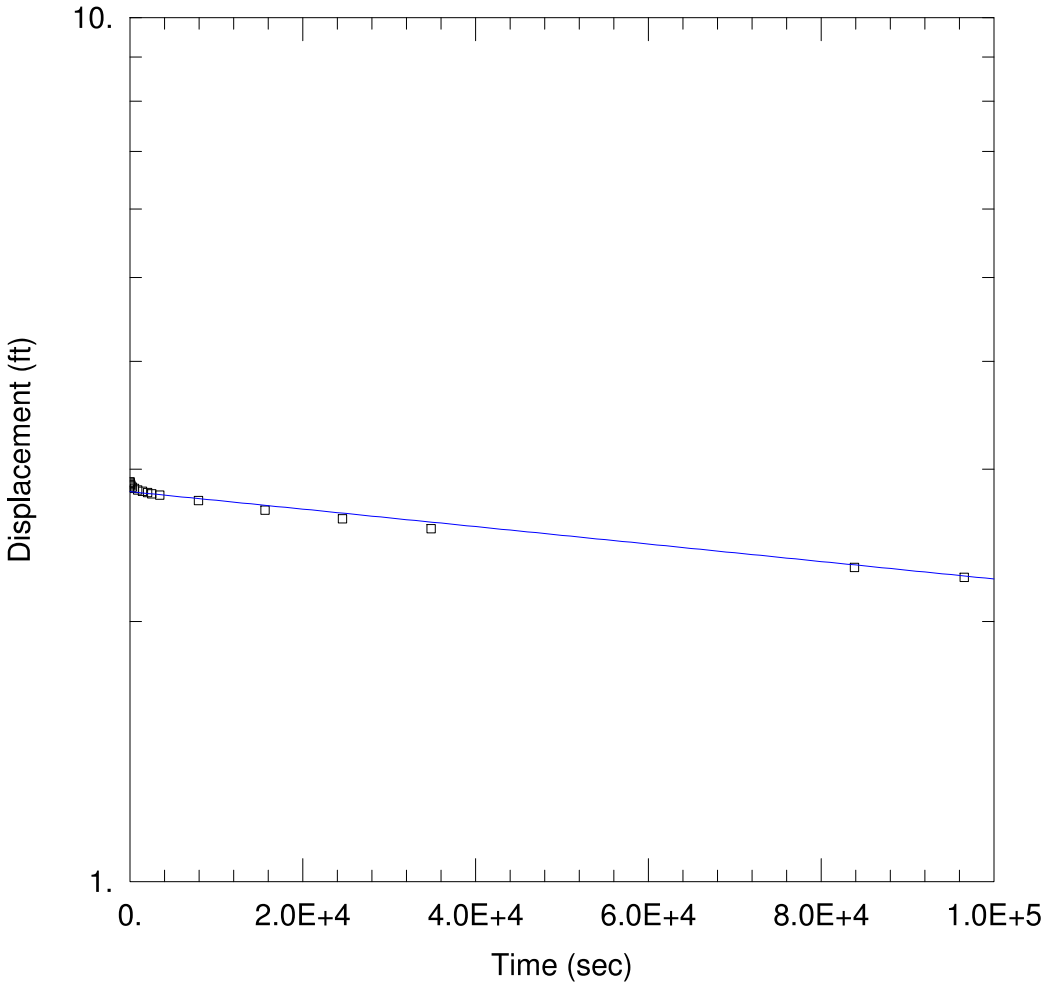
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.152

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0002296	cm/sec
y0	1.56	ft

$T = K*b = 0.6781$ cm²/sec



SLUG OUT 1

Data Set: P:\...\G52D Slug Out 1.aqt
Date: 09/22/17 Time: 14:28:08

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G52D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 55.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G52D SO1)

Initial Displacement: 2.9 ft
Total Well Penetration Depth: 4.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 10.03 ft
Screen Length: 4.2 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 7.129E-8 cm/sec
y0 = 2.826 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 1
Date: 09/22/17
Time: 14:29:14

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G52D

AQUIFER DATA

Saturated Thickness: 55.9 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G52D SO1

X Location: 832927.9 ft
Y Location: 198098.9 ft

Initial Displacement: 2.9 ft
Static Water Column Height: 10.03 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 4.2 ft
Total Well Penetration Depth: 4.2 ft

No. of Observations: 17

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.9	2555.	2.81
69.	2.89	3455.	2.8
108.	2.88	7949.	2.76
145.	2.87	1.566E+4	2.69
286.	2.86	2.462E+4	2.63
528.	2.85	3.488E+4	2.56
891.	2.84	8.386E+4	2.31
1461.	2.83	9.658E+4	2.25
2039.	2.82		

SOLUTION

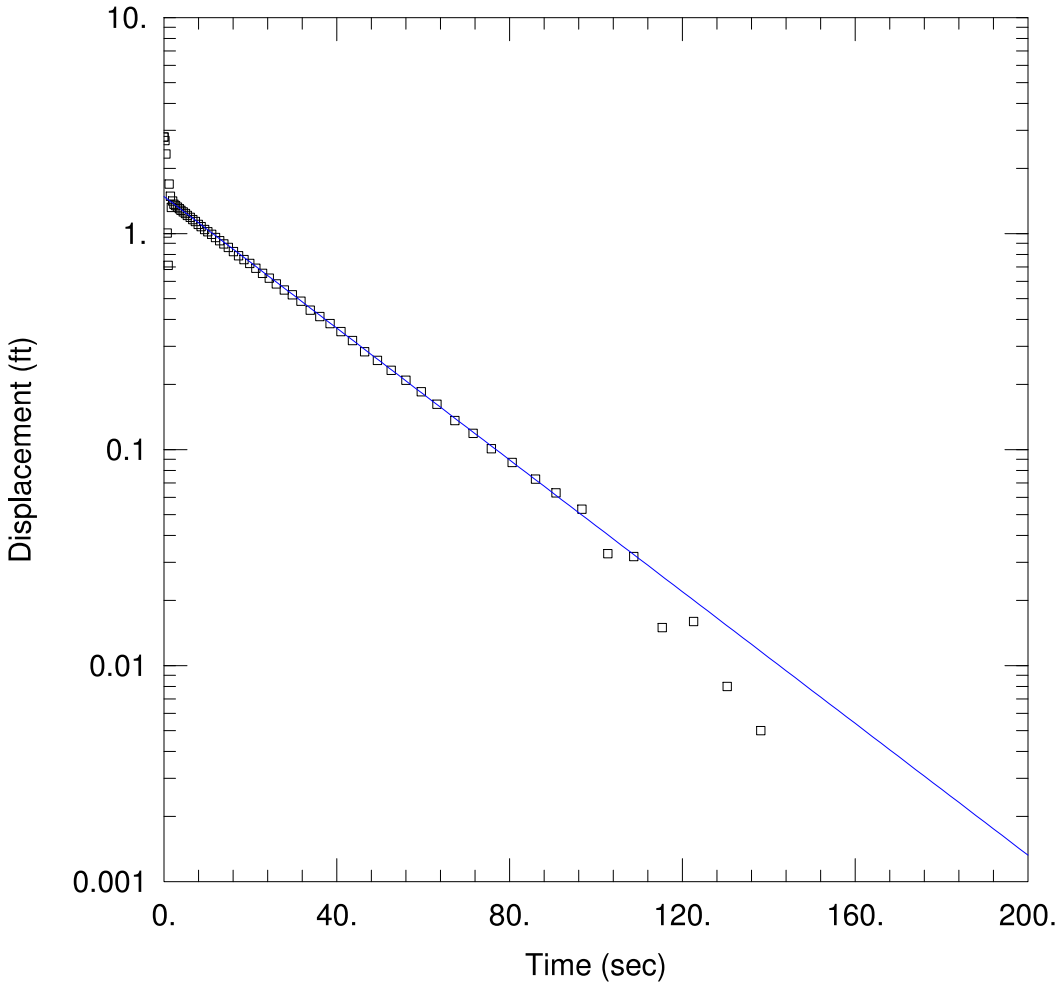
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.396

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	7.129E-8	cm/sec
y0	2.826	ft

T = K*b = 0.0001215 cm²/sec



SLUG IN 1

Data Set: P:\...\G53D Slug In 1.aqt
Date: 09/22/17 Time: 14:32:18

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G53D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 94.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G53D SI1)

Initial Displacement: 2.799 ft
Total Well Penetration Depth: 15.91 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 20. ft
Screen Length: 9.6 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0007519 cm/sec
y0 = 1.485 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 1
Date: 09/22/17
Time: 14:32:46

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G53D

AQUIFER DATA

Saturated Thickness: 94.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G53D SI1

X Location: 833980.2 ft
Y Location: 200075.2 ft

Initial Displacement: 2.799 ft
Static Water Column Height: 20. ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.6 ft
Total Well Penetration Depth: 15.91 ft

No. of Observations: 64

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.799	19.88	0.726
0.25	2.695	21.32	0.691
0.5	2.335	22.82	0.654
0.75	1.006	24.38	0.621
1.	0.713	26.06	0.584
1.25	1.695	27.86	0.548
1.5	1.489	29.72	0.521
1.75	1.321	31.76	0.486
2.	1.415	33.86	0.442
2.36	1.365	36.08	0.413
2.72	1.35	38.48	0.383
3.14	1.323	41.	0.351
3.56	1.304	43.64	0.319
3.98	1.281	46.46	0.284
4.46	1.26	49.46	0.259
5.	1.237	52.64	0.233
5.48	1.212	56.	0.209
6.08	1.186	59.6	0.185
6.68	1.159	63.2	0.162
7.28	1.136	67.4	0.136
7.94	1.103	71.6	0.119
8.66	1.076	75.8	0.101
9.44	1.045	80.6	0.087
10.22	1.019	86.	0.073
11.06	0.99	90.8	0.063
11.96	0.959	96.8	0.053
12.92	0.926	102.8	0.033
13.88	0.895	108.8	0.032
14.96	0.862	115.4	0.015
16.1	0.825	122.6	0.016

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
17.3	0.79	130.4	0.008
18.56	0.757	138.2	0.005

SOLUTION

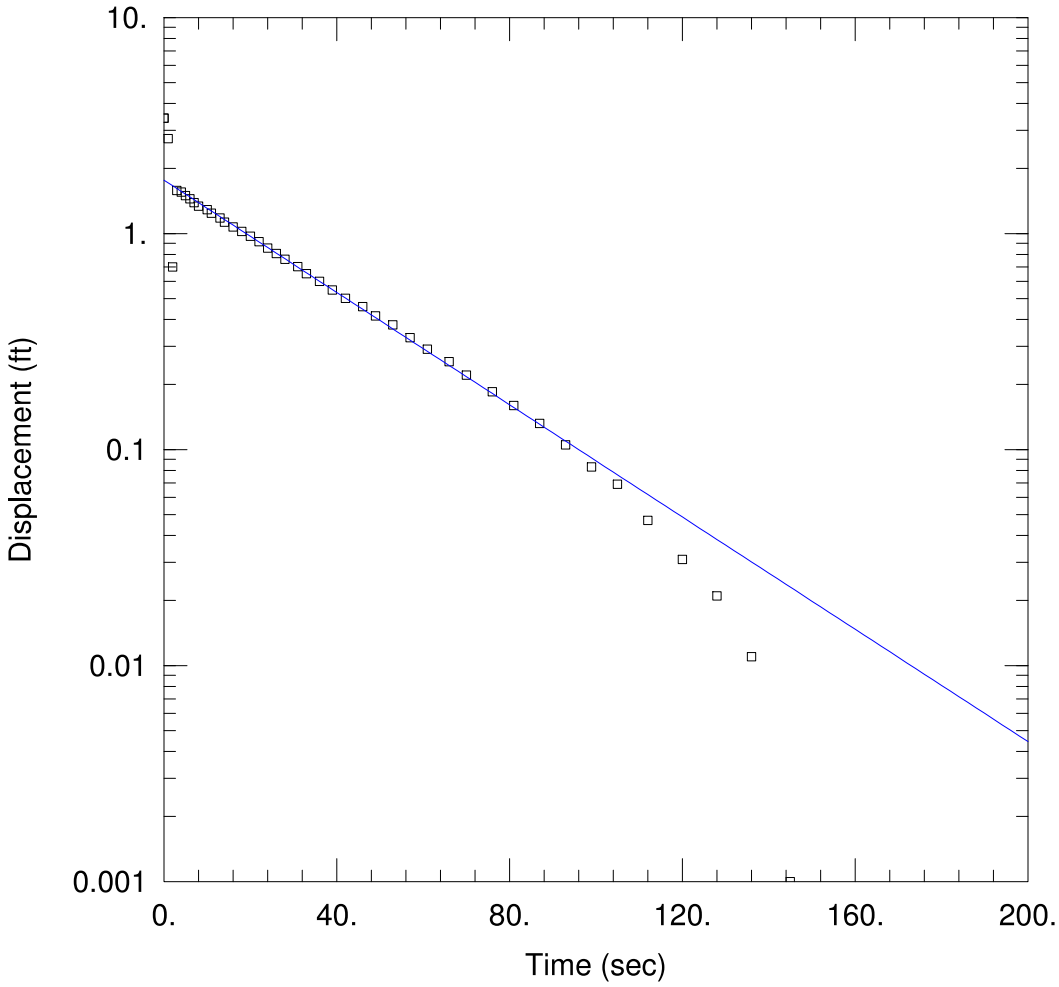
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.232

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0007519	cm/sec
y0	1.485	ft

$T = K*b = 2.159$ cm²/sec



SLUG IN 2

Data Set: P:\...\G53D Slug In 2.aqt
Date: 09/22/17 Time: 14:34:32

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G53D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 94.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G53D SI2)

Initial Displacement: 3.419 ft
Total Well Penetration Depth: 15.91 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 20. ft
Screen Length: 9.6 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0006408 cm/sec
y0 = 1.766 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug In 2
Date: 09/22/17
Time: 14:34:48

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G53D

AQUIFER DATA

Saturated Thickness: 94.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G53D SI2

X Location: 833980.2 ft
Y Location: 200075.2 ft

Initial Displacement: 3.419 ft
Static Water Column Height: 20. ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.6 ft
Total Well Penetration Depth: 15.91 ft

No. of Observations: 43

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	3.419	36.	0.601
1.	2.745	39.	0.548
2.	0.7	42.	0.501
3.	1.58	46.	0.459
4.	1.553	49.	0.415
5.	1.497	53.	0.377
6.	1.449	57.	0.329
7.	1.388	61.	0.291
8.	1.339	66.	0.255
10.	1.291	70.	0.221
11.	1.241	76.	0.185
13.	1.178	81.	0.16
14.	1.129	87.	0.132
16.	1.074	93.	0.105
18.	1.023	99.	0.083
20.	0.971	105.	0.069
22.	0.916	112.	0.047
24.	0.856	120.	0.031
26.	0.807	128.	0.021
28.	0.761	136.	0.011
31.	0.702	145.	0.001
33.	0.652		

SOLUTION

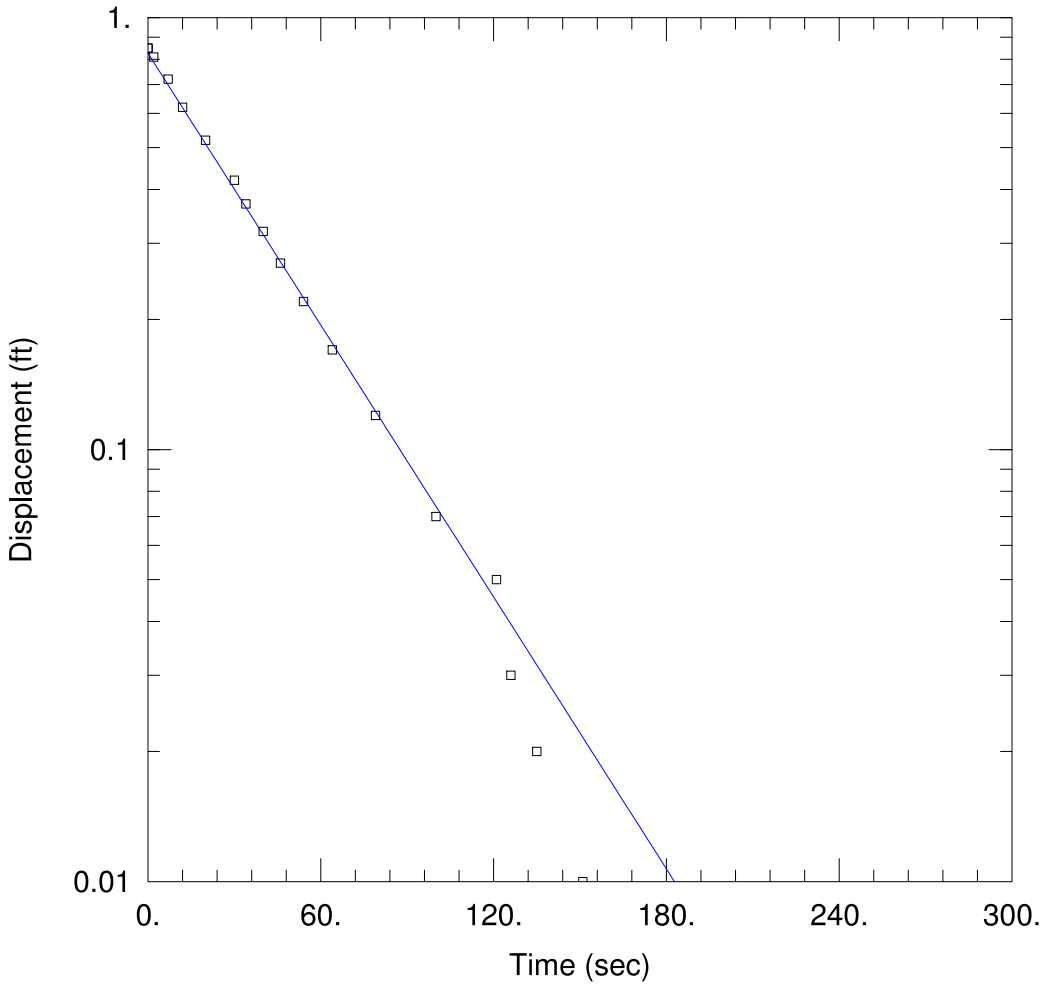
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.232

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0006408	cm/sec
y0	1.766	ft

T = K*b = 1.84 cm^2/sec



SLUG OUT1

Data Set: P:\...\G53D Slug Out 1.aqt
Date: 09/22/17 Time: 14:37:09

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G53D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 94.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G53D SO1)

Initial Displacement: 0.85 ft
Total Well Penetration Depth: 15.91 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 20. ft
Screen Length: 9.6 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 0.0005172 cm/sec y0 = 0.8263 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out1
Date: 09/22/17
Time: 14:37:25

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G53D

AQUIFER DATA

Saturated Thickness: 94.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G53D SO1

X Location: 833980.2 ft
Y Location: 200075.2 ft

Initial Displacement: 0.85 ft
Static Water Column Height: 20. ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.6 ft
Total Well Penetration Depth: 15.91 ft

No. of Observations: 20

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	0.85	54.	0.22
2.	0.81	64.	0.17
7.	0.72	79.	0.12
12.	0.62	100.	0.07
20.	0.52	121.	0.05
25.	-0.53	126.	0.03
30.	0.42	135.	0.02
34.	0.37	151.	0.01
40.	0.32	167.	0.
46.	0.27	209.	-0.01

SOLUTION

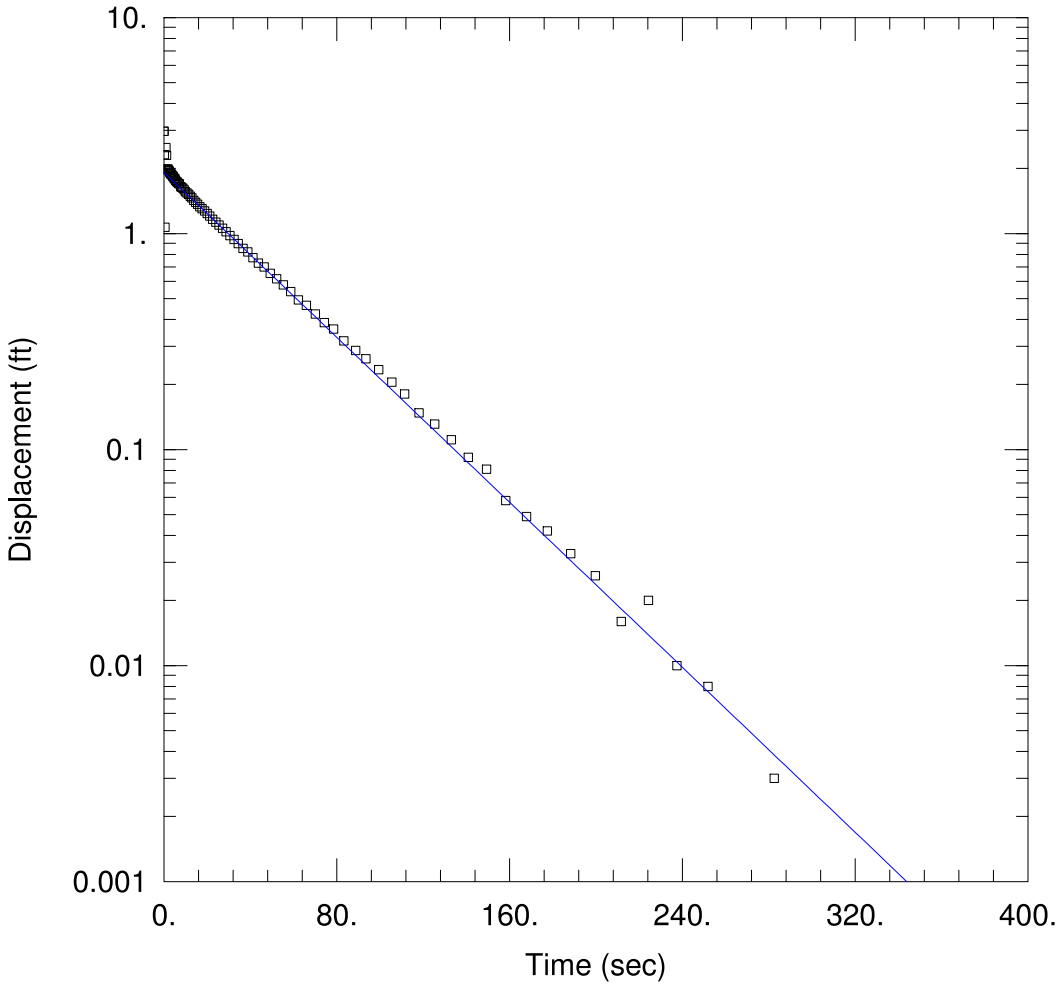
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.232

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0005172	cm/sec
y0	0.8263	ft

T = K*b = 1.485 cm²/sec



SLUG OUT 2

Data Set: P:\...\G53D Slug Out 2.aqt
Date: 09/22/17 Time: 14:38:38

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G53D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 94.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G53D S02)

Initial Displacement: 2.971 ft
Total Well Penetration Depth: 15.91 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 20. ft
Screen Length: 9.6 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004708 cm/sec
y0 = 1.92 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 2
Date: 09/22/17
Time: 14:39:04

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G53D

AQUIFER DATA

Saturated Thickness: 94.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G53D S02

X Location: 833980.2 ft
Y Location: 200075.2 ft

Initial Displacement: 2.971 ft
Static Water Column Height: 20. ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.6 ft
Total Well Penetration Depth: 15.91 ft

No. of Observations: 90

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.971	25.57	1.095
0.25	2.32	27.13	1.059
0.5	1.067	28.81	1.019
0.75	1.982	30.61	0.979
1.	2.502	32.47	0.938
1.25	2.3	34.51	0.897
1.5	1.991	36.61	0.854
1.75	1.99	38.83	0.823
2.	1.981	41.23	0.773
2.25	1.955	43.75	0.73
2.5	1.95	46.39	0.7
2.75	1.919	49.21	0.654
3.	1.897	52.21	0.617
3.25	1.888	55.39	0.578
3.5	1.88	58.75	0.539
3.75	1.864	62.35	0.493
4.	1.843	65.95	0.465
4.25	1.836	70.15	0.424
4.5	1.824	74.35	0.387
4.75	1.798	78.55	0.361
5.11	1.793	83.36	0.318
5.47	1.764	88.82	0.287
5.89	1.74	93.55	0.263
6.31	1.728	99.55	0.234
6.73	1.706	105.6	0.205
7.21	1.699	111.6	0.181
7.75	1.65	118.2	0.148
8.23	1.636	125.3	0.131
8.83	1.62	133.2	0.111
9.43	1.595	140.9	0.092

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.03	1.563	149.3	0.081
10.69	1.541	158.3	0.058
11.41	1.517	167.9	0.049
12.19	1.487	177.6	0.042
12.97	1.461	188.3	0.033
13.81	1.425	199.8	0.026
14.71	1.396	211.8	0.016
15.67	1.366	224.3	0.02
16.63	1.328	237.6	0.01
17.71	1.302	251.9	0.008
18.85	1.27	266.9	-0.002
20.05	1.238	282.6	0.003
21.31	1.204	299.4	-0.006
22.63	1.164	317.4	-0.007
24.07	1.13	335.9	-0.004

SOLUTION

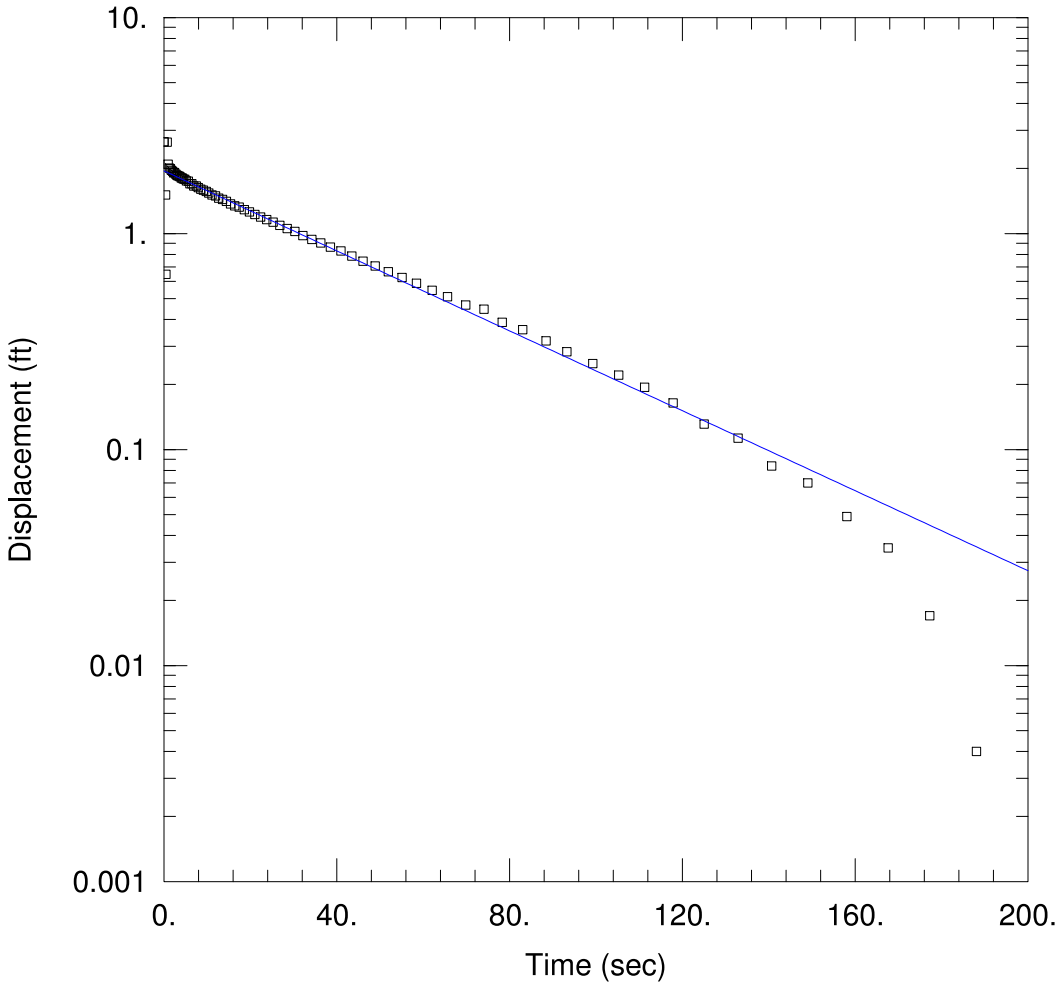
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.232

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0004708	cm/sec
y0	1.92	ft

T = K*b = 1.352 cm²/sec



SLUG OUT 3

Data Set: P:\...\G53D Slug Out 3.aqt
Date: 09/22/17 Time: 14:40:46

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G53D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 94.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G53D SO3)

Initial Displacement: 2.656 ft
Total Well Penetration Depth: 15.91 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 20. ft
Screen Length: 9.6 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.0004565 cm/sec
y0 = 1.95 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: Slug Out 3
Date: 09/22/17
Time: 14:41:01

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G53D

AQUIFER DATA

Saturated Thickness: 94.2 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G53D SO3

X Location: 833980.2 ft
Y Location: 200075.2 ft

Initial Displacement: 2.656 ft
Static Water Column Height: 20. ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 9.6 ft
Total Well Penetration Depth: 15.91 ft

No. of Observations: 79

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.656	19.8	1.26
0.379	1.509	21.06	1.227
0.502	0.648	22.38	1.193
0.75	2.652	23.82	1.16
1.	2.095	25.32	1.129
1.272	2.011	26.88	1.09
1.5	1.994	28.56	1.056
1.75	1.961	30.36	1.023
2.	1.944	32.22	0.979
2.25	1.906	34.26	0.939
2.5	1.913	36.36	0.903
2.75	1.882	38.58	0.864
3.	1.865	40.98	0.829
3.25	1.853	43.5	0.787
3.5	1.844	46.14	0.745
3.75	1.834	48.96	0.707
4.	1.806	51.96	0.666
4.25	1.805	55.14	0.625
4.5	1.79	58.5	0.588
4.86	1.784	62.1	0.546
5.22	1.752	65.7	0.51
5.64	1.745	69.9	0.467
6.06	1.702	74.1	0.447
6.48	1.698	78.3	0.388
6.96	1.66	83.1	0.359
7.5	1.662	88.5	0.318
7.98	1.632	93.3	0.284
8.58	1.603	99.3	0.25
9.18	1.586	105.3	0.221
9.78	1.567	111.3	0.194

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.44	1.542	117.9	0.164
11.16	1.51	125.1	0.131
11.94	1.492	132.9	0.113
12.72	1.459	140.7	0.084
13.56	1.436	149.1	0.07
14.46	1.407	158.1	0.049
15.42	1.373	167.7	0.035
16.38	1.343	177.3	0.017
17.46	1.323	188.1	0.004
18.6	1.291		

SOLUTION

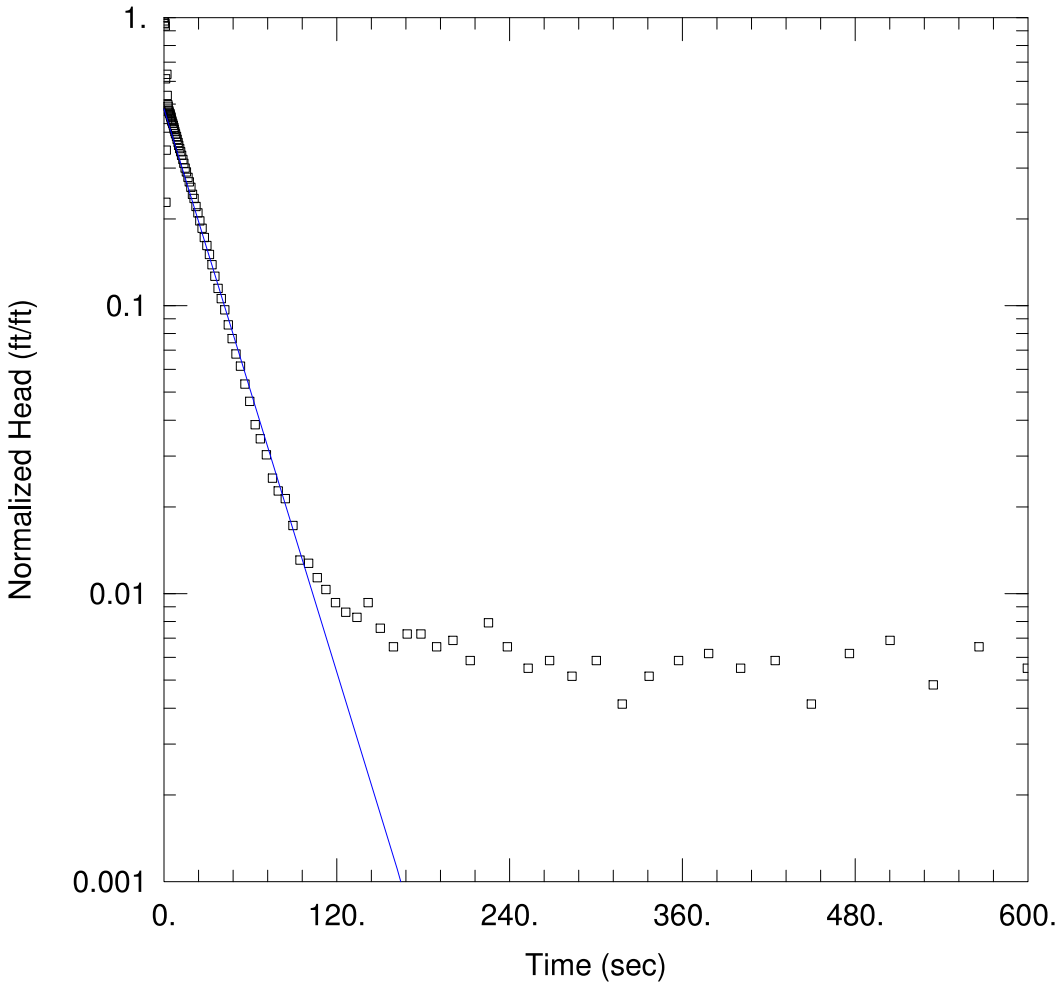
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 2.232

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0004565	cm/sec
y0	1.95	ft

$T = K*b = 1.311$ cm²/sec



G54D SLUG IN 1

Data Set: P:\...\G54D Slug In 1.aqt
Date: 09/22/17 Time: 14:43:41

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G54D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 59.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G54D SI1)

Initial Displacement: 2.906 ft Static Water Column Height: 6.14 ft
Total Well Penetration Depth: 5.66 ft Screen Length: 5.66 ft
Casing Radius: 0.08333 ft Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice
K = 0.0009929 cm/sec y0 = 1.4 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G54D Slug In 1
Date: 09/22/17
Time: 14:44:07

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G54D

AQUIFER DATA

Saturated Thickness: 59.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G54D SI1

X Location: 831610.4 ft
Y Location: 199066.8 ft

Initial Displacement: 2.906 ft
Static Water Column Height: 6.14 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 5.66 ft
Total Well Penetration Depth: 5.66 ft

No. of Observations: 104

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.906	31.61	0.437
0.284	2.832	33.47	0.403
0.5	2.768	35.51	0.367
0.75	2.78	37.61	0.333
1.	2.717	39.83	0.307
1.25	1.779	42.23	0.281
1.5	0.664	44.75	0.249
1.75	1.007	47.39	0.223
2.	1.844	50.21	0.197
2.25	1.559	53.21	0.179
2.5	1.285	56.39	0.155
2.75	1.446	59.75	0.135
3.	1.427	63.35	0.112
3.25	1.387	66.95	0.1
3.5	1.38	71.15	0.088
3.75	1.366	75.35	0.073
4.	1.352	79.55	0.066
4.25	1.342	84.35	0.062
4.5	1.328	89.75	0.05
4.75	1.316	94.55	0.038
5.	1.305	100.6	0.037
5.25	1.289	106.6	0.033
5.5	1.278	112.6	0.03
5.75	1.264	119.2	0.027
6.11	1.249	126.3	0.025
6.47	1.228	134.2	0.024
6.89	1.208	141.9	0.027
7.31	1.187	150.3	0.022
7.73	1.166	159.3	0.019
8.21	1.147	168.9	0.021

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
8.75	1.122	178.6	0.021
9.23	1.099	189.3	0.019
9.83	1.07	200.8	0.02
10.43	1.045	212.8	0.017
11.03	1.02	225.3	0.023
11.69	0.993	238.6	0.019
12.41	0.967	252.9	0.016
13.19	0.934	267.9	0.017
13.97	0.905	283.6	0.015
14.81	0.873	300.4	0.017
15.71	0.845	318.4	0.012
16.67	0.809	336.9	0.015
17.63	0.781	357.4	0.017
18.71	0.747	378.4	0.018
19.85	0.707	400.6	0.016
21.05	0.683	424.6	0.017
22.31	0.642	449.8	0.012
23.63	0.609	476.1	0.018
25.07	0.572	504.4	0.02
26.57	0.539	534.4	0.014
28.13	0.501	566.1	0.019
29.81	0.47	599.8	0.016

SOLUTION

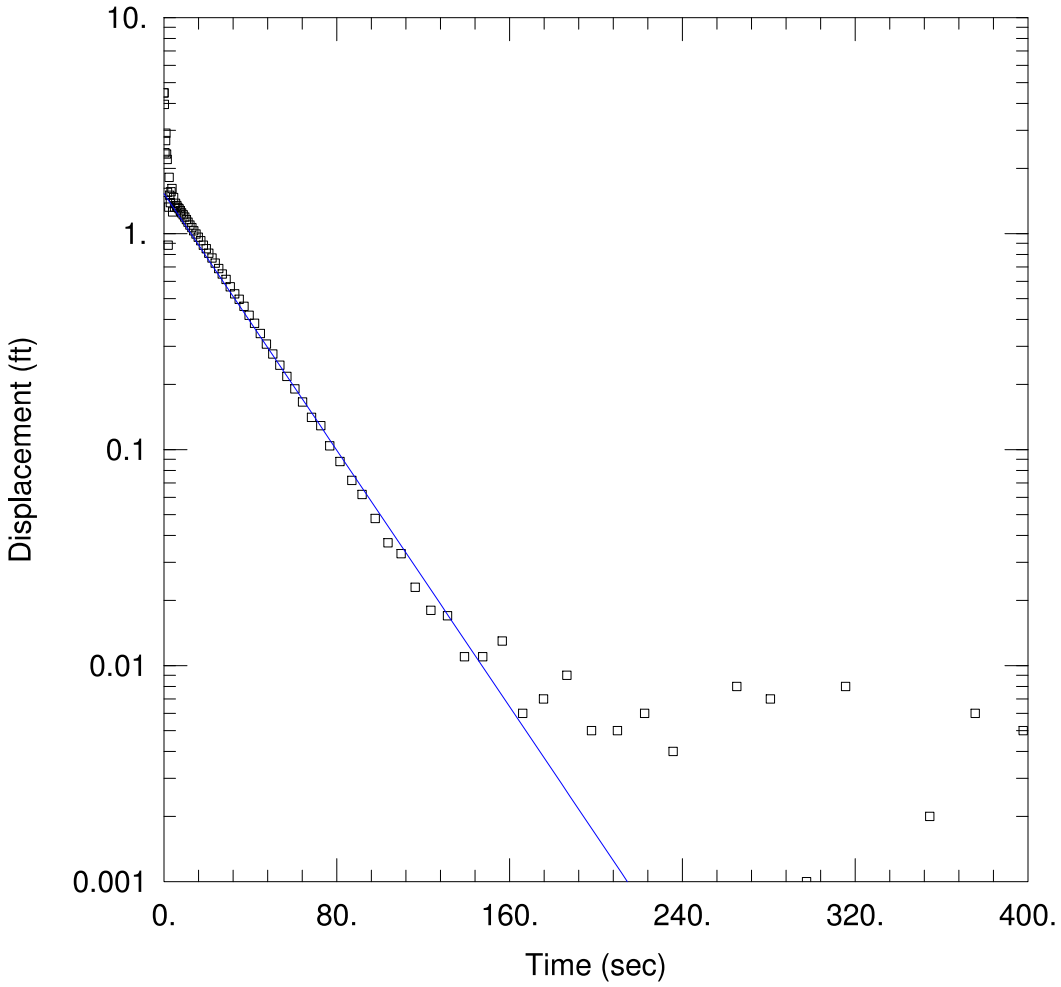
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.626

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0009929	cm/sec
y0	1.4	ft

$T = K*b = 1.807$ cm²/sec



G54D SLUG IN 2

Data Set: P:\...\G54D Slug In 2.aqt
Date: 09/22/17 Time: 14:45:25

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G54D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 59.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G54D SI2)

Initial Displacement: 4.476 ft Static Water Column Height: 6.14 ft
Total Well Penetration Depth: 5.66 ft Screen Length: 5.66 ft
Casing Radius: 0.08333 ft Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice
K = 0.0009041 cm/sec y0 = 1.528 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G54D Slug In 2
Date: 09/22/17
Time: 14:45:41

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G54D

AQUIFER DATA

Saturated Thickness: 59.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G54D SI2

X Location: 831610.4 ft
Y Location: 199066.8 ft

Initial Displacement: 4.476 ft
Static Water Column Height: 6.14 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 5.66 ft
Total Well Penetration Depth: 5.66 ft

No. of Observations: 86

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	4.476	32.76	0.526
0.25	3.961	34.86	0.496
0.5	2.37	37.08	0.46
0.75	2.692	39.48	0.419
1.	2.914	42.	0.384
1.25	2.337	44.64	0.344
1.5	2.204	47.46	0.308
1.75	1.552	50.46	0.277
2.	0.884	53.64	0.246
2.25	1.323	57.	0.218
2.5	1.822	60.6	0.191
2.75	1.505	64.2	0.166
3.	1.391	68.4	0.141
3.36	1.563	72.6	0.129
3.72	1.615	76.8	0.104
4.14	1.26	81.6	0.088
4.56	1.47	87.	0.072
4.98	1.325	91.8	0.062
5.46	1.382	97.8	0.048
6.	1.347	103.8	0.037
6.48	1.322	109.8	0.033
7.08	1.301	116.4	0.023
7.68	1.275	123.6	0.018
8.28	1.248	131.4	0.017
8.94	1.219	139.2	0.011
9.66	1.193	147.6	0.011
10.44	1.158	156.6	0.013
11.22	1.13	166.2	0.006
12.06	1.093	175.8	0.007
12.96	1.064	186.6	0.009

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
13.92	1.03	198.	0.005
14.88	0.996	210.	0.005
15.96	0.961	222.6	0.006
17.1	0.925	235.8	0.004
18.3	0.882	250.2	0.
19.56	0.85	265.2	0.008
20.88	0.812	280.8	0.007
22.32	0.771	297.6	0.001
23.82	0.73	315.6	0.008
25.38	0.688	334.2	-0.001
27.06	0.65	354.6	0.002
28.86	0.613	375.6	0.006
30.72	0.566	397.8	0.005

SOLUTION

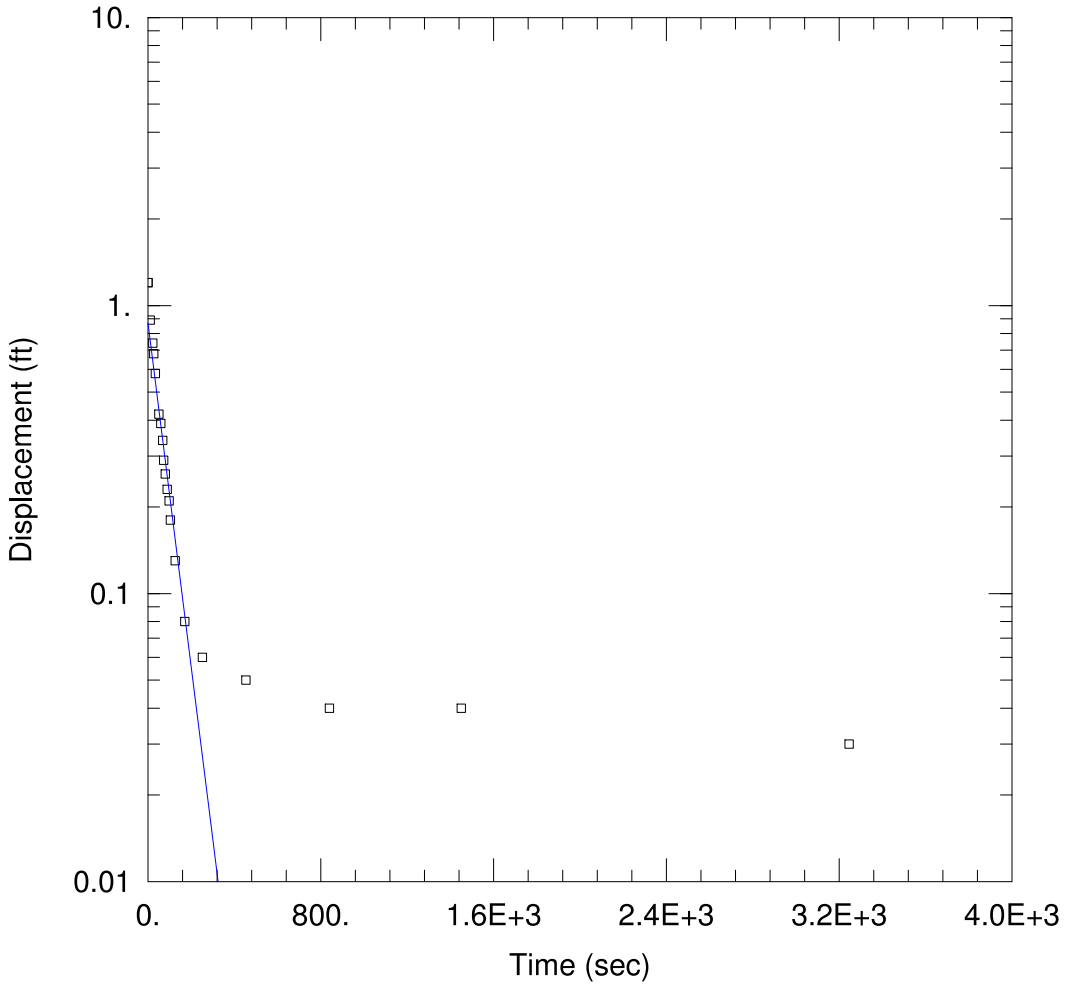
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.626

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0009041	cm/sec
y0	1.528	ft

$T = K*b = 1.645$ cm²/sec



G54D SLUG OUT 1

Data Set: P:\...\G54D Slug Out 1.aqt
Date: 09/22/17 Time: 14:47:11

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G54D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 59.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G54D SO1)

Initial Displacement: 1.2 ft
Total Well Penetration Depth: 5.66 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.14 ft
Screen Length: 5.66 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 0.0004181 cm/sec y0 = 0.8699 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G54D Slug Out 1
Date: 09/22/17
Time: 14:47:25

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G54D

AQUIFER DATA

Saturated Thickness: 59.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G54D SO1

X Location: 831610.4 ft
Y Location: 199066.8 ft

Initial Displacement: 1.2 ft
Static Water Column Height: 6.14 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 5.66 ft
Total Well Penetration Depth: 5.66 ft

No. of Observations: 20

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	1.2	89.	0.23
11.	0.89	98.	0.21
23.	0.74	104.	0.18
27.	0.68	126.	0.13
35.	0.58	171.	0.08
51.	0.42	252.	0.06
60.	0.39	454.	0.05
69.	0.34	841.	0.04
73.	0.29	1451.	0.04
81.	0.26	3246.	0.03

SOLUTION

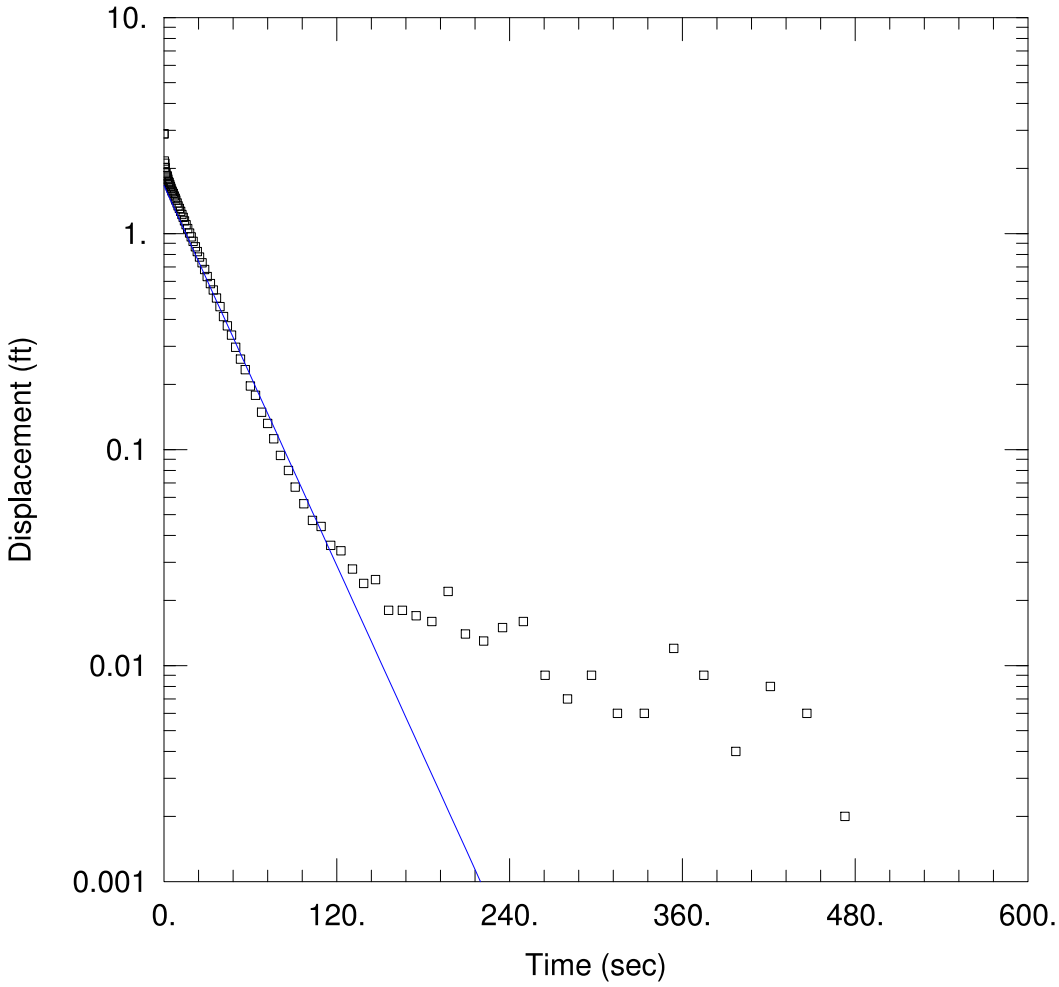
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.626

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0004181	cm/sec
y0	0.8699	ft

T = K*b = 0.7609 cm²/sec



G54D SLUG OUT 2

Data Set: P:\...\G54D Slug Out 2.aqt
Date: 09/22/17 Time: 14:48:47

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G54D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 59.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G54D SO2)

Initial Displacement: 2.891 ft
Total Well Penetration Depth: 5.66 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.14 ft
Screen Length: 5.66 ft
Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.000893 cm/sec
y0 = 1.668 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G54D Slug Out 2
Date: 09/22/17
Time: 14:49:02

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G54D

AQUIFER DATA

Saturated Thickness: 59.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G54D SO2

X Location: 831610.4 ft
Y Location: 199066.8 ft

Initial Displacement: 2.891 ft
Static Water Column Height: 6.14 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 5.66 ft
Total Well Penetration Depth: 5.66 ft

No. of Observations: 88

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	2.891	38.98	0.458
0.25	2.168	41.5	0.413
0.5	2.022	44.14	0.374
0.75	2.114	46.96	0.338
1.	2.014	49.96	0.297
1.25	1.911	53.14	0.262
1.5	1.908	56.5	0.234
1.75	1.858	60.1	0.197
2.	1.849	63.7	0.178
2.25	1.843	67.9	0.149
2.5	1.805	72.1	0.132
2.86	1.78	76.3	0.112
3.22	1.742	81.1	0.094
3.64	1.721	86.5	0.08
4.06	1.69	91.3	0.067
4.48	1.655	97.3	0.056
4.96	1.621	103.3	0.047
5.5	1.586	109.3	0.044
5.98	1.559	115.9	0.036
6.58	1.532	123.1	0.034
7.18	1.491	130.9	0.028
7.779	1.458	138.7	0.024
8.44	1.427	147.1	0.025
9.159	1.384	156.1	0.018
9.94	1.341	165.7	0.018
10.72	1.307	175.3	0.017
11.56	1.267	186.1	0.016
12.46	1.225	197.5	0.022
13.42	1.186	209.5	0.014
14.38	1.144	222.1	0.013

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
15.46	1.1	235.3	0.015
16.6	1.056	249.7	0.016
17.8	1.006	264.7	0.009
19.06	0.964	280.3	0.007
20.38	0.919	297.1	0.009
21.82	0.867	315.1	0.006
23.32	0.824	333.7	0.006
24.88	0.778	354.1	0.012
26.56	0.731	375.1	0.009
28.36	0.681	397.3	0.004
30.22	0.631	421.3	0.008
32.26	0.586	446.5	0.006
34.36	0.547	472.9	0.002
36.58	0.503	501.1	0.

SOLUTION

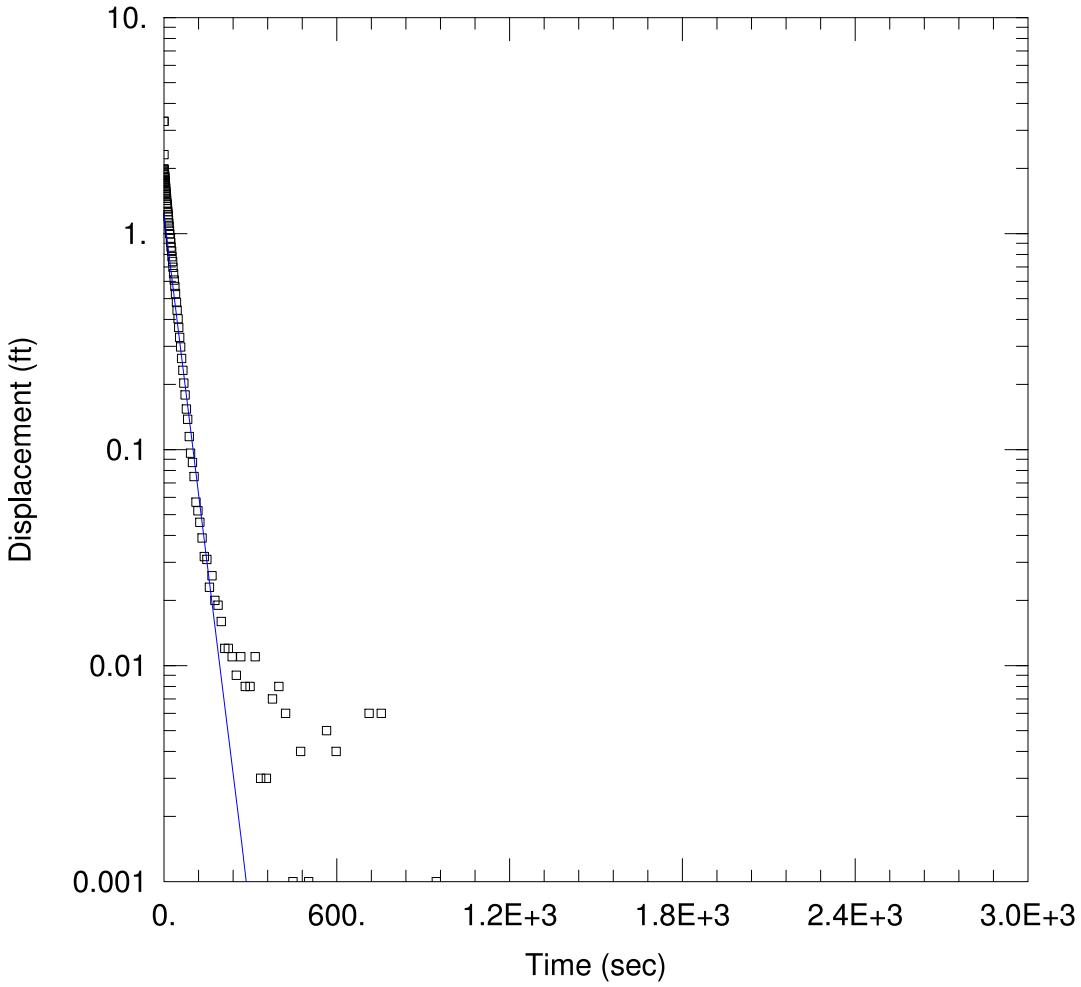
Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.626

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.000893	cm/sec
y0	1.668	ft

$T = K*b = 1.625$ cm²/sec



G54D SLUG OUT 3

Data Set: P:\...\G54D Slug Out 3.aqt
Date: 09/22/17 Time: 14:50:24

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Well: G54D
Test Date: 4/3/2017

AQUIFER DATA

Saturated Thickness: 59.7 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G54D SO3)

Initial Displacement: 3.308 ft Static Water Column Height: 6.14 ft
Total Well Penetration Depth: 5.66 ft Screen Length: 5.66 ft
Casing Radius: 0.08333 ft Well Radius: 0.3458 ft

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice

K = 0.0006569 cm/sec y0 = 1.225 ft

Data Set: P:\2200\2285\Data\Slug Testing\DC, HAV, COF, JOP, NEWT 2_2017\Joppa Tests\AQTESOLV and PDF
Title: G54D Slug Out 3
Date: 09/22/17
Time: 14:50:37

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Electric Energy, Inc. - Joppa
Project: 2285
Location: Joppa Power Station
Test Date: 4/3/2017
Test Well: G54D

AQUIFER DATA

Saturated Thickness: 59.7 ft
Anisotropy Ratio (Kz/Kr): 1.

SLUG TEST WELL DATA

Test Well: G54D SO3

X Location: 831610.4 ft
Y Location: 199066.8 ft

Initial Displacement: 3.308 ft
Static Water Column Height: 6.14 ft
Casing Radius: 0.08333 ft
Well Radius: 0.3458 ft
Well Skin Radius: 0.3458 ft
Screen Length: 5.66 ft
Total Well Penetration Depth: 5.66 ft

No. of Observations: 125

Observation Data

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
0.	3.308	78.3	0.154
0.25	2.319	83.1	0.138
0.5	1.98	88.5	0.115
0.75	1.985	93.3	0.096
1.	1.986	99.3	0.087
1.25	1.947	105.3	0.075
1.5	1.93	111.3	0.057
1.75	1.892	117.9	0.052
2.	1.873	125.1	0.046
2.25	1.87	132.9	0.039
2.5	1.839	140.7	0.032
2.75	1.822	149.1	0.031
3.	1.813	158.1	0.023
3.25	1.783	167.7	0.026
3.5	1.754	177.3	0.02
3.75	1.754	188.1	0.019
4.	1.742	199.5	0.016
4.25	1.723	211.5	0.012
4.5	1.697	224.1	0.012
4.86	1.697	237.3	0.011
5.22	1.658	251.7	0.009
5.64	1.641	266.7	0.011
6.06	1.623	282.3	0.008
6.48	1.581	299.1	0.008
6.96	1.562	317.1	0.011
7.5	1.533	335.7	0.003
7.98	1.511	356.1	0.003
8.58	1.481	377.1	0.007
9.18	1.457	399.3	0.008
9.78	1.424	423.3	0.006

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
10.44	1.386	448.5	0.001
11.16	1.365	474.9	0.004
11.94	1.33	503.1	0.001
12.72	1.301	533.1	0.
13.56	1.262	564.9	0.005
14.46	1.226	598.5	0.004
15.42	1.193	634.5	-0.003
16.38	1.155	670.5	0.
17.46	1.119	712.5	0.006
18.6	1.079	754.5	0.006
19.8	1.036	796.5	0.
21.06	0.999	844.5	-0.001
22.38	0.952	898.5	-0.005
23.82	0.912	946.5	0.001
25.32	0.866	1006.5	-0.003
26.88	0.827	1066.5	-0.001
28.56	0.782	1126.5	-0.004
30.36	0.741	1192.5	-0.005
32.22	0.698	1264.5	-0.006
34.26	0.652	1342.5	-0.009
36.36	0.609	1420.5	-0.01
38.58	0.568	1504.5	-0.007
40.98	0.528	1594.5	-0.015
43.5	0.479	1690.5	-0.011
46.14	0.442	1786.5	-0.012
48.96	0.403	1894.5	-0.018
51.96	0.368	2008.5	-0.012
55.14	0.331	2128.5	-0.019
58.5	0.298	2254.5	-0.014
62.1	0.264	2386.5	-0.011
65.7	0.233	2530.5	-0.023
69.9	0.203	2680.5	-0.022
74.1	0.179		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Bouwer-Rice
ln(Re/rw): 1.626

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
K	0.0006569	cm/sec
y0	1.225	ft

T = K*b = 1.195 cm²/sec

BORING LOGS

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 1 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	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)
0				SS	14/24	2 2 3 6	5	(0') CLAY (CL); some silt, high organics/roots, brown (10YR 4/3). (0.25') CLAYEY SILT (ML); brownish yellow (10YR 6/6), soft, dry, some light gray mottling.		
				SS	20/24	2 3 4 5	7	(2') As above: higher plasticity. (MH)		
5				SS	23/24	2 3 5 6	8	(4') As above: few sand, lower plasticity. (ML)		
				SS	24/24	2 3 4 6	7	(6') SILT (ML); few sand and clay, yellowish brown (10YR 5/6), medium dense, dry, some light gray mottling.		
				SS	23/24	1 4 6 7	10	(8') As above.		
10				SS	23/24	2 6 6 8	12	(11') As above: trace fine gravel from 11 to 11.5' bgs.		
				SS	24/24	2 6 7 10	13	(12') As above: brownish yellow (10YR 6/6).		
				SS	24/24	2 3 5 5	8	(14') As above: more light gray (10YR 7/2) mottling.		
15				SS	24/24	2 3 5 6	8	(16') As above: trace sand.		
				SS	24/24	3 4 5 9	9	(18') As above: light gray (10YR 7/2) becomes dominant.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 2 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	1 4 8 10	12	(20') SILT (ML); few clay, brownish yellow (10YR 6/6), very stiff, dry.		
				SS	24/24	4 6 7 4	13	(22') SANDY SILT (ML); yellowish brown (10YR 5/6), soft, dry.		
				SS	24/24	2 5 5 8	10	(24') As above: becomes moist, few red (2.5YR 4/6) silt.		
25				SS	24/24	1 5 5 6	10	(26') As above: red silt disappears.		
				SS	24/24	1 3 4 6	7	(28') As above: becomes grayish brown (10YR 5/2).		
30				SS	24/24	1 4 4 5	8	(30') As above.	30-32 Chem	
				SH	24/24				32-34 Geotech	
				SS	24/24	3 4 5 6	9	(34') POORLY GRADED SAND (SP-SM); fine grained, few silt, brownish yellow (10YR 6/6), loose, moist to wet.		
35				SS	24/24	2 2 3 5	5	(36') SANDY SILT (ML); light yellowish brown (10YR 6/4), soft, moist, medium plasticity.		
		▼		SS	24/24	2 2 3 5	5	(38') As above: becomes evenly mottled with light gray (10YR 7/2).		
40										

NOTES: SBG03- (32-34)-20210202: 15.5% moisture content, 730 U mg/kg total organic carbon, 112.7 pcf dry unit weight, 2.659 specific gravity, 4.7x 10^{-7}, 27 LL, 16 PL, 11 PI, 0.6% gravel, 53.8% sand, 45.6% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 3 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	1 4 4 4	8	(40') SILT (ML); little sand, brownish yellow (10YR 6/6), soft, moist, medium plasticity.		
				SS	24/24	1 3 4 5	7	(42') As above.		
				SS	24/24	2 4 6 6	10	(44') As above: becomes dry, stiff.		
45				SS	24/24	2 4 13 13	17	(46') SILTY SAND (SP-SM); very pale brown (10YR 7/3), loose, moist.		
				SS	23/24	8 10 10 9	20	(48') As above: becomes brownish yellow (10YR 6/8).		
50				SS	20/24	1 6 10 13	16	(50.5') Wet at 50.5 to 50.8' bgs.		
								(51') SAND (SP); fine grained, light gray (10YR 7/2), loose, moist.		
				SS	24/24	1 1 1 5	2	(52') As above: brownish yellow (10YR 6/6).		
				SS	12/24	1 1 1 3	2	(54') GRAVELLY SAND (SW); very pale brown (10YR 7/4), loose, wet.		
55				SS	24/24	1 1 1 3	2	(56') As above: moist, very loose.		
				SS	11/24	1 1 1 7	2	(58') WELL-GRADED SAND (SW); medium to coarse grained, few gravel, very pale brown (10YR 7/4), very loose, moist.	58-60 Chem and Geotech (not tested)	
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G03
Page: 4 of 4

Drilling Start Date:	02/02/2021	Boring Depth (ft):	67	Well Depth (ft):	67
Drilling End Date:	02/02/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	38.23	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	358.56	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	354.84	Seal Material(s):	Grout & Bentonite
Logged By:	SK	Location (Lat/Long):	37.22078, -88.85045	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	20/24	2 6 10 11	16	(60') WELL-GRADED SAND (SW); medium to coarse grained, few gravel, very pale brown (10YR 7/4), wet, loose.	60-62 Geotech	
				SS	24/24	1 3 13 12	16	(62') As above: reddish yellow (7.5YR 6/6).		
65				SS	24/24	1 15 14 13	29	(64') GRAVELLY SAND (SW); reddish yellow (7.5YR 6/8), wet, loose.		
				SS	8/12	1 4		(66') As above: brownish yellow (10YR 6/6).		
70								(67') End of Boring.		

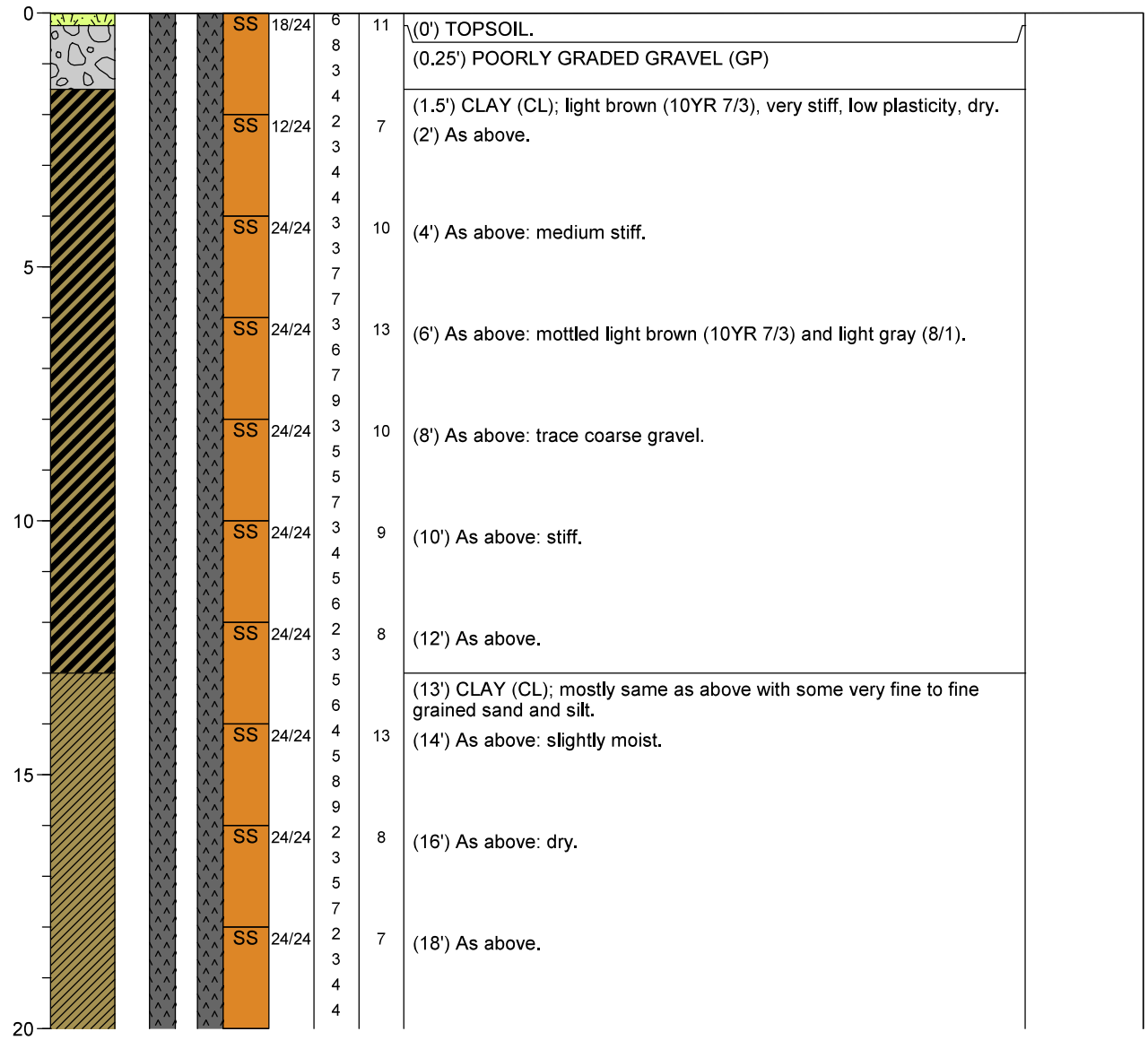
NOTES: SBG03- (60-62)-20210202: 20.0% moisture content, 740 U mg/kg total organic carbon, 2.671 specific gravity, 1.5% gravel, 94.4% sand, 4.1% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 1 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
0	SS	18/24	6 8 3 4	11	(0') TOPSOIL. (0.25') POORLY GRADED GRAVEL (GP)		
	SS	12/24	2 3 4 4	7	(1.5') CLAY (CL); light brown (10YR 7/3), very stiff, low plasticity, dry. (2') As above.		
5	SS	24/24	3 3 7 7	10	(4') As above: medium stiff.		
	SS	24/24	3 6 7 9	13	(6') As above: mottled light brown (10YR 7/3) and light gray (8/1).		
	SS	24/24	3 5 5 7	10	(8') As above: trace coarse gravel.		
10	SS	24/24	3 4 5 6	9	(10') As above: stiff.		
	SS	24/24	2 3 5 6	8	(12') As above.		
	SS	24/24	4 5 8 9	13	(13') CLAY (CL); mostly same as above with some very fine to fine grained sand and silt. (14') As above: slightly moist.		
15	SS	24/24	2 3 5 7	8	(16') As above: dry.		
	SS	24/24	2 3 4 4	7	(18') As above.		
20							

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 2 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	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				SS	24/24	4 6 6 9	12	(20') As above.		
				SS	24/24	3 5 6 7	11	(22') As above: medium stiff.		
				SS	24/24	4 7 7 4	14	(24') As above.		
25				SS	24/24	3 4 7 9	11	(26') As above: stiff.		
				SS	24/24	4 5 8 10	13	(28') As above.		
30				SS	24/24	2 4 6 7	10	(30') As above.		
				SH	24/24	3 8 11 12	19	(32') As above.		
				SS	24/24	8 10 11 12	21	(34') As above.		
35				SS	24/24	3 5 7 9	12	(36') As above.		
				SS	24/24	3 8 11 14	19	(38') SILTY CLAY (CL); same as above with more silt.		
40										

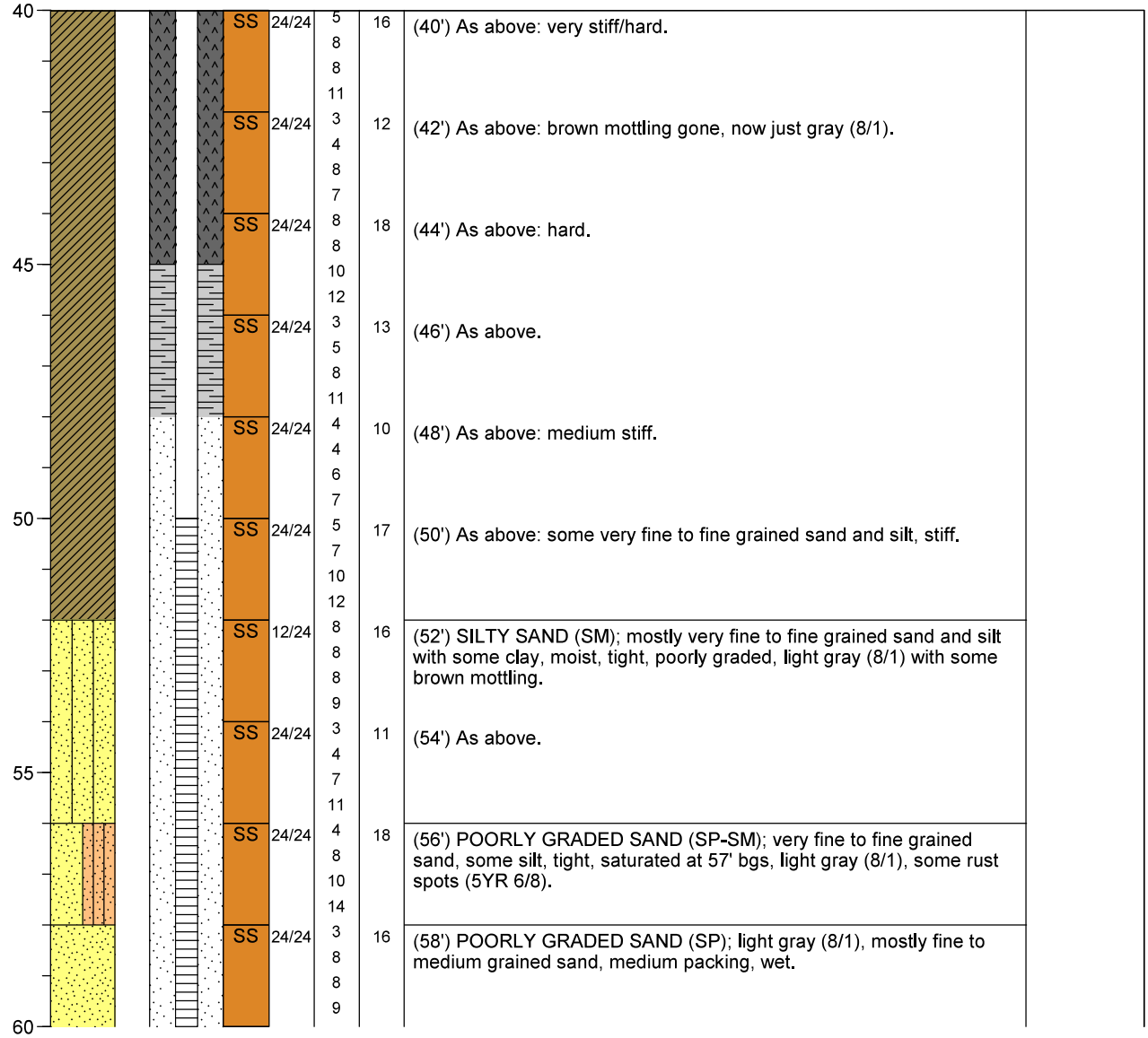
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 3 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
40	SS	24/24	5 8 8 11	16	(40') As above: very stiff/hard.		
	SS	24/24	3 4 8 7	12	(42') As above: brown mottling gone, now just gray (8/1).		
	SS	24/24	8 8 10 12	18	(44') As above: hard.		
45	SS	24/24	3 5 8 11	13	(46') As above.		
	SS	24/24	4 4 6 7	10	(48') As above: medium stiff.		
	SS	24/24	5 7 10 12	17	(50') As above: some very fine to fine grained sand and silt, stiff.		
50	SS	12/24	8 8 8 9	16	(52') SILTY SAND (SM); mostly very fine to fine grained sand and silt with some clay, moist, tight, poorly graded, light gray (8/1) with some brown mottling.		
	SS	24/24	3 4 7 11	11	(54') As above.		
55	SS	24/24	4 8 10 14	18	(56') POORLY GRADED SAND (SP-SM); very fine to fine grained sand, some silt, tight, saturated at 57' bgs, light gray (8/1), some rust spots (5YR 6/8).		
	SS	24/24	3 8 8 9	16	(58') POORLY GRADED SAND (SP); light gray (8/1), mostly fine to medium grained sand, medium packing, wet.		
60							

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G05
Page: 4 of 4

Drilling Start Date:	02/01/2021	Boring Depth (ft):	66	Well Depth (ft):	60
Drilling End Date:	02/01/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	361.68	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	358.45	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.21716, -88.84883	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)
60				SS	24/24	2 4 5 8	9	(60') As above: wet. (61') As above: moist, some red color lamination.		
				SS	24/24	2 2 3 4	5	(62') As above: some silt, saturated, poorly graded, medium packing/toughness. (SP-SM) (63') As above: moist, some red lamination.		
65				SS	24/24	1 2 3 5	5	(64') As above: saturated, medium to loose toughness. (65.5') SAND (SW); some gravel, color change to (5YR 7/6) (66') End of Boring.		
70										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 1 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	4 8 6 6	14	(0') TOPSOIL. (0.25') FAT CLAY (CH); light brown (5YR 6/8), stiff, dry.		
				SS	12/24	4 5 5 6	10	(2') As above.		
5				SS	24/24	4 4 7 5	11	(4') As above.		
				SS	24/24	4 6 7 8	13	(6') As above.		
				SS	24/24	4 3 3 5	6	(8') As above: medium stiffness.		
10				SS	24/24	4 4 7 8	11	(10') LEAN CLAY (CL); light brown (5YR 7/4) to gray (mottled), stiff, dry.		
				SS	24/24	4 5 5 6	10	(12') As above: top 6" soft with plant material.		
				SS	24/24	3 3 4 4	7	(14') As above.		
15				SS	24/24			(16') As above.		
				SS	24/24	3 4 5 7	9	(18') As above: silt and clay, some fine sand, stiff, dry. (ML-CL)		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 2 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	3 4 6 7	10	(20') As above: rust spots.		
				SS	24/24	3 3 4 6	7	(22') As above: moist.		
				SS	24/24	3 3 4 5	7	(24') As above: mottled (10R 8/1).		
25				SS	24/24	3 4 7 7	11	(26') SILTY SAND (SP-SM); mostly silt, fine grained sand, some mottling as previous, poorly graded, tight, moist.		
				SS	24/24	3 6 7 7	13	(28') POORLY GRADED SAND (SP); very fine to fine grained sand, light gray (10R 8/1), tight, moist.		
30				SS	24/24	9 20 21 26	41	(30') As above. (31') POORLY GRADED SAND (SP); medium to coarse grained, loose, moist, (10R 8/1).		
				SH	18/24	10 6 9 9	15	(32') As above: color change to orange (5YR 6/8), clay at bottom.		
				SS	24/24	4 5 6 7	11	(34') FAT CLAY (CH); stiff, moist, light gray/orange mottled (10R 8/1 to 5YR 6/8).		
35				SS	24/24	3 3 5 5	8	(36') As above: medium stiffness.		
				SS	24/24	2 2 2 3	4	(38') As above.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 3 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	3 3 5 8	8	(40') As above.		
				SS	24/24	6 12 23 24	35	(42') SILTY SAND (SP-SM); very fine grained sand and silt, tight, moist, poorly graded, light gray (10R 8/1).		
				SS	18/24	7 18 27 33	45	(44') As above.		
45								(45') POORLY GRADED SAND (SP); very fine to fine grained sand, tight, moist, (10R 8/1).		
				SS	24/24	7 18 43 47	61	(46') POORLY GRADED SAND (SP); fine to medium grained sand, loose, wet, interbedded gray to reddish orange (5YR 6/8) - seams 2cm.		
				SS	18/24	14 17 18 7	35	(48') DIAMICTON (GW); mostly fine to coarse gravel and medium to coarse sand, saturated, very loose, well graded, (5YR 7/8).		
50				SS	24/24	12 22 36 39	58	(50') WELL-GRADED SAND (SW); medium to coarse grained with fine gravel, saturated, loose.		
				SS	24/24	9 11 14 18	25	(52') As above: (5YR 7/6).		
								(53') DIAMICTON (GW-SW); same as above, (5YR 6/8).		
				SS	24/24	19 31 53	84	(54') Same as above (SW).		
55				SS	24/24	7 21 14 8	35	(55') WELL-GRADED GRAVEL and SAND (GW-SW); mostly fine to coarse grained gravel and fine to medium sand, loose, wet, light gray (10R 8/1), orangish tan chert nodules. (57') As above: top 1' tan (5YR 6/8) bottom gray (10R 8/1), wet.		
				SS	24/24	6 9 11 16	20	(58') POORLY GRADED SAND (SP); mostly very fine to fine grained sand, wet, loose, tan (7.5YR 8/4).		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G07
Page: 4 of 4

Drilling Start Date:	01/29/2021	Boring Depth (ft):	62	Well Depth (ft):	60
Drilling End Date:	01/29/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	353.86	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	352.47	Seal Material(s):	Grout & Bentonite
Logged By:	BA & CL	Location (Lat/Long):	37.21116, -88.8492	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)
60				SS	24/24	32 48 38 8	86	(60') As above. (62') DIAMICTON (GW-SW); same as above.		
								(62') End of Boring.		
65										

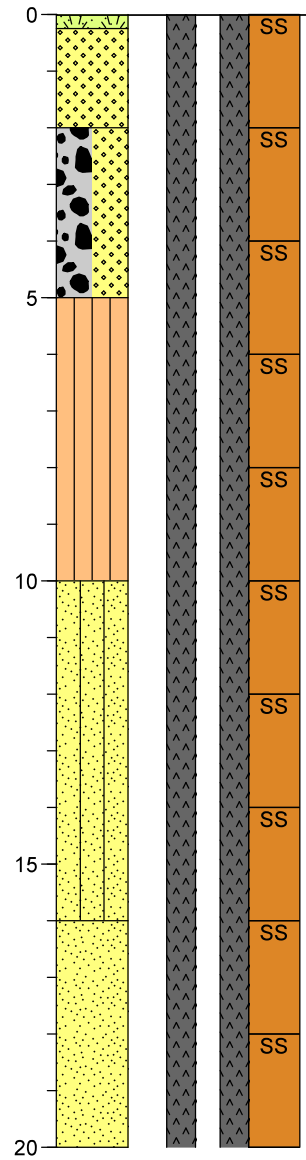
NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 1 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand



DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
0	SS		7	7	(0') TOPSOIL.		
			3		(0.25') WELL-GRADED SAND (SW); light brown/gray, loose, dry.		
	SS		4				
			6				
			14	18	(2') GRAVELLY SAND (GW-SW); loose, dry, mostly fine to coarse grained gravel and sand.		
	SS		11				
			7				
			6				
	SS		4	7			
			3				
5			4		(5') SILT (ML); low plasticity, dark gray, dry, trace coarse gravel.		
			4				
	SS		3	4	(6') As above.		
			2				
			2				
			4				
	SS		2	4	(8') As above: trace fine gravel.		
			2				
			2				
			2				
			2				
10	SS		3	8	(10') SILTY SAND (SM); dark gray, loose, dry, well-graded.		
			4				
			4				
			4				
	SS		2	5	(12') As above.		
			2				
			3				
			3				
	SS		2	5	(14') As above: clay seam at 15' (1-2").		
			3				
15			2				
			4				
	SS		2	4	(16') POORLY GRADED SAND and CLAY (SP/CL); dark gray interbedded with dark gray, medium stiff, clay - 2" beds alternating.		
			2				
			2				
			2				
			2				
	SS		1	3			
			2				
			1				
20			1				

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 2 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	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				SS		1 1 1	2	(20') CLAY (CH); high plasticity, soft, moist, gray to green.		
				SS		2 1 1 1 1	2	(21.5') SILTY SAND (SM); wet, loose, gray to green. (22') As above.		
25				SS		3 2 2 2 2	4	(24') SILT (ML); loose, dark gray, black clay seam - 2".		
				SS		2 2 1 2	3	(26') CLAY (CH); gray to green, saturated, high plasticity.		
								(27') SILT (ML); soft, moist, gray to green.		
30				SS		1 1 1 2	2	(28') SILTY SAND (SM-SP); light gray, firm, saturated, mostly poorly graded fine to medium grained sand and silt.		
				SS		3 2 3 4	5	(30') As above.		
				SS		3 3 4 4	7	(31') SILTY SAND (SM); tight, light gray, poorly graded, fine to medium grained sand. (32') As above.		
35				SS		4 4 4 4	7	(33') CLAY (CL); light gray, hard, low plasticity, dry. (35') As above: some fine grained sand.		
				SS		3 3 4 4	8	(36') As above: gradually grades to fine to medium sand.		
				SS		4 5 3 3	6	(37') POORLY GRADED SAND (SP); fine to medium grained sand, tight, trace gravel, mottled with rusty red color. (38') As above.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 3 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS		5 10 12 12	22	(40') POORLY GRADED SAND (SP); fine to medium grained, tight, light gray, mottled with rust color. (41') As above: saturated.		
				SS		3 5 8 8	13	(42') As above: some fine to coarse gravel. (43.5') As above: nodule (red chert), saturated.		
45				SS		3 6 7 7	13	(44') As above: lots of fine to coarse gravel, yellow/orange/red, gravel/nodules.		
				SS		5 7 7 11	14	(46') GRAVELLY SAND (GW-SW); mostly fine grained sand and fine to coarse gravel, light gray, gravel bits are red/yellow, saturated.		
				SS		1 5 5 5	10	(48') As above: very loose.		
50				SS		9 9 5 14	14	(50') As above. (51.5') As above: some silt.		
				SS		3 11 11 10	22	(52') WELL-GRADED SAND (SW); fine to coarse grained, trace fine gravel, tan, very loose.		
				SS		9 14 12 10	26	(54') WELL-GRADED GRAVELLY SAND (GW-SW); tan, moist, coarse grained gravel, fine to coarse sand, very loose, wet. (55') As above: light gray.		
55				SS		17 19 17 17	36	(56') POORLY GRADED SAND (SP); fine to medium grained, wet, loose, dark tan.		
				SS		6 8 11 12	19	(57.5') WELL-GRADED GRAVELLY SAND (GW); dark tan, loose. (58') As above. (59') WELL-GRADED SAND (SW); dark tan, wet, loose, trace fine gravel.		
60										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 4 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	24/24	14 10	24	(60') As above.		
						14 11		(61') GRAVELLY SAND (GW-SW); dark tan, well-graded, coarse chert nodules, wet, loose.		
				SS	18/24	5 3	7	(62') As above.		
						4 5				
				SS	12/24	4 8	13	(64') As above.		
65						5 8				
				SS	18/24	5 8	16	(66') As above.		
						8 7				
				SS	18/24	5 7	14	(68') As above: saturated.		
						7 8				
70				SS	12/24	5 6	13	(70') As above.		
						7 7				
				SS	18/24	7 9	18	(72') As above.		
						9 11				
				SS	24/24	7 7	15	(74') As above: mostly silt and gravel, (5YR 6/8).		
75						8 9				
				SS	18/24	10 16	33	(76') WELL-GRADED SAND (SW); mostly medium to coarse grained sand, wet, loose, (5YR 6/8).		
						17 25				
				SS	24/24	8 15	54	(78') DIAMICTON (SW-SM); mostly coarse grained gravel, fine sand, silt, wet, medium density, (5YR 6/8).		
						39 42		(79') Same fine to coarse gravel, more coarse gravel, (5YR 6/8). (GW-SW)		
80										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G08
Page: 5 of 5

Drilling Start Date:	01/27/2021	Boring Depth (ft):	86	Well Depth (ft):	85
Drilling End Date:	01/28/2021	Boring Diameter (in):	7.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):		Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	344.22	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	341.72	Seal Material(s):	Grout & Bentonite
Logged By:	BA	Location (Lat/Long):	37.20984, -88.85066	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)
80				SS	18/24	6 11	23	(80') As above. (SW)		
						12 14		(81.5') 1/2" seam - orangish sand, medium packing, moist, (7.5YR 8/6). (SP)		
				SS	24/24	7 14	33	(82') Same as above. (SW)		
						19 21		(83') Same as above, top 3" (10R 6/6), tight, moist. (SP)		
				SS	12/24	19 27	42	(84') As above.		
85						15 5		(85') 2cm seam of reddish/oxidized fine grained sand, dry.		
								(86') End of Boring.		
90										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 1 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	6/24	6 4 5 6	9	(0') LEAN CLAY (CL); brown (7.5YR 5/3), stiff, dry, some reddish brown mottling, trace sand.		
				SS	22/24	4 5 6 4	11			
				SS	24/24	2 3 3 4	6	(4') FAT CLAY (CH); light brown (7.5YR 6/4), medium dense, moist.		
5				SS	24/24	0 3 3 4	6	(6') As above: lean clay, moist. (CL)		
				SS	24/24	2 3 5 5	8	(8') As above: brown (7.5YR 5/4), some reddish brown mottling.		
10				SS	20/24	2 3 4 5	7	(10') As above.	10-12 Chem	
				SS	22/24	2 4 5 5	9	(12') CLAY (CL); gray to light brown (7.5YR 6/1) mottled, medium dense, dry, few sand.		
				SS	21/24	2 3 5 5	8	(14') As above: brown (7.5YR 5/4).		
15				SH	24/24			(16') As above: light brown (7.5YR 6/3).	16-18 Geotech	
				SS	23/24	2 5 6 7	11	(18') CLAY (CL); gray to light brown (7.5YR 6/1) mottled, very stiff, moist, few sand.		
20										

NOTES: SBG09M- (16-18)-20210127: 20.6% moisture content, 950 mg/kg total organic carbon, 105.4 pcf dry unit weight, 2.666 specific gravity, 8.3x 10^{-8} cm/s vertical hydraulic conductivity, 39 LL, 16PL, 23PI, 0.0% gravel, 5.0% sand, 95.0% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 2 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	2 4 7 8	11	(20') CLAY (CL); light gray with brown (10YR 7/1) mottling, very stiff, moist, trace sand and silt.	20-22 Chem	
				SS	24/24	4 6 7 8	13	(22') As above: (10YR 7/2).		
				SS	24/24	2 5 7 8	12	(24') As above: fewer brown mottling.		
25				SS	24/24	3 3 6 7	9	(27-28') As above: increased reddish brown mottling.		
				SS	24/24	4 8 8 7	16	(28') SILT (ML); with few sand and clay, light gray (10YR 7/2) with some brown mottling, dry, stiff.		
30				SS	24/24	4 8 6 8	14	(30') As above: moist.		
				SS	24/24	4 5 6 7	11	(32') As above.		
				SS	24/24	2 4 4 6	8	(34') SANDY CLAY (SC); light gray (10YR 7/2) with some brown mottling, moist.		
35								(34.5') SILT (ML); with some sand, few clay, stiff.		
				SS	24/24	3 4 5 8	9	(36') As above: trace black organics.		
				SS	24/24	5 20 18 17	38	(38') SANDY CLAY (SC); fine grained sand, few silt, gray (7.5YR 5/1), moist.		
40										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 3 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value / RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
40				SS	24/24	3 6 8 7	14	(40') SILT WITH SAND (ML); few clay, gray (7.5YR 6/1), moist.		
				SS	24/24	5 3 4 5	7	(42') As above: some reddish brown mottling.		
				SS	24/24	2 3 5 6	8	(44') As above: fewer clay, more sand.		
45				SH	24/24				46-48 Geotech	
				SS	24/24	5 8 18 12	26	(48') SILT WITH CLAY (ML); gradationally sandier, becomes moist, stiff to medium dense, gray (7.5YR 6/1).	48-50 Chem	
50		▼		SS	20/24	18 8 15 23	23	(50') POORLY GRADED SAND (SP); light gray (7.5YR 7/1), moist, loose.		
				SS	16/24	16 22 28 32	50	(52') POORLY GRADED SAND (SP); fine grained, with gravel up to cobble size, light gray (10YR 7/1), medium dense to loose, moist.		
				SS	20/24	25 45 49 49	94	(54') POORLY GRADED SAND (SP); fine to medium grained, light gray (7.5YR 7/1), moist, loose. (55') As above: few coarse gravel, reddish yellow (7.5YR 7/6).		
55				SS	23/24	27 33 20 20	53	(56') POORLY GRADED SAND (SP); fine to coarse grained, with coarse gravel, moist, gray (7.5YR 7/1) to reddish yellow (7.5YR 7/8).		
				SS	18/24	8 33 47 34	80	(58') As above: fine gray sand contains trace silt.		
60										

NOTES: SBG09M-(46-48)-20210127: 19.8% moisture content,105.4 pcf dry unit weight, 2.715 specific gravity, 3.5x 10^{-7} cm/s vertical hydraulic conductivity, 35 LL, 15 PL, 20 PI, 0.0% gravel, 17.2% sand, 82.8% fines.

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 4 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
60				SS	16/24	32 35 47 21	82	(60') POORLY GRADED SAND (SP); coarse grained, reddish yellow (7.5YR 6/8), moist, loose.		
				SS	16/24	22 50/5 14	64	(62') POORLY GRADED SAND (SP); coarse grained, reddish yellow (7.5YR 6/8), medium dense, some coarse gravel pebble size.		
65				SS	13/24	17 11 12 12	23	(64') As above: increasing fine to coarse gravel.		
				SS	12/24	15 16 15 11	31	(66') As above.		
				SS	11/24	38 50	50	(68') POORLY GRADED GRAVEL WITH SAND (GP); strong brown (7.5YR 5/6), loose, moist.		
70				SS	12/24	14 17 30 32	47	(70') As above.		
				SS	12/24	25 24 15 16	39	(72') As above: reddish yellow (7.5YR 6/8).		
				SS	8/24	6 25 20 12	45	(74') As above: sand disappears, wet.		
75				SS	14/24	7 7 8 7	15	(76') As above: strong brown (7.5YR 5/8).		
				SS	16/24	11 22 14 8	36	(78') As above: with some sand.		
80										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 5 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
80				SS	12/24	2 17 19 12	36	(80') POORLY GRADED GRAVEL (GP); little sand, reddish yellow (7.5YR 6/8), very loose, wet.	80-82 Chem	
				SS	10/24	5 18 13 14	31		82-84 Geotech	
85				SS	14/24		19	(83.7') POORLY GRADED SAND (SP); medium grained, trace gravel, reddish brown (7.5YR 6/8), loose, moist.		
				SS	14/24	12 9 10 10	22	(86') WELL-GRADED GRAVEL (GW); few sand, trace clay, reddish brown (7.5YR 6/8), loose, wet.		
				SS	14/24	25 14 8 6	14	(88') As above: clay disappears.		
90				SS		4 6 8 7		(91') GRAVELLY LEAN CLAY (CL); very pale brown (10YR 8/2), moist, soft.		
				SS		2 3 3 4	6	(92') CLAY (CL); trace gravel, gray (7.5YR 6/1), medium dense.		
				SS		2 1 3 3	4	(94') As above: gray (10YR 5/1).		
95				SS		1 6 23 23	29	(96') POORLY GRADED SAND (SP); fine grained, strong brown (7.5YR 5/8), loose.		
				SS		5 14 25 23	39	(98') As above.		
100										

NOTES: SBG09M- (82-84)-20210127: 7.6% moisture content, 740 U mg/kg total organic carbon, 100.0 pcf dry unit weight, 2.686 specific gravity, 22.7% gravel, 75.4% sand, 1.9% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 6 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
100				SS	14/24	14 14	27	(100') CLAY (CL); (10YR 6/1), very soft, trace gravel.		
						13 15		(101') CLAYEY GRAVEL (GC); (7.5YR 5/8), moist, loose.		
				SS	15/24	14 12	20	(102') As above: some sand, brown (7.5YR 4/4).		
						8 15				
				SS	9/24	12 12	21	(104') GRAVELLY CLAY (CL); light gray (2.5Y 7/2), stiff, moist.		
105						9 14				
				SS	15/24	12 12	24	(106') CLAYEY GRAVEL (GC); pinkish gray (7.5YR 7/2), medium dense, moist.		
						12 20				
				SS	14/24	9 28	39	(108') POORLY GRADED SAND (SP); fine grained, yellow (10YR 7/6) to white (10YR 8/1) at 109.8' bgs, moist, loose.		
						11 11				
110				SS	15/24	8 12	20	(110') As above: light gray (10YR 7/1).	110-112 Chem	
						8 12				
				SH	8/24				112-114 Geotech	
				SS	13/24	10 11	20	(114') As above: yellow (10YR 7/6), trace gravel.		
115						9 10				
				SS	12/24	7 9	18	(116') As above: light gray (10YR 7/2), no gravel.	116-118 Geotech (not tested)	
						9 12				
				SS	22/24	7 1	3	(118') SILT WITH SAND (ML); gray (10YR 6/1) with some light brown mottling, soft, moist.		
						2 3		(119.5') CLAY (CL); little silt, gray (10YR 6/1), stiff, moist.		
120										

NOTES: SBG09M- (110-112)-20210127: 25.5% moisture content, 760 U mg/kg total organic carbon, 87.0 pcf dry unit weight, 2.675 specific gravity, 0.7% gravel, 84.1% sand, 15.2% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 7 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
120				SS	21/24	2 3 4	7	(120') SAND WITH SILT (SM); light gray (10YR 7/1), medium dense, moist.		
						14		(121') As above: less silty. (SP-SM)		
				SS	16/24	7 7 22	29			
						31		(123.5') As above: yellow (2.5Y 7/6). (SP)		
				SS	11/24	13 14 16	30	(124') POORLY GRADED SAND (SP); fine to medium grained, red (2.5YR 5/6), loose, dry.		
125						14				
				SS	16/24	3 5 8 10	13	(126') CLAY (CL); few silt and sand, light brownish gray (10YR 6/2), very stiff, dry.		
				SS	15/24	3 8 9 13	17	(128') As above.	128-130 Chem	
130				SS	15/24	8 13 17	30			
						6		(130') Crushed SAPROLITE, dark yellowish brown (10YR 3/4) to black (10YR 2/1).		
				SS	16/24	6 4 6 6	10	(132') CLAY (CL); few gravel, few sand, yellowish brown (10YR 5/4), moist, stiff.	132-134 Chem	
				SS	22/24	1 2 6 7	8	(134') As above: light brownish gray (10YR 6/2), no sand.		
135				SS	20/24	2 5 5 6	10	(136') As above: very pale brown (10YR 7/3).		
				SS	13/24	4 8 7 21	15	(138') As above: light yellowish brown (5YR 6/4).		
140										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G09M
Page: 8 of 8

Drilling Start Date:	01/26/2021	Boring Depth (ft):	158	Well Depth (ft):	155
Drilling End Date:	01/28/2021	Boring Diameter (in):	4.25	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	51.93	Riser Material:	Sch 80 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	351.53	Screen Material:	Sch 80 PVC Slotted
Driller:		Ground Elev. (ft):	348.60	Seal Material(s):	Grout & Bentonite
Logged By:	SK & AT	Location (Lat/Long):	37.21040, -88.85422	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)
140				SS	6/24	70/1		(140') CALCARENITE, very pale brown (10YR 7/3), dry.	140-142 Chem	
145										
150										
155								(155') End of Boring.		
								(158') Redrilled to 158' due to well installation difficulties.		
160										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 1 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
0				SS	24/24	6 4 9 7	13	(0') TOPSOIL. (0.2') ASH (ML) (0.8') LEAN SILT (ML); trace fine sand, stiff, moist, tan (2.5Y 7/4).		
				SS	17/24	1 1 2 4	3	(2.7') LEAN CLAY (CL); some orange fine sand, soft, wet, brown (2.5Y 3/3).		
				SS	16/24	5 21 50/6	71	(5.1') SILTY SAND (SM); fine to medium grained, with coal, some organics, very dense, gray (N3), moist, well-graded.		
5				SS	17/24	5 7 5 5	12	(7.0') LEAN CLAY (CL); stiff, moist, tan (5Y 7/2) with gray (N8) mottles.		
				SS	24/24	1 3 5 6	8	(8') As above: becomes medium stiff, orange (10YR 7/12) mottles.		
10				SS	24/24	2 5 8 6	13	(10') As above: becomes stiff, black inclusions, trace organics.		
				SS	23/24	2 4 5 7	9	(12') As above.		
				SS	24/24	2 5 6 8	11	(14') As above.		
15				SS	24/24	2 4 5 6	9	(16') As above.		
				SS	24/24	3 7 9 10	16	(18') LEAN SILT (ML); trace sand, stiff, moist, tan (5Y 7/2) with orange (10YR 7/12) and black mottling.		
20										

NOTES:

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 2 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand

DEPTH (ft)	LITHOLOGY	WATER LEVEL	WELL COMPLETION	COLLECT: Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	MEASURE: Lab Sample	DEPTH (ft)
20				SS	24/24	3 6 8 8	14	(20.1') LEAN CLAY (CL); trace fine sand, stiff, moist, tannish orange (10YR 7/6) with gray (N8) mottles.		
				SS	27/24	2 4 6 7	10	(22') As above.	22-24 Chem	
				SS	27/24			(24') As above.	24-26 ST	
25				SS	24/24	3 4 5 7	9	(26') As above.		
				SS	24/24	3 4 6 7	10	(28') As above.		
30				SS	26/24	2 4 4 6	8	(30') As above: with increased moisture.		
				SS	24/24	2 4 4 6	8	(32') As above.		
				SS	25/24	4 5 8 7	13	(34') As above: with fine sand.		
35				SS	26/24	2 5 5 5	10	(36') As above: orange (10YR 7/12) inclusions, gray (N8) with tan orange (10YR 7/6) mottling.		
				SS	25/24	2 4 6 6	10	(38') As above: trace silt.		
40										

NOTES: SBG11-(24-26)-20210119: 18.5% moisture content, 415 U mg/kg total organic carbon, 109.1 pcf dry unit weight, 2.688 specific gravity, 5.6×10^{-8} cm/s vertical hydraulic conductivity, 36 LL, 15 PL, 21 PI, 0.0% gravel, 11.5% sand, 88.5% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 3 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	Filter Pack:	Sand

DEPTH (ft)	Sample Type	Recovery (in)	Blow Counts	N Value RQD (%)	SOIL/ROCK VISUAL DESCRIPTION	Lab Sample	DEPTH (ft)
40	SS	25/24	2 3 4 4	7	(40') As above: becomes medium stiff.		
	SS	27/24	2 4 4 6	8	(42') LEAN CLAY (CL); orange (10YR 7/6) silty fine sand seams, medium stiff, moist, gray (N8).		
45	SS	25/24	2 4 5 6	9	(44') As above: stiff.		
	SS	25/24	3 6 9 10	15	(46') As above: seams are silt only.		
	SS	24/24	3 4 5 8	9	(48') As above: no seams, trace orange (10YR 7/6) silt, increased moisture.		
50	SS	27/24	1 3 0 3	3	(50') As above: increased moisture.		
	SS	27/24	2 3 3 6	6	(52') As above: gray (N9) sand layer.		
	SS	27/24	3 8 26 26	34	(53.2') POORLY GRADED SAND (SP); fine to medium grained, trace silt, loose, gray (N9), wet. (54') As above: becomes dense, trace clay, trace orange (10YR 7/6) silt inclusions.		
55	SS	8/24			(56') As above.	56-58 Geotech	
	SS	24/24	7 14 16 13	30	(58') As above: trace gravel, no silt, some orange (10YR 7/6) fine to medium sand.	58-60 Chem	
60							

NOTES:
SBG11-(56-58)-20210119: 14.4% moisture content, 679 U mg/kg total organic carbon, 110.0 pcf dry unit weight, 2.661 specific gravity, 0.2% gravel, 87.7% sand, 12.1% fines.
*U = Analyte was not present in concentrations above method detection limit and is reported as the reporting limit

Geosyntec consultants
engineers | scientists | innovators

Client: Dynegy
Project: GLP0821, Joppa Ash Pond
Address: Unnamed Road, Metropolis, IL 62960

WELL LOG
Well No. G11
Page: 4 of 4

Drilling Start Date:	01/19/2021	Boring Depth (ft):	66	Well Depth (ft):	66
Drilling End Date:	01/19/2021	Boring Diameter (in):	7.5	Well Diameter (in):	2
Drilling Company:	Geotechnology	DTW During Drilling (ft):		Screen Slot (in):	0.010
Drilling Method:	Hollow Stem Auger	DTW After Drilling (ft):	45.66	Riser Material:	Sch 40 PVC
Drilling Equipment:	CME 55LC	Top of Casing Elev. (ft):	366.88	Screen Material:	Sch 40 PVC Slotted
Driller:		Ground Elev. (ft):	363.38	Seal Material(s):	Grout & Bentonite
Logged By:	ZJF & AT	Location (Lat/Long):	37.21436, -88.85636	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)
60				SS	20/24	6 14 15 16	29	(60') As above: increased orange sand.		
				SS	14/24	0 6 11 13	17	(62') WELL-GRADED SAND (SW); fine to medium grained, medium dense, wet, orangish tan (7.5YR 8/8) with some gray (N9) sand layers.		
65				SS	18/24	2 10 15 11	25	(64') As above: with sandy gravel layer (~5" thick).		
								(66') End of Boring.		
70										

NOTES:

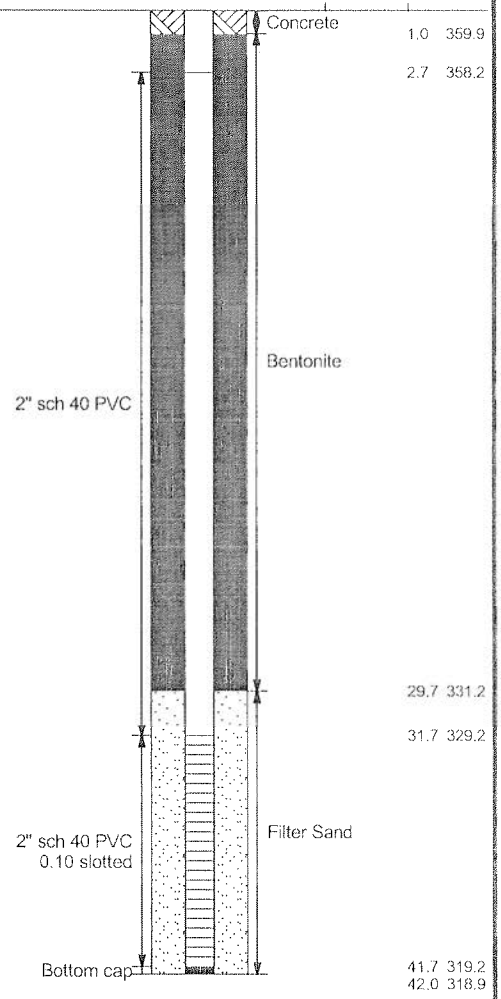
Surface Elevation: 360.9 | Completion Date: 6/19/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	GRAVEL			SS1
	Medium stiff to stiff, brown and gray, silty CLAY - (CL)		3-4-4-5	SS2
5			2-3-3-5	SS3
			3-3-4-4	SS4
	- k = 1.6 x 10^{-8}cm/s		1-2-3-5	SS5
10			3-5-5-6	SS6
			2-4-5-6	SS7
15			2-3-4-5	SS8
	Medium stiff to stiff, brown and gray, silty CLAY, trace sand - CL		3-4-6-7	SS9
			3-4-6-6	SS10
20			3-5-7-8	SS11
			3-5-7-9	SS12
25			2-3-5-6	SS13
			3-5-7-6	SS14
			3-5-8-8	SS15
30			4-7-9-4	SS16
			4-4-6-7	SS17
35			2-4-3-5	SS18
	Medium stiff to very stiff, brown and gray, sandy CLAY with silt - CL		5-5-7-14	SS19
			13-13-10 -8	SS20
40			2-4-6-7	SS21
	Boring terminated at 42 feet.			
45				
50				

WELL DIAGRAM

Flushmount



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 J017150.02ENV - EEI JOPPA.GPJ GTINC 063301.GPJ 9/22/10

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

___ AUGER ___ HOLLOW STEM

WASHBORING FROM ___ FEET

PH DRILLER BGF LOGGER

___ DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RBP	App'vd. by: RBP
Date: 7/14/10	Date: 9/20/10	Date: 9/20/10

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ash Pond Evaluation
EEI Facility
Joppa, Illinois

LOG OF BORING: G-151

Project No. J017150.02

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
	0/60 *0%*	BD					2			360	
	0/60 *0%*	BD					4			358	
	0/60 *0%*	BD					6			356	
							8			354	
							10	Blind drill - see G151 boring log		352	
							12			350	
							14			348	
							16			346	
							18			344	
							20			342	

NOTE(S): G51D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
	0/60 0%	BD					22				
							24			338	
							26			336	
	0/60 0%	BD					28			334	
							30	Blind drill - see G151 boring log *[Continued from previous page]*		332	
	0/60 0%	BD					32			330	
							34			328	
							▼			326	
	0/60 0%	BD					36			324	
							38			322	
							▼				
							40				
9A	24/24 100%	SS	*6-7* *4-4* N=11	22		*1.50*		Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, medium, CLAY with few silt and little very fine- to fine-grained sand.		320	
							42				

NOTE(S): G51D installed in borehole.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Joppa Power Station
Location: Joppa, Illinois
Project: 15E0030
DATES: **Start:** 8/17/2015
Finish: 8/18/2015
WEATHER: Partly cloudy, warm, mid-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-750 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: G51D
Well ID: G51D
Surface Elev: 361.10 ft. MSL
Completion: 59.90 ft. BGS
Station: 200,430.10N
832,151.51E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Joppa
Township: 15S;3E
Section 14, **Tier** 15S; **Range** 3E

WATER LEVEL INFORMATION:
▼ = 39.50 - During Drilling
▼ = 34.91 - 8/18/15
▽ =

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
10A	24/24 100%	SS	1-2 4-5 N=6	20		1.50	44	Yellowish brown (10YR5/8) with 20% gray (10YR5/1) mottles, moist, medium, CLAY with few silt and little very fine- to fine-grained sand. *[Continued from previous page]*		318	
11A	24/24 100%	SS	3-4 4-4 N=8	16		0.25	46	Yellowish brown (10YR5/8) with 50% gray (10YR6/1) mottles, moist, soft, very fine- to medium-grained SAND with some silt and little clay.		316	
12A	24/24 100%	SS	5-7 10-11 N=17	13		1.50	48	Yellowish brown (10YR5/8) with 50% gray (10YR6/1) mottles, moist, stiff, very fine- to medium-grained SAND with some silt, little clay, and trace small gravel.		314	
13A	20/24 83%	SS	5-12 14-15 N=26	15		0.25		Yellowish brown (10YR5/8) with 20% gray (10YR6/1) mottles, wet, loose, very fine- to medium-grained SAND with trace silt, trace clay and trace small gravel.		312	
14A	23/24 96%	SS	5-15 19-21 N=34	15		1.25	50			310	
15A	22/24 92%	SS	3-12 14-7 N=26	15		1.50	52			308	
16A	24/24 100%	SS	1-5 6-11 N=11	17		0.00	54	Strong brown (7.5YR5/8), wet, loose, very fine- to medium-grained SAND with trace silt, trace clay, and trace small gravel.		306	
17A	24/24 100%	SS	2-7 8-11 N=15	19		0.00	56			304	
	0/23 0%	BD					58			302	Drilled past end of sample interval

End of boring = 59.9 feet

NOTE(S): G51D installed in borehole.

ATTACHMENT 2

RAMBOLL RESPONSE LETTER DATED NOVEMBER 6, 2023

RAMBOLL

ENVIRONMENT
& HEALTH

November 6, 2023

VIA E-MAIL
Lauren.Martin@epa.gov
EPA.CCR.PART845.COORDINATOR@ILLINOIS.GOV
EPA.CCR.Part845.Notify@Illinois.gov

Re: Joppa Power Plant East Ash Pond Alternative Source Demonstration Response to IEPA Comments

To Whom It May Concern:

This letter addresses the following requests for information from the Illinois Environmental Protection Agency (IEPA) provided on October 26, 2023 via email from Lauren Hunt regarding the Joppa Power Plant East Ash Pond alternative source demonstration (ASD) submitted on October 21, 2023:

1. Source characterization of the CCR at the East Ash Pond must include total solids sampling, analysis and reporting in accordance with SW846.
2. Hydraulic conductivities from laboratory or insitu testing must be collected, analyzed and presented with hydrogeologic characterization of all units including aquifers and confining units. Hydraulic conductivity data must include field and software analysis.
3. Characterization to include sample and analysis in accordance with 35 IAC 845.640 of alternative source must be provided with the ASD.

Background

Alternative source demonstrations use a multiple lines of evidence approach to support the conclusions that 1) the coal combustion residuals (CCR) unit is not the source of an exceedance, and 2) there is an alternative source of the exceedance. The multiple lines of evidence approach is consistent with the approach used in many areas of environmental analysis such as ecological risk assessment, monitored natural attenuation (MNA), and vapor intrusion (USEPA, 2016; USEPA, 1999; ITRC, 2007). The goal of a multiple lines of evidence approach is to provide robust support for a causal relationship based on many smaller individual qualitative or quantitative pieces of evidence (USEPA, 2016). Critically, no individual line of evidence will be completely conclusive, and each will have varying degrees of certainty. The final determination of a conclusion is based on the totality of the evidence provided.

ASDs based on a multiple lines of evidence approach are routinely prepared by environmental consultants to comply with federal CCR rules (Title 40 of the Code of Federal Regulations [40 C.F.R.] § 257) and State CCR rules (Title 35 of the Illinois Administrative Code [35 I.A.C.] § 845). In Georgia, where the CCR permitting authority has been delegated to the State, the Georgia Environmental Protection Division has approved ASDs using multiple lines of evidence to satisfy the requirements of federal CCR rule. An example of such approval is documented in the summary section (page 3) of the 2023 Annual Groundwater Monitoring and Corrective Action Report found in the publicly accessible files linked here: https://www.georgiapower.com/content/dam/georgia-power/pdfs/company-pdfs/plant-mcmanus/20230731_2023agwmcar_mcm_ap-1.pdf.

The East Ash Pond ASD was completed in conformance with the Electric Power Research Institute (EPRI) guidance for development of ASDs at CCR sites (EPRI, 2017). The EPRI document presents an approach for developing ASD lines of evidence that relies, where possible, on leachate samples collected from leachate wells, lysimeters, and/or leachate collection systems to provide samples that are representative of interstitial porewater. This direct approach for evaluating the potential for the East Ash Pond to impact groundwater is in contrast to the indirect approach implied by the IEPA request to characterize the CCR at the East Ash Pond using methods in accordance with SW-846 (specifically those used for waste characterization [*e.g.,* EP, TCLP, SPLP, LEAF[1]]), as discussed below.

Additionally, the lines of evidence as presented as section headings in the East Ash Pond ASD commonly contain multiple qualitative and quantitative pieces of information that contribute to the body of evidence that support the conclusion that the CCR surface impoundment (SI) is not the source of an exceedance.

Response to Request Number 1: SW-846 Characterization of CCR Material

The CCR porewater most accurately represents the mobile constituents associated with the waste management activity within the CCR SI (EPRI, 2017). The composition of CCR porewater accumulated at the base of the CCR unit, which is derived from, and represents contact with, CCR material above and around the well screen, is the truest representation of mobile constituents throughout the CCR SI. Leach tests presented in SW-846 (*e.g.*, TCLP, SPLP, LEAF 1313 - 1316) are inconsistent predictors or surrogates of *in situ* porewater chemical concentrations (EPRI, 2020; EPRI, 2021; and EPRI, 2022). Indeed, laboratory leach test effectiveness is determined by comparing results to porewater data (USEPA, 2014; EPRI, 2020; EPRI, 2021; and EPRI, 2022). These laboratory leach tests most accurately predict porewater concentrations when conditions in the test closely reflect conditions present in the field (USEPA, 2019). In many cases, the pH and/or redox potential of porewater is poorly represented by any laboratory leach test conditions. For these reasons, analysis of actual CCR porewater is more representative of potential contributions to groundwater observed in compliance monitoring wells than laboratory leach testing. The uncertainty in comparing the laboratory leach test results with the actual porewater concentrations means that the contribution of laboratory leach test data as a line of evidence to an ASD would be minimal.

Prior to performing hydrogeologic investigations in 2021, Ramboll completed a review of existing data to determine whether sufficient information existed to meet the requirements of 35 I.A.C. § 845. Based on the review, Ramboll developed an approach to fully characterize the CCR material as part of the 2021 investigation. Three locations for porewater wells were selected by evaluating the extent of ash through time on aerial photographs (**Figure 1**), identifying visible differences (color) in surficial materials, and capturing a representative spatial distribution. Porewater was encountered at an elevation of approximately 370 to 374 feet (Ramboll, 2021). For the purpose of visualization, **Figure 2** shows the areas within the SI that were not accessible for potential sampling and testing as illustrated by different colored portions of the East Ash Pond. Of the 122 acre unit, about 66%was accessible for safely installing porewater monitoring wells. A total of three porewater wells were installed in 2021.

[1] Extraction Procedure, Toxic Characteristic Leaching Procedure, Synthetic Precipitation Leaching Procedure, Leaching Environmental Assessment Framework

During installation of the porewater wells, the borings were logged, and solid samples were collected from six intervals for geotechnical and chemical analysis. Samples were analyzed for total metal concentrations via EPA Method 6010B and 6020A (SW-846) and results were summarized in the Hydrogeologic Site Characterization Report (Ramboll, 2021) and submitted in the 2021 Operating Permit (Burns and McDonnell, 2021).

As established above, testing porewater is a direct source term for evaluating potential influence on groundwater. SW-846 provides analytical methods for evaluating solid waste using leach tests that are designed to replicate potential *in situ* conditions (either current or future). The goal of these laboratory leach tests is to predict the potential concentration of chemicals under laboratory controlled conditions (*e.g.*, landfill leachate, synthetic precipitation, variable pH) which may or may not represent conditions observed in the field. The use of leach test results performed under variable conditions collected from any number of locations within the CCR SI to estimate a total potential for chemical leaching from CCR into groundwater under a variety of different conditions is irrelevant to an ASD. ASDs are prepared to evaluate the potential for actual porewater leaking from a CCR SI to be the cause of a detected exceedance observed in a compliance well.

Response to Request Number 2: Provide Hydraulic Conductivity Data

Responses to Request Number 2 are provided in the cover letter to this Attachment and in Attachment 1 to that cover letter.

Response to Request Number 3: Alternative Source Characterization

In the East Ash Pond ASD, the multiple lines of evidence approach is appropriate for identifying that a source other than the East Ash Pond caused the observed exceedance and that the East Ash Pond did not contribute to the cobalt exceedance at G05 or the low pH at G11 and G51D. Ramboll's investigation determined that release of naturally occurring cobalt from manganese oxides was the source of cobalt at G05. Results of solid sampling indicates the presence of cobalt in native materials from multiple locations at the site and naturally occurring cobalt was found to be associated with manganese throughout the site.

Mixing of oxidizing and reducing waters was identified as the source of the low pH at G11 and G51D. A distinct redox transition was identified, shifting from more reducing conditions in upgradient waters to more oxidizing conditions in downgradient wells, including the exceedance wells. The oxidation of dissolved iron to iron oxides is known to produce acidity (Hem and Cropper, 1959) and is believed to be the cause of the low pH at G11 and G51D.

When an exceedance is caused by natural variability driving geochemical reactions (*e.g.*, as by mixing of waters with different compositions), direct sampling of a "source" becomes challenging. The closest approximation of direct sampling would involve using collected materials in complex laboratory simulations which would attempt to replicate field conditions. Instead, site-specific hydrogeologic, groundwater composition, and solid phase data were analyzed using industry-standard geochemical and statistical methods to provide multiple lines of evidence which support the conclusions. As described above, a multiple lines of evidence approach allows for determination of robust conclusions when specific source data are inaccessible.

Conclusions

The combined strength of the lines of evidence in the East Ash Pond ASD demonstrates that the East Ash Pond is not the source of the cobalt exceedance at G05 or the low pH at G11 and G51D (and did not contribute to these exceedances) and that the likely source is natural variability in groundwater due to water-solid interactions and groundwater mixing, respectively. Ramboll does not believe that additional lines of evidence based on leach test data or testing of the alternative source would change the conclusion of the full body of evidence presented in the ASD that the East Ash Pond is not the source of the exceedances and did not contribute to the exceedances.

References

Burns & McDonnell, 2021. Initial Operating Permit. Joppa East Ash Pond. October 25.

Geosyntec Consultants, Inc. (Geosyntec), 2023. Supplemental Site Investigation Report. Joppa Power Station, East Ash Pond (CCR Unit #401), Electric Energy, Inc. April

Interstate Technology Regulatory Council (ITRC), 2007. Technical and Regulatory Guidance Vapor Intrusion Pathway: A Practical Guide. January 2007.

Electric Power Research Institute (EPRI), 2017. Guidelines for Development of Alternative Source Demonstrations at Coal Combustion Residual Sites. EPRI, Palo Alto, CA: 2017. 3002010920.

Electric Power Research Institute (EPRI), 2020. Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment: Capped Unit. EPRI, Palo Alto, CA: 2020. 3002017363.

Electric Power Research Institute (EPRI), 2021. Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit: Plant 42197. EPRI, Palo Alto, CA: 2021. 3002018780.

Electric Power Research Institute (EPRI), 2022. Evaluation and Comparison of Leach Test and Porewater Variability for Multiple Coal Combustion Product Management Units. EPRI, Palo Alto, CA: 2022. 3002024214.

Hem, J.D. and W.H. Cropper. 1959. Survey of Ferrous-Ferric Chemical Equilibria and Redox Potentials. Chemistry of Iron in Natural Water. Geological Water-Supply Paper 1459-A.

Natural Resource Technology, an OBG Company, 2017. Hydrogeologic Monitoring Plan, Joppa East Ash Pond, CCR Unit ID 401 October 17.

Ramboll Americas Engineering Services (Ramboll), 2021. Hydrogeologic Site Characterization Report. Newton Power Plant Primary Ash Pond. October

United States Environmental Protection Agency (USEPA), 2019. Leaching Environmental Assessment Framework (LEAF) How-To Guide. SW-846 Update VII. Revision 1. May.

United States Environmental Protection Agency (USEPA), 2016. Weight of Evidence in Ecological Assessment. EPA/100/R-16/001. December.

United States Environmental Protection Agency (USEPA), 2014. Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework. EPA 600/R-14/061 September.

United States Environmental Protection Agency (USEPA), 1999. Use of Monitoring Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive Number 9200.4-17P.

Attachments

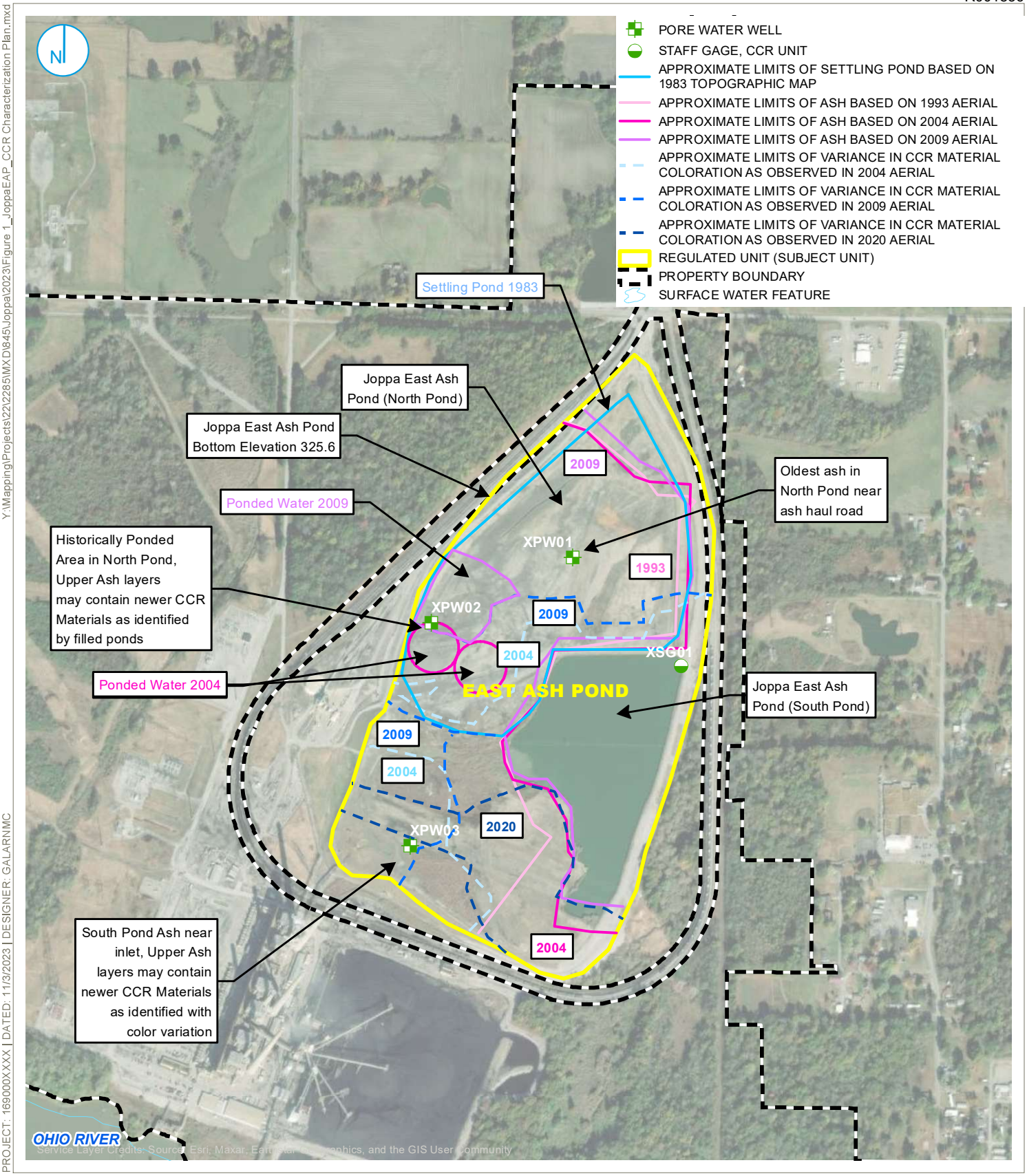
Figure 1 CCR Characterization
Figure 2 2022 Conditions

If you have any questions about this letter, please do not hesitate to contact Brian Hennings or Frances Ackerman, as referenced below.

Sincerely,

Brian G. Hennings, PG
Project Officer, Hydrogeology
D +1 414 837 3524
D +1 262 719 4512
brian.hennings@ramboll.com

A. Frances Ackerman, PE
Subject Matter Expert/Technical Manager 2
D +1 414 308 0811
M +1 414 308 0811
frances.ackerman@ramboll.com



Y:\Mapping\Projects\22\2285\MXD\845\Joppa\2023\Figure 1_JoppaEAP_CCR Characterization Plan.mxd

PROJECT: 169000XXXX | DATED: 11/3/2023 | DESIGNER: GALARNMC

0 400 800 Feet

CCR CHARACTERIZATION

JOPPA POWER STATION
JOPPA, ILLINOIS

FIGURE 1

RAMBOLL US CORPORATION
A RAMBOLL COMPANY

RAMBOLL

PROJECT: 169000XXXX | DATED: 11/6/2023 | DESIGNER: GALARNMC

Y:\Mapping\Projects\22\2285\MXD\845\Joppa\2023\Figure 2_JOP 2022 Conditions.mxd

PORE WATER WELL
STAFF GAGE, CCR UNIT
REGULATED UNIT (SUBJECT UNIT)
PROPERTY BOUNDARY

ACTIVE SLUICE AREA
HEAVY VEGETATION AREA
OPEN WATER
TRANSMISSION LINES AREA
ELEVATION BELOW 370FT

0 150 300 Feet

2022 CONDITIONS

FIGURE 2

EAST ASH POND
JOPPA POWER PLANT
JOPPA, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

DOCUMENT 29

Rees, Jeromy

From: Hunt, Lauren
Sent: Tuesday, November 7, 2023 12:26 PM
To: Voelker, Brian
Subject: RE: Alternate Source Demonstration - Joppa Power Plant

Hi Brian.
When I checked with our listserv folks I had them send out a different email contact because I am not sure where that came from.
To eliminate this issue in the future, we have set up an email for all Groundwater Section CCR folks. It is EPA.BOW.GWS.CCR@illinois.gov. Heather, Justin, Matt, Mike, Lynn and myself all have access.
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: Voelker, Brian <Brian.Voelker@vistracorp.com>
Sent: Monday, November 6, 2023 6:29 PM
To: EPA.CCR.Part845.Notify <EPA.CCR.Part845.Notify@Illinois.gov>; EPA.CCR.Part845.Coordinator <EPA.CCR.Part845.Coordinator@Illinois.gov>; Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Cc: Morris, Phil <Phil.Morris@vistracorp.com>; Mitchell, David <David.Mitchell@vistracorp.com>; More, Joshua <joshua.more@afslaw.com>; Fuller, Rhys <Rhys.Fuller@vistracorp.com>; Modeer, Victor <Victor.Modeer@vistracorp.com>; Cravens, Stuart <Stuart.Cravens@txu.com>; Davies, Sam <SAMANTHA.DAVIES@vistracorp.com>; Vodopivec, Cynthia <Cynthia.Vodopivec@vistracorp.com>
Subject: [External] RE: Alternate Source Demonstration - Joppa Power Plant

Lauren,
Electric Energy, Inc. is submitting the additional information (attached) as follow-up to communication with the agency regarding the ASD submitted for the Joppa Power Plant East Ash Pond on October 21, 2023.

The listserve notice was received on October 23, and this submittal is within the 14-day period allowed for written comments.

Let me know if you have issues opening the attachment.

Note: I tried sending this to the lauren.martin@epa.gov email address as listed on the listserv and received an undeliverable message stating that email address was not found.

Thanks,

Brian Voelker
Environmental Manager
(217) 412-6605
brian.voelker@vistrcorp.com

DOCUMENT 30

Strauss, Rebecca Y.

From: Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Sent: Tuesday, November 7, 2023 4:47 PM
To: LeCrone, Darin
Subject: FW: Environmental Groups' Comments on Joppa, Baldwin, and Newton ASDs
Attachments: FINAL 11.6.23 Earthjustice, PRN and SC comments on ASDs for Joppa, Newton, and Baldwin.pdf

FYI

From: Jenny Cassel <jcassel@earthjustice.org>
Sent: Monday, November 6, 2023 1:13 PM
To: Hunt, Lauren <Lauren.Hunt@Illinois.gov>; Mullenax, Heather <Heather.Mullenax@Illinois.gov>; Dunaway, Lynn <LYNN.DUNAWAY@Illinois.gov>
Cc: Faith Bugel <fbugel@gmail.com>; arehn <arehn@prairierivers.org>; Mychal Ozaeta <mozaeta@earthjustice.org>; Lauren Piette <lpiette@earthjustice.org>
Subject: [External] Environmental Groups' Comments on Joppa, Baldwin, and Newton ASDs

Ms. Hunt, Ms. Mullenax, and Mr. Dunaway,

Please see attached comments from Earthjustice. Prairie Rivers Network, and Sierra Club on proposed Alternative Source Determinations (ASDs) for CCR surface impoundments at the Joppa, Newton, and Baldwin facilities. Please don't hesitate to reach out if you have any questions or would like to discuss further.

Thank you,
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

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 31

Strauss, Rebecca Y.

From: Rompot, Derek <Derek.Rompot@Illinois.gov>
Sent: Thursday, November 16, 2023 8:47 AM
To: Hunt, Lauren; Dunaway, Lynn
Cc: LeCrone, Darin; Seif, Josiah
Subject: Joppa ASD: No comments received by Derek & Josiah

Neither myself nor Josiah have received comments about Joppa's ASD.

As a side note, since the ASD is not part of a permit application and will be signed by Mike, Groundwater will need to send the appropriate documents to the file room to be imaged in accordance with their SOP.

Derek

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 32

Strauss, Rebecca Y.

From: Hunt, Lauren <Lauren.Hunt@Illinois.gov>
Sent: Thursday, November 16, 2023 9:03 AM
To: Dunaway, Lynn
Subject: Joppa ASD letter
Attachments: Draft ASD JEAP NonConcurrence letter Oct 2023.docx

Here you go

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 33

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

{ DATE \@ "MMMM d, yyyy" }

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Joppa Power Plant East Ash Pond; W1270100004-02
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 Joppa East Ash Pond Alternative Source Demonstration (ASD) dated October 21, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Source characterization of the CCR at the East Ash Pond must 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. Characterization to include sample and analysis in accordance with 35 IAC 845.640 of alternative source must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods and field and laboratory quality control and quality assurance.
    b. 35 IAC 845.650(e) requires alternative source data as 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.

If you have any questions, please contact: **Lauren Hunt** 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,

Michael Summers, P.G.
Manager, Groundwater Section
Division of Public Water Supplies
Bureau of Water

cc: Lauren Hunt
Keegan MacDonna
WPC Files 06M
Jenny Cassel, EARTHJUSTICE

DOCUMENT 34

Rees, Jeromy

From: Hunt, Lauren
Sent: Thursday, November 16, 2023 9:08 AM
To: Summers, Michael
Cc: Dunaway, Lynn; Mullenax, Heather; Garee, Matthew J.; Bierwagen, Justin
Subject: Joppa ASD Non Concurrence Letter
Attachments: Final ASD JEAP NonConcurrence letter Oct 2023.docx

Hi Mike.
We need this signed and sent off today. I will stop by with a printed copy shortly.
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.

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 35

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

November 16, 2023

Dianna Tickner
Electric Energy, Inc.
1500 Eastport Plaza drive
Collinsville, Illinois 62234

Re: Joppa Power Plant East Ash Pond; W1270100004-02
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 Joppa East Ash Pond Alternative Source Demonstration (ASD) dated October 21, 2023. The Illinois EPA does not concur due to the following data gaps:

1. Source characterization of the CCR at the East Ash Pond must 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. Characterization to include sample and analysis in accordance with 35 IAC 845.640 of alternative source must be provided with the ASD.
    a. 35 IAC 845.640(a) requires evidence of field collection methods and field and laboratory quality control and quality assurance.
    b. 35 IAC 845.650(e) requires alternative source data as 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.

If you have any questions, please contact: **Lauren Hunt** 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,

Michael Summers, P.G.
Manager, Groundwater Section
Division of Public Water Supplies
Bureau of Water

cc: Lauren Hunt
Keegan MacDonna
Records Files 06M
Jenny Cassel, EARTHJUSTICE